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8 Assessment of Bleaching Technology and Emission Control in the Pulp and Paper Industry

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ASSESSMENT OF BLEACHING TECHNOLOGY AND EMISSION CONTROL IN THE PULP AND PAPER INDUSTRY

Jaakko Pöyry

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Jaako Pöyry Consulting AB is a member of the Jaakko Pöyry Group, the largest independent international consulting and engineering company providing a full range of services, related to forestry, the forest industry and other process industries worldwide.

Assessment of Bleaching Technology and Emission Control in the Pulp and Paper Industries

PREFACE

International Finance Corporation has assigned Jaakko Pöyry Consulting Oy to carry out an assessment of bleaching technology, effluent and emission control in the pulp and paper industry on a world-wide basis. The study has also been coordinated with International Institute for Environment and Development, IIED, in London, U.K.

The study presents data for a number of regions in the world as defined through discussions with IFC and IIED. These regions cover about 98 % of the pulp and paper production capacity in the world.

The study includes

- description of production technologies,
- emission control methods in the pulp and paper industry,
- production capacities in the different regions,
- bleaching technology and production levels of pulps bleached according to different methods,
- emission levels and emission amounts,
- costs (investment costs and annual costs) to reduce the emission levels.

The data used in the study have been extracted from Jaakko Pöyry Data Banks as well as from general sources. A limited number of mill interviews have been carried out to verify different assumptions for different regions.

We hope the report will be of interest and value to IFC and IIED.

Jaakko Pöyry Consulting

Johan Mjöberg

Assessment of Bleaching Technology and Emission Control in the Pulp and Paper Industries

CONTENTS

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

SI Units

J	joule

SI Prefixes

m	milli, $10^{-3} = 0{,}001$
k	kilo, $10^{+3} = 1000$
M	mega, 10^{+6}
G	giga, 10^{+9}
T	tera, 10^{+12}
P	peta, 10^{+15}
E	exa, 10^{+18}

Other

a	annum; year
ADt	air dry ton (of pulp); pulp at 90 % dryness
AOX	adsorbable organic halogen; adsorbable halogenated organic compounds
Bl	bleached (pulp)
BOD	biochemical oxygen demand, analysed through 5 or 7 days' incubation time
C	chlorine (Cl_2) stage in pulp bleaching
COD	chemical oxygen demand, analysed through dichromate oxidation
CPO	computer printouts (for recycling)
CTMP	chemi-thermomechanical pulp
d	day, 24 h
D	chlorine dioxide (ClO_2) stage in pulp bleaching
DAF	dissolved air flotation
DIP	deinked pulp; pulp produced from deinked waste printing paper,

	e.g. newsprint, through processes including deinking
DS	dry solids
E	alkaline ("extraction" with NaOH) stage in pulp bleaching
ECF	elemental chlorine-free (bleached pulp); chemical pulp bleached without elemental chlorine as Cl_2 or dissolved in alkali as HClO (only ClO_2 being used as chlorine chemical)
EO	alkaline stage in pulp bleaching with oxygen reinforcement
FAS	formamidine sulphinic acid being used for bleaching of DIP
h	hour(s)
H	hypochlorite (NaClO) + sodium hydroxide (NaOH) stage in pulp bleaching
% ISO	brightness unit according to ISO, the International Organisation for Standardisation
LPG	liquified petroleum gas
LWA	light weight aggregates
LWC	light weight coated (paper)
NACO	pulping process with sodium carbonate being basic chemical. Sodium hydroxide and oxygen are also used in the process
NOSC	no sulphur, semi-chemical (pulp)
NSSC	neutral sulphite, semi-chemical (pulp)
O	oxygen delignification stage in pulping
OCC	old corrugated containers (for recycling)
OMG	old magazines (for recycling)
ONP	old newspapers (for recycling)
OW	office waste (for recycling)
P	sodium hydroxide (NaOH) + hydrogen peroxide (H_2O_2) stage in

	pulp bleaching
Paa	peracetic acid (CH_3COOOH) treatment in pulp bleaching
PCB	polychlorinated biphenyls
Q	treatment with chelating (sequestrian) agents like DTPA (diethylene-triaminopentaacctic acetate) in pulp bleaching
RCF	recycled fibre(s); pulp produced through waste paper processing
SGW	stone groundwood pulp
t	metric ton, 1 t = 1000 kg)
TCF	totally chlorine free (bleached pulp); chemical pulp bleached without any chlorine compounds
TMP	thermomechanical pulp
TOC	total organic carbon
TSS	total suspended solids (in waste water)
USD	US dollar(s)
VOC	volatile organic compounds
Z	stage with ozone in pulp bleaching

EXECUTIVE SUMMARY

Emissions from Pulp and Paper Industry in Focus

Specific emissions from pulp and paper industry has gradually been reduced through an interaction between producers, suppliers and authorities. Since the middle of the 1980s, environmental issues have become of concern also for the market place. The industry now often has to present environmental information like emissions, control means, procedures, etc. to customers. The market place has forced many producers to reduce emissions to lower levels than stated by regulations. In particular the processes for bleaching of pulp have undergone major changes.

Wood is Preferred as Raw Material

Pulp is mainly produced from wood as raw material. There is a difference between softwoods (coniferous species) and hardwoods in the sense that the fibre length typically is higher for softwoods than for hardwoods. This makes softwoods better suited for products with high strength characteristics like sack paper and packaging grades or reinforcement fibres in printing grades like LWC, while hardwoods are better suited for achieving surface smoothness because of better formation.

Non-wood fibres from annual plants (straw, reed, bagasse residues, etc.) are used in many countries, but mainly in the case of lack of wood raw material. Non-wood raw material contains a high amount of silicates making evaporation and recovery of chemicals and production of energy difficult. Normally non-wood pulping plants have to discharge the spent liquors implying high chemical costs, high costs for purchased energy, and high emission levels. Furthermore, the non-wood fibres have inferior paper making properties (with a few exceptions like the cotton fibre, abaca fibre, flax and hemp fibre).

Pulp Yield Control Pulp Properties

The pulp yield that is obtained from pulping of wood is decisive for the use of the pulp. Simply expressed, the more chemical processing that takes place the lower the yield will become. The yield is highest for a mechanical disintegration and lowest for a completely chemical dissolution of lignin. For processes with some chemical treatment and some mechanical (chemimechanical and semichemical pulps) the yields are intermediate.

When bleaching to high brightnesses and to high brightness stabilities, most of the lignin must first be removed by chemical reactions. Residual lignin is then removed by means of bleaching chemicals that selectively react with the lignin substance. Conventionally, this bleaching has been carried out by means of chlorine compounds, but recent development has introduced non-chlorine compounds like oxygen, ozone, and hydrogen peroxide as new bleaching chemicals.

Mechanical and chemimechanical pulps and often deinked pulps may be bleached but brightness stability is poor because of all the remaining lignin. In these pulps the chromophores in the lignin are only (temporarily) converted by means of bleaching chemicals into less chromophoric analogues. These bleaching chemicals mainly include non-chlorine compounds like peroxide and dithionite.

Non-wood pulps are often delignified and then bleached like chemical pulps, but mainly by means of chlorine compounds. Hypochlorite (clorine gas dissolved in alkali) is often used because of simplicity in handling.

Liquors and Wood Residues Used for Steam Generation and Chemical Recovery

Wood residues (from bark and wood waste) and wood substances (from spent liquors) are burnt to a large extent for steam production. Steam from boilers is often used for power generation through back-pressure turbines. This heat and power generation is necessary to reduce or eliminate costs of mineral fuels.

A modern chemical pulp mill produces a surplus of heat and electric power. Furthermore, through the incineration of the spent liquors followed by chemical recovery the process chemicals are regenerated. This is necessary in order to reduce effluent discharges and to reduce operating costs (chemical costs).

A mechanical pulp mill has to purchase power from outside for the mechanical processes. However, togethet with steam from bark boiler, steam generated from the processes is often sufficient for the process needs.

For semichemical pulping the spent liquors contain less amounts of used cooking chemicals and less amounts of organic material than for chemical pulping (because of higher yield). Evaporation becomes more costly, the fuel value is lower and the value of the chemicals is lower. Thus many semichemical mills have avoided recovery systems, which results in increasing effluent loads. Some semichemical mills use recovery systems of their own, some use cross-recovery systems in combination with kraft mills.

Non-wood pulping give spent liquors with high silicate content making evaporation and incineration less possible. Mostly these mills simply discharge the effluents, sometimes to effluent treatment systems, but mostly directly to the recipient. In this way they loose the fuel value and the value of the chemicals and pollution becomes high.

Demand for Pulp and Paper is Increasing

The demand for paper and paperboard products is about 270 million t/a and increasing by almost 3 % p.a. on a world-wide basis. This paper production is based on about 163 million t/a of virgin pulps, about 9 million t/a of fillers and coatings, and about 98 million t/a of secondary fiber (RCF/DIP). About 7 million t/a of virgin pulps are used for other products like diapers, napkins, and so on.

The increase in paper demand of 3 % corresponds to more than 8 million t/a as new production. The use of recycled fibre is increasing more than the use of virgin fibre. Thus, in rough terms, recycled fibre accounts for a growth of almost 5 million t/a, mechanical pulps for about 0.5 million t/a, bleached chemical pulps for 1.6 million t/a and unbleached kraft pulps for 0.5 million t/a.

Emissions to Water from Many Sources

Emissions to water include dissolved wood substances, residual chemicals, and compounds produced through reactions between process chemicals and wood substances. These emissions are usually characterized through group analyses like BOD, COD, AOX and suspended solids.

Emissions to water originates from wood handling (especially in colder climates), from condensates, from bleach plants, from screen rooms and wash plants, and from accidental spills. Often contaminated waters are mixed with clean water (like cooling water) and discharged through one effluent.

Emissions to the Atmosphere mainly from Boilers

Emissions to the atmosphere from pulp and paper industry are mainly generated by boilers and include sulphur dioxide and nitrogen oxides as main emissions. Other emissions from boilers are carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and solid particulates. Carbon monoxide and hydrogen sulphide emissions may be considered as disturbances. Solid particulates (dust) have mainly a local impact while gaseous components may be conveyed over large distances in the atmosphere.

In kraft mills, reduced sulphur compounds (TRS, malodorous gases) are generated and released in small quantities. Because of the foul smell of these gases they cause local nuisance, but they are not considered as harmful (apart from hydrogen sulphide).

From bleach plants, chlorine and chlorine dioxide may be released because of improper procedures. Such leakages must be very limited because of the high toxicity of these compounds.

Biological Treatment is Mostly Required

Most bigger mills in the world are treating the effluents by mechanical as well as biological treatment. The activated sludge process has become the most common system for biological treatment due to high efficiency. The efficiency for BOD is above 90 % and for COD around 70 %. Even with implementation of significant internal measures, biological treatment systems will remain a requirement for bigger mills.

Many small mills do not have any biological treatment and frequently they also lack mechanical treatment systems. Since the same mills often lack other recovery facilities the specific emission levels become very high indeed from these mills.

Bleaching Technology in Turbulence: Chlorine goes out, Closure comes in

Bleaching has undergone big changes because of the concern connected with the discovery of polychlorinated dioxins and furans in bleach plant effluents in the 1980s. Conventionally, the industry was using chlorine (Cl_2) as the main bleaching compound in combination with chlorine dioxide, hypochlorite and alkali. In the 1980s it was found that by eliminating hypochlorite and by replacing chlorine in full by chlorine dioxide (ECF bleaching), no dioxins were detectable in effluents, the AOX formation decreased 3-5 times, and the AOX that was formed shows lower degrees of substitution (mainly mono- and di-chlorination). The main ECF sequence today is OD(EOP)DD.

By using oxygen, ozone and/or peroxide in prebleaching low-AOX sequences within the ECF ones have become implemented. For instance, the sequence OQ(PO)DD is such a low-AOX sequence.

At high pace the development work focused on completely chlorine-free chemicals like oxygen, ozone, peroxide and peracids for totally chlorine-free bleaching (TCF). First, around 1990, it was only possible to produce semibleached pulps with these chemicals, but gradually the producers have become more successful in controlling different crucial conditions. By today many mills are able to reach full brightnesses, 88-90 % ISO, by TCF bleaching. A large number of new process alternatives are today available and the following process options show some of these sequences:

- Oxygen and peroxide (Lignox): OQP, OQ(P/P), OQ(PO)P
- Ozone: OQPZP, OQ(PO/PO)ZP, OAZ(EOP)P, OAZQP
- Peroxy acids: OQPPaaP, OQ(PO)PaaP

The development work is presently focused on increased closure of the effluent side in the bleach plants. The objective with this work is to reduce discharges from the bleach plant and to increase incineration of emission substances. The challenge in this work is to avoid build-up of foreign substances and elements. A number of mills are working in this direction, but it is still too early to make any conclusion as to final degree of closure. It seems likely that the discharge volumes from the bleach plants will be substantially reduced, but some discharges will probably have to be made to avoid serious operating problems and excessive costs.

Emissions much Lower from Modern Plants

Apart from the chemical changes that have taken place also many other techniques have contributed in reducing emissions. It must be emphasized that to achieve the lowest possible emissions changes have to be implemented for each department in the fibre line including the wood handling side. The following issues may be mentioned as contributing factors for lower emission levels:

- Improved debarking
- Reduced use of fresh water in wood handling department
- Improved chippers for more uniform chips
- Chip screening and upgrading of oversized material
- Proper presteaming of chips before digester
- Extended delignification technologies
- Improved washing including the use of wash presses
- Improved screening
- Oxygen delignification
- Introduction of medium consistency (MC) pumps and mixers
- Introduction of new instruments (like kappa number analyzer, brightness instruments, etc) and better control systems

Many of these equipment or systems cannot be installed with old equipment in an old fibre line. The production level is usually too low to justify the investments in the expensive new technology and it may also be impossible to modify some equipment to comply with the new processes. For instance, a digester is normally not possible to modify for extended delignification.

Furthermore, the mill capacity may decrease substantially if an old mill implements some of the processes (like extended delignification in a continuous digester).

Thus the best process systems can really only be implemented in full in connection with construction of new fibre lines.

Table 0.1 presents some specific water emission data that may be stated as representative international guidelines for pulp and paper mills. Many smaller mills are exceeding these levels by 50-100 % or even more. These data may be interpreted as typical for an average standard of technology on a world-wide basis. A mill may probably be able to meet these data either with extensive internal measures or with adequate external treatment systems. Mills with modern internal technology as well as with mechanical and biological effluent treatment systems will reach lower emission levels indicated by the data in paranthesis.

Table 0.1
Waste water discharge guidelines for pulp and paper mills.

Process	TSS, kg/t	COD, kg/t	BOD_5, kg/t	AOX, kg/t
Bleached kraft pulp mills	7 (5)	70 (25)	15 (4)	2.0 (0.8)
Unbleached kraft pulp mills	7 (4)	40 (10)	8 (2)	n.a.
Bleached sulphite pulp mills	7	140	30	1.5
Semichemical pulp mills	7 (4)	60 (25)	15 (5)	n.a.
Mechanical pulp mills	7 (3)	40 (15)	10 (4)	n.a.
Non-wood pulp mills	7	140	30	1.5
Recycled fibre mills[a]	5-10	20 - 50	10 - 20	n.a.
Paper mills	3 (1)	10 (1)	4 (0.5)	n.a.

[a] Higher values for deinking mills.

Guidelines for emissions to the atmosphere are more difficult to state in the same format since the energy and recovery side varies greatly depending on process and energy generation systems. Nevertheless, the following data may be given as general guidelines for pulp and paper mills:

- solid particulates (TSP) < 6 kg/t
- sulphur dioxide (SO_2) < 4 kg/t from process areas and < 5 kg/t from energy generation
- nitrogen oxides (NO_x as NO_2) < 3 kg/t

There are big variations in these mill data and for instance mechanical pulp mills may operate with a high portion of electric power for their overall energy supply resulting in low specific emission data. Other mills may have to produce condensing power from high sulphur fuels for their own operation resulting in high emission levels. Thus, the atmospheric emission data must be interpreted with such differences in mind.

Investments to Rectify All Mills Would Not be Feasible to Finance

To improve the environmental standards for all mills on a world-wide basis is not realistic and will not take place. The smaller mills would never be able to carry the environmental costs. The biggest environmental problems (highest specific discharges) are associated with non-wood pulp mills. Some of these mills should preferable be closed and replaced by new and modern mills.

For bigger mills the environmental measures have to be implemented step-wise. A better uniformity in regulations between different regions (Africa, Asia, Europe, North America, Latin America) is important to avoid cost disadvantages for mills with high environmental standards.

In Chapter 7 some estimates of the world-wide environmental costs in the pulp and paper industry are presented. The purpose with these estimates is to illustrate the additional costs required in order to transform all mills to a very good standard. Table 0.2 shows a summary of these estimates for the different main territories. In Table 0.2 the specific costs are shown based on total territorial costs divided by the production capacity in the territory. Since the main environmental costs are associated with pulp manufacturing, the production capacities of pulp only has simply been used in this context. The specific cost data in Table 0.2 are only presented to show orders of magnitude for the additional environmental costs to reach an overall good level. (Production capacities are given in Appendix I).

Table 0.2 shows investment costs as well as annual costs. The basis for the estimates of the investment costs is described in Section 4.2. The annual costs are calculated as described in Section 4.3 and include operating costs and capital costs as interest and depreciation.

(In Table 0.2 the costs for the many small mills (below 1000 t/a) in China have not been included.)

Table 0.2
Additional environmental costs for pulp and paper mills in different main territories to reach good environmental standards.

Main territory	Costs for environmental control	Estimated additional costs, 1 000 000 USD	Estimated costs per ton of pulp, USD/t
Africa	Investment costs	465	121
	Annual costs	165	43
Asia	Investment costs	6 434	95
	Annual costs	2 241	33
Europe	Investment costs	4 489	53
	Annual costs	1 764	21
Latin America	Investment costs	1 523	90
	Annual costs	645	38
North America	Investment costs	6 952	60
	Annual costs	3 434	30
Oceania	Investment costs	159	41
	Annual costs	73	19

It should be emphasized that in terms of specific data (in the right-hand column in Table 0.2), smaller mills would normally show bigger numbers while bigger mills would often show smaller numbers than the ones shown. This situation is simply related to the economy of scale as well as to the fact that by necessity bigger mills are often performing better in environmental terms than smaller ones.

1 INTRODUCTION

1.1 Pulp and Paper Production

Pulp an paper is produced all over the world in about 9400 pulp mills and about 14 000 paper mills. A large number of these mills (about 8000) are very small producing less than 1000 t/a with a lot of manual work and with no importance for the future. Most of those small mills are located in China and will probably be closed down within the next 10-20 years.

There are mills producing more than 1 million ADt/a of pulp, but average production levels are around 150 000 ADt/a for pulp and about 80 000 t/a for paper. Many mills are integrated with pulp and paper manufacturing at the same complex but there is still a large number of non-integrated paper mills producing paper from purchased pulp or from waste paper.

Total production of pulp is about 170 million ADt/a (excluding recycled fibre) and of paper and paper board about 270 million t/a. The production of paper is increasing by 2.5-3 % per year on a world-wide basis.

The average per capita consumption of paper is about 48 kg/a per capita with highest levels being more than 300 kg/a per capita and lowest levels being 1 kg/a per capita as country averages.

1.2 Pulp and Paper Grades

Pulp and paper is primarily manufactured from wood that is defibrated into pulp by chemical and/or mechanical means. To a smaller extent, pulp is also manufactured from annual plants (non-wood species) because of local deficiency of wood raw material and because of availability of residuals from agricultural areas.

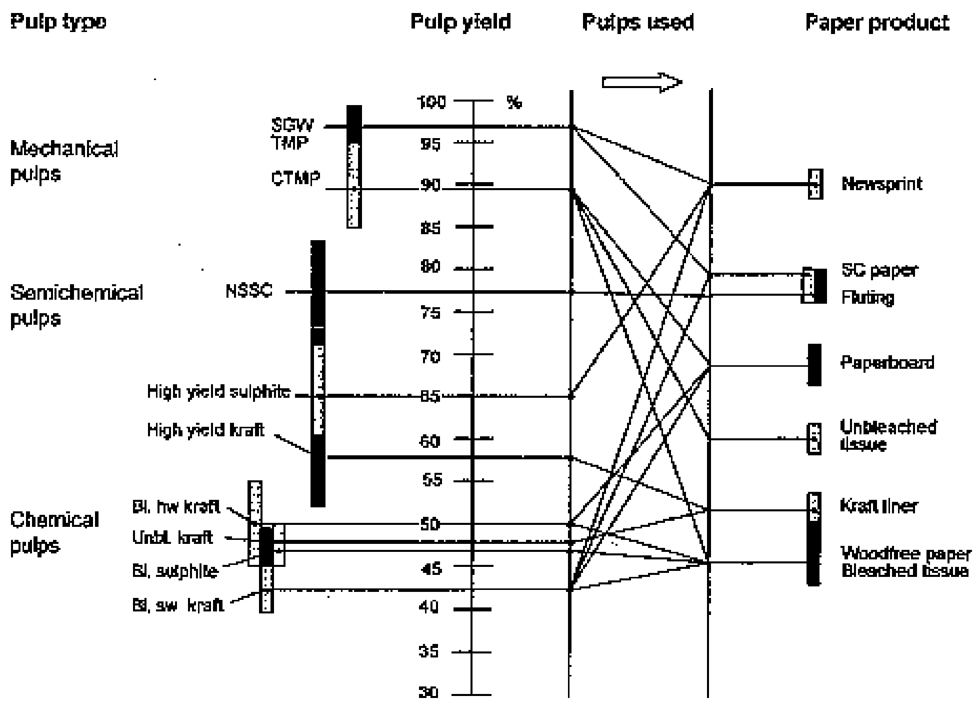
Paper is used for many different purposes with varying requirements with respect to the properties. These differences in paper imply different quality requirements of pulps. Quality aspects of paper may relate to different strength properties of the paper, to surface properties, to printability, and so on. An important property in the context of pulp mill emission is the brightness, commonly measured as percent ISO where 100 % ISO represents a surface that reflects 100 % of the incident light. A paper surface might reach a brightness of at most 93 to 94 % ISO, unless optical brighteners are added.

Defibration of the raw material through chemical dissolution of wood substances generally speaking gives the best quality in terms of strength characteristics and in terms of bleachability. On the other hand these pulps suffer from low pulp yields and thus from high raw material costs. Thus, white fine papers as well as packaging paper grades are usually produced through chemical pulping processes, especially through the kraft process.

On the other hand, mechanical pulps are well suited as printing papers with lower brightness requirements, as for instance for newsprint and for many magazine grades. The advantages with the mechanical pulps are higher yields and good optical properties for these kinds of products.

Figure 1.1 shows the correlation between different pulp yields and different paper grades. It is important to realise that these relationships vary widely depending on quality demand, raw material availability and costs.

Figure 1.1
Pulp yields for different pulps and the use in different paper products.



1.3 Emissions

Generally speaking, the losses of wood substances in the processes give rise to environmental problems. Thus, for pulps with lower yields the spent liquors must be taken care of because of the value (chemicals and fuel value) of the liquors and because of emission problems if they were discharged. For pulps with higher yield the waste waters contain organic substances at lower concentrations and a recovery is not feasible. In those cases the effluents have to be treated before being discharged to the recipients.

For many small mills the investment costs for recovery of spent liquors or for effluent treatment systems are impossible to finance and pay for and most of the small mills in the world simply discharge the effluents with no or with minor treatment. This is negative from an environmental point of view, but because of the small size of these mills the environmental impact is limited. For larger mills the specific emissions (as kg/t) have been decrease by 5-10 times or more over the last 20-30 years through internal process modifications and through external effluent treatment methods. For example in the production of bleached chemical pulps, the BOD discharge to the recipients have been reduced from 50-100 kg BOD/ADt for an old mill towards 1-2 kg BOD/ADt for a modern mill. Simultaneously the reduction in COD has been made from levels of 200-300 kg COD/ADt down to 20-30 kg COD/ADt. This successful reduction has also been necessary because of the large amount of discharges from the bigger and bigger mills.

Apart from the emission of wood substances a lot of other compounds may be released from pulp and paper industries like chemicals used in processes and substances that come with the wood. Because of the processing of large volumes of wood such substances may be released at quite large amounts even if the concentration in the wood is small. Thus, the mills often monitor water emissions like

- *Suspended solids*, including fibres and fibre fragments, bark particles and inorganic particles such as lime mud and paper fillers.

- *Organic matter*, dissolved or particulate, which can be biologically degraded while consuming oxygen (biodegradable). This material is characterized by the BOD_5 or BOD_7 analysis.

- *Total organic matter*, dissolved or particulate, partly biodegradable and partly non-biodegradable. This material is characterized by the COD analysis. Also the TOC analysis may be used, but this is not so much practised today (due to the expensive analysis equipment).

- *Toxic matter*, i. e. substances that are toxic to water-living organisms. Many of the extractive substances in bark and wood show high toxicity. Toxicity is specified through acute or chronic toxicity data. Acute toxicity measurement of effluents represents a "first-line" or primary defense means to safeguard recipient waters against a discharge of substances lethal to aquatic flora and fauna. Chronic toxicity measurement is carried out to identify a "safe" or "no effect concentration", thereby addressing a waters's ability to propagate and protect fish and other aquatic life. Whole effluent chronic toxicity bioassay endpoints such as reproductive success, organism growth, and long-term survival serve as early warning signals of potential environmental problems based on discharged materials.

- *Chlorinated organic matter*, generally characterized by the AUX analysis.

- *Coloured matter*, generally characterized by the Pt-Co (platinum) units (photometric measurement).

- *Acids* or *alkali*, giving extreme pH values.

- *Chlorate* ($NaClO_3$), originating in the chlorine dioxide bleaching of chemical pulps.

- *Nitrogen* and *phosphorus* compounds (nutrients).

- *Heavy metals* that are mainly precipitated in the liquor preparation but may also be released in measurable quantities.

Emissions to the atmosphere from pulp and paper mills include emissions from processes as well as from boilers

- *Solid particulates* that mainly give problems locally.

- *Sulphur dioxide* which is an acidic gas and is transported over large distances in the atmosphere. The sulphur mainly originates from chemicals in processes or from fuels (oil, coal).

- *Nitrogen oxides* which are acidic gases as well as plant nutrients and that are also transported large distances. The nitrogen oxides are formed in combustion processes through reactions between nitrogen (mainly from the air, but also from the fuel) and oxygen at high temperatures.

- *Reduced sulphur compounds, TRS (malodorous compounds)* including methylmercaptan, dimethylsulphide, dimethyldisulphide and also hydrogen sulphide. These compounds are formed in the kraft cooking process and at anaerobic conditions. Because of the foul smell these emissions usually present a problem in the neighbourhoods of mills. Hydrogen sulphide is very poisonous and must be well controlled.

- *Carbon monoxide*, which is formed in combustion under oxygen deficiency. This gas is very poisonous but with no smell. Under normal conditions very small quantities should be released.

- *Other odorous/toxic substances* like acetic acids, methanol, chlorine compounds, solvents, and so on. These substances may come from processes or from process chemicals and they must be controlled. Normally these miscellaneous gases should not present a big environmental problem.

Emissions to the atmosphere are reduced through

- flue gas cleaning with reduction of solid particulates emission through mechanical cleaning and with reduction of sulphur dioxide through alkaline scrubber systems.

- collection and incineration systems for malodorous gases (TRS).

- control of process conditions (internal process changes)

The nitrogen oxides, NO_x, have come into focus during the last 10 years and the specific discharge of these gases has not yet been reduced as much as other emissions.

Many old pulp and paper mills could not carry the costs for substantial reductions of the emissions through a modernisation. The units are simply too small to carry the required investments. Thus, to reduce emissions from the pulp and paper industry in the most effective way would require the construction of more new and large units with modern processes with lower discharges and with affordable effluent treatment systems.

In this connection it may be mentioned that small mills will hardly be able to meet the same emission levels as bigger mills simply because the investment costs for emission control would be much higher when calculated on a specific basis (cost per ton of product) due to the economy of scale that is very important in the pulp and paper industry. Thus, to become or stay competitive a smaller mill will always have more difficulties in meeting high environmental demands. Typically this is the case for many pulp mills operating on non-wood raw materials. For this kind of mills, there is a further difficulty following from the fact that no satisfactory technology for evaporation and recovery of chemicals is available. This means that these mills have to discharge their spent liquors and this is often done without any effluent treatment.

However, it may also be pointed out that the environmental impact from a small mill may be limited if the recipient is large enough. Even if the specific emissions are high, the total discharges may be limited if the mill is very small.

In this study, world-wide emissions from the pulp and paper industry are analysed and costs to reduce the environmental impact are calculated on a regional basis. It is important to emphasize that in many regions the mills would not be able to cover these costs because of the reasons given above. The implementation of more stringent emission levels on a world-wide basis would eliminate many small mills from the scene and large investments in new mills would be required. Thus, the calculation of environmental costs to meet certain emission requirements is superficial in the sense that small mills would simply have to shut down instead of making the environmental investments. The true investment costs for environmental improvements would then be better represented by making the environmental investment cost estimates for some completely new mills and consider many small mills as necessary to close. This approach is however not analysed in the present study but the estimates are based on making improvements in the present mills.

2 PROCESSES AND EMISSIONS

2.1 Pulping Processes and Emissions

The most important raw material for pulp manufacturing is wood, but non-wood fibres from annual plants are also used in some regions of the world. The use of recycled fibres is growing strongly, but the need for new or "virgin" fibres will not cease since we are facing a growing demand for paper products and the fibres may only be reused for a limited number of times. Furthermore, even with a recovery rate as high as 40-50 %, a major part of the fibres is lost after only two cycles. In the process of separating wood fibres, parts of the wood substance is dissolved. Part of lost substance may be burned for energy production, other will be emitted to the environment unless not properly taken care of. The fibres can be separated through a chemical dissolution process, through mechanical defibration, or through a combination of chemical and mechanical means.

Chemical pulps are manufactured by separating the fibres by digesting wood chips under pressure and high temperature in alkaline or acid solution thereby dissolving parts of the wood substances. The pulp is then washed, screened and bleached with several acidic and alkaline treatments using chlorine chemicals, oxygen, caustic soda, hydrogen peroxide and other chemicals. Pulp is then dried or used on the site in integrated paper manufacturing.

Mechanical pulps are manufactured with no or minor assistance of chemicals and they have many characteristics different from chemical pulp. The pulp yield from the wood for mechanical products is high (Figure 1.1) since the wood substances are preserved. Thus there is usually no need to recover any dissolved organic matter. Organic matter is lost into waste water in the process. The main part of the mechanical pulp produced is used for integrated paper production at the same site.

The pulp processes described below are the kraft process, which is the dominating chemical pulp process, followed by the sulphite pulp process. Among the mechanical pulp processes the thermomechanical (TMP) and the stone groundwood (SGW) processes will be discussed. Also processes where a combination of chemical and mechanical separation is used such as the chemithermomechnical (CTMP) and the semichemical processes are discussed as well as the treatment of recycled fibres.

2.1.1 Wood Handling

Wood may be received by the pulp mill either as logs or as wood chips which are a secondary product from saw mills. The logs have to be debarked and for most pulp processes cut into chips before further fibre separation can take place. In some processes the fibres may however be separated directly from the logs through a grinding process (SGW). The main purpose of the wood handling is to provide the pulp mill with bark-free and clean chips of suitable dimensions and moisture content.

Wood handling at a pulp mill comprises the following operations:

- reception of wood, i. e. unloading logs or chips from trucks or railcars, taking up floated log bundles or rafts from the water
- storage of unbarked wood in piles or in water
- thawing of frozen bark
- debarking of wood
- chipping and chip screening
- storage of barked wood in log (SGW) or chip piles

The debarking degree is crucial. Many bark particles are not fully degraded or removed before the bleach plant and to eliminate them in bleaching consumes a great deal of bleaching chemicals and results in additional effluent loadings. Smaller wood particles, "fines", produced in chipping and chip handling usually contain more extractives (a class of chemicals present in the wood besides the lignin and the cellulose) than the average chips, thereby generating increased discharges of chlorinated organic substances, if bleaching with chlorinated chemicals is applied. Also the chip dimensions are important to optimize the pulping process and thereby reduce the need of bleaching chemicals.

Waste water from the wood handling plant may be a source of potential environmental impact due to the presence of fatty and resin acids and sterols. At higher concentrations, these substances are known as acute toxic and indications also point at interference with reproductive processes. Such compounds are also dissolved in the cooking process. By dry debarking, the waste water from wood handling is minimised. There will be a wood handling effluent (about 3 m^3/ADt), mostly in mills in cold climates, because water is used for thawing wood in the winter and also to remove impurities from logs.

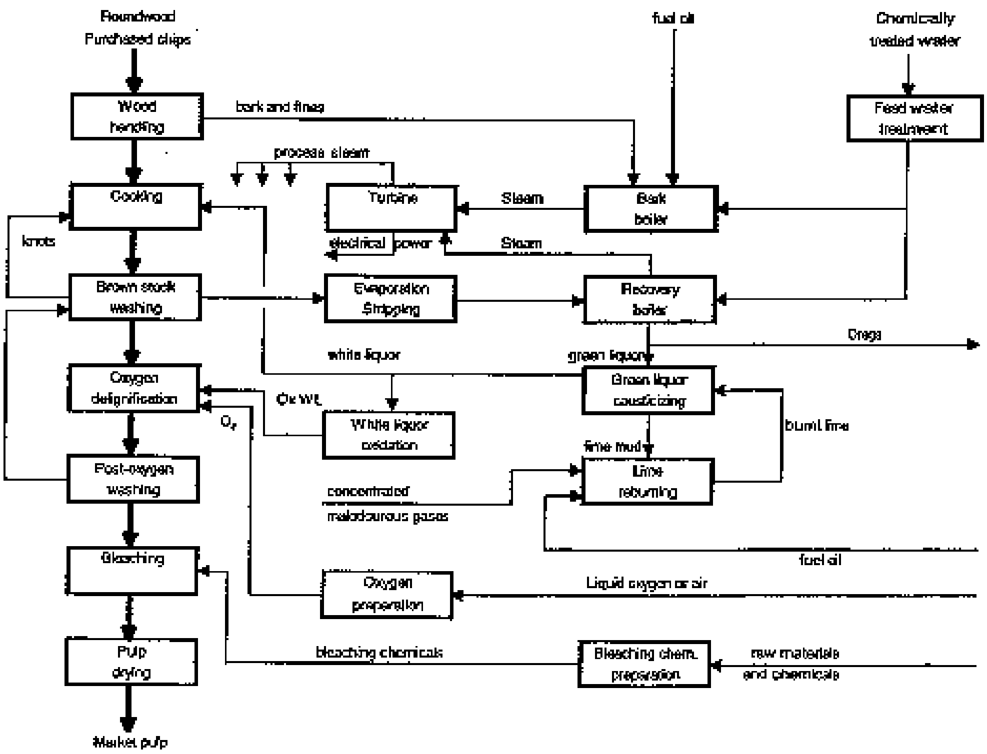
In the pulping of non-wood plants, the raw material usually has to be harvested in a short period and stored for a large part of the year. This causes inconveniences with respect to storage requirements and to degradation problems.

2.1.2
Chemical Pulping

The Kraft Process

In chemical pulping the purpose is to selectively remove undesirable lignin from cellulose and hemicelluloses and thereby separate the wood fibres. The unbleached yield from wood is generally 45-55 %. The dissolved parts, which is mainly constituted by lignin, but also a fair amount of hemicelluloses and cellulose, is washed away from the cellulose fibres, together with the cooking chemicals. The kraft process is the dominating chemical pulping process worldwide. An orientation diagram on the process is shown in Figure 2.1. In the kraft process the chips are first steamed and impregnated with cooking liquor (white liquor) which is a solution of sodium hydroxide and sodium sulphide. Cooking takes place at about 170µC in a digester. Economic and environmental requirements result in a need to recover both process chemicals and as much as possible of the dry wood material. This has resulted in relatively sophisticated recovery systems generally including an incineration unit (recovery boiler), which simultaneously recovers energy from the wood-originated organic substances and transforms the chemicals for further treatment back to their "original" state as cooking chemicals.

Figure 2.1
The kraft pulping system including recovery.



In order to preserve the pulp yield, the cook is terminated at a lignin content of 3-5 %. The lignin content is often referred to as kappa number and the cooking is thus performed to a kappa of around 20-30. To remove further lignin by cooking would destroy the cellulose fibres themselves. One kappa unit corresponds roughly to 0.15 % lignin in the pulp.

Water emissions from the kraft pulping processes are illustrated by Figure 2.2 and air emissions by Figure 2.3.

Figure 2.2
Water emissions from kraft pulp mills.

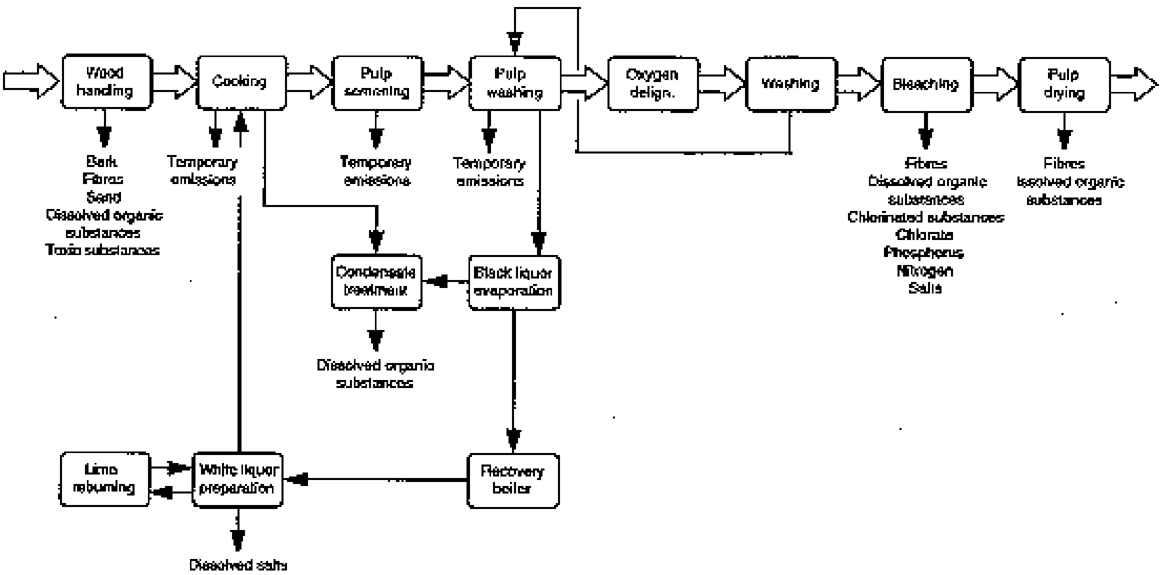
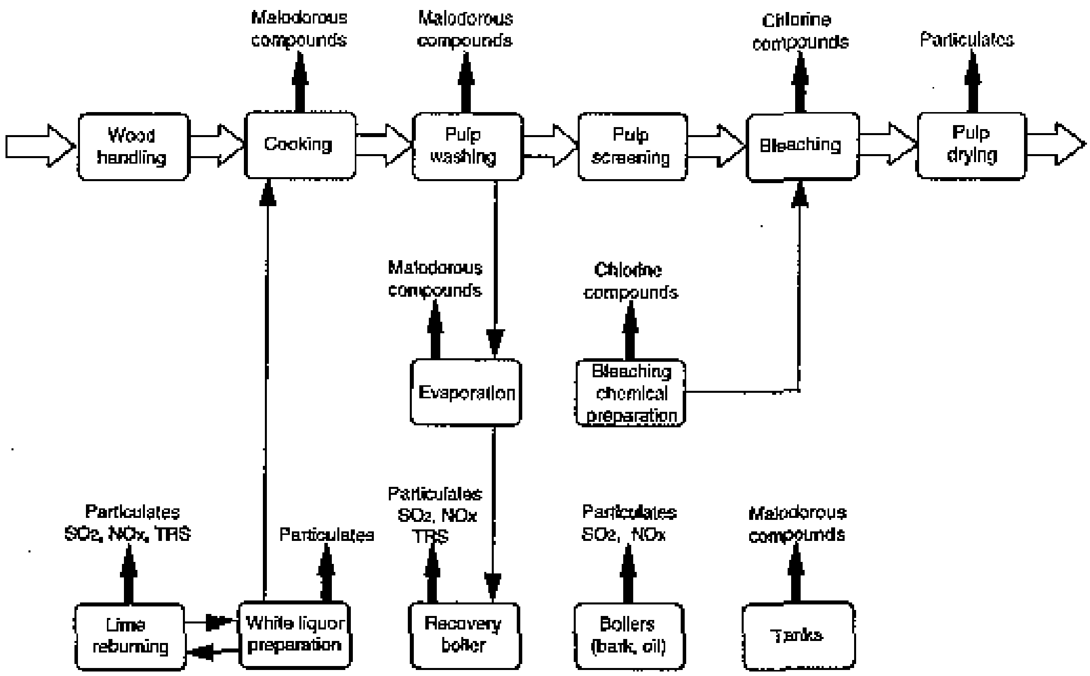


Figure 2.3
Atmospheric emissions from kraft pulp mills.



Emissions from the recovery boiler are mainly represented by particulates and sulphur dioxide. The emission levels are kept as low as possible by optimizing the combustion parameters such as temperature, air supply, black liquor dryness content and chemical balance. Particulates leaving the burners are generally trapped in filters and the sulphur dioxide is dissolved in water in a scrubber. The sulphuric water is recycled into the process. The NO_x emissions are more difficult to take care of (collect or absorb) and a reduction must be achieved through changes of combustion parameters. The malodorous compounds leaving the process are collected and burnt in the lime kiln or in a dedicated incinerator with alkaline scrubber.

Modified Cooking

During the 1980s some fundamental changes of the cooking technology were made in the development of extended delignification, often called "modified cooking". The development was based on the concept that the delignification in the cook can be extended beyond conventional limits by improving the selectivity, i.e. the degradation/dissolution rate of lignin is increased compared to that of cellulose. An important aspect is that an improved selectivity corresponds to improved pulp strength properties at the same degree of delignification (kappa number). Through the new cooking processes it has become possible to reduce the kappa number significantly with preserved pulp strength and yield. In batch cooking the new processes also involve a significant reduction in the steam consumption.

Primarily, the endeavour to extend the delignification in the cook has been aimed at minimising the need for bleaching. Thus, the use of bleaching chemicals is reduced and the formation of chlorinated compounds decreases when modified cooking is used.

Oxygen Delignification

Unbleached kraft pulp is brown (cf. sackpaper). Before bleaching, about 50 % of the remaining lignin in the unbleached pulp can be removed in an oxygen delignification stage. Oxygen and alkali is charged to the pulp. Organic matters dissolved in the oxygen stage and the inorganic compounds are recycled back to the chemical recovery system. To precede the bleaching by oxygen delignification gives a reduction of the consumption of bleaching chemicals and a reduced effluent load from the bleach plant. Installation of oxygen delignification means high investment costs, but production cost benefits are apparent in both ECF and TCF bleaching. Moreover, oxygen delignification is fundamental in the development of methods for recycling of bleach plant filtrates.

In combinations with modernisation of the fibre line, kappa numbers after oxygen delignification of 10-14 can be achieved for softwoods and 8-12 for hardwoods.

Sulphite Pulping

Before 1950 sulphite pulping was the dominant chemical pulping process for production of "white" pulps but has since decreased. With the development of multi-stage bleaching processes including chlorine dioxide bleaching, also high brightness kraft pulps could be produced and since then the kraft pulps have gradually replaced sulphite pulps because of several advantages. The main reasons for the continuous decrease of sulphite pulp production in the 1960s and 70s are:

- kraft pulping has better potential for chemical recovery and causes less air and water pollution

- sulphite pulp can only be manufactured from a limited number of wood species

- sulphite pulp does not have as good strength properties as kraft pulp

Sulphite pulping however has a few advantages compared to kraft pulping: The unbleached sulphite pulp is brighter and also easier to bleach to higher brightnesses and for softwood the pulp yield is 5-8% higher at a given degree of delignification. Through the development during the 1980s the sulphite process accordingly attracted some renewed interest since the process made an elimination of the use of chlorine compounds possible. In the cases where sodium (Na^+) is used as the cation (base) in the system, a change to non-chlorine containing chemicals (TCF, totally chlorine-free) makes a further closure of the effluent system possible through an integration with the chemical recovery system. In this way the competitiveness of the sulphite process has improved somewhat for the sodium-based mills.

The cooking process itself has not undergone any major changes during the 1980's. Calcium (Ca^{2+}) has essentially been abandoned as cation since it cannot be recovered as a base which is a drawback from the operating cost point of view. (Some mills continuing with calcium base have improved their environmental situation as well as their financial result by recovering by-products like fodder yeast, ethanol, lignosulphonates, etc. from the spent liquors.) Magnesium (Mg^{2+}) offers an attractive recovery alternative while sodium (Na^+) offers flexible cooking conditions but complicated chemical recovery. These facts have given magnesium a dominating role in the present sulphite pulp production.

High sulphur charges and the low dry solids content after evaporation compared to the kraft recovery system, make the primary emission of sulphur dioxide (SO_2) from a sodium sulphite recovery boiler much higher than for a kraft recovery boiler. Furthermore, in sulphite recovery boilers all sulphur is oxidized into sulphur dioxide and recovered through scrubber systems. In kraft recovery boilers most of the sulphur is reduced into sodium sulphide, while smaller amounts are oxidized into sulphur dioxide. In this case the sulphur dioxide emissions are often controlled by an alkaline scrubber before the stack of the recovery boiler. For sulphite mills, the sulphur dioxide (SO_2) emission to the atmosphere, which earlier could be very high (above 5-10 kg S/ADt), has however continuously been reduced through improved collection systems and through improved scrubber arrangements. Presently, emission limits for SO_2 from processes are commonly below 2-3 kg S/ADt for many sulphite mills.

The emissions of reduced sulphur compounds (TRS) are much less from a sulphite mill than from a kraft mill and primarily limited to cases where anaerobic conditions prevail, with hydrogen sulphide (H_2S) being the dominating reduced sulphur compound. Such conditions should not be considered as regular. In the kraft process the reduced sulphur compounds are formed in reactions between wood substances (hemicelluloses and lignin) and sulphide ions, thus being directly generated through the cooking process. From kraft mills emissions of sulphur dioxide, SO_2, are generated to some extent upon combustion

2.1.3 Mechanical Pulping

In traditional mechanical pulping, fibres are separated with mechanical energy using special grinding machines or disc refiners. As there are many different wood species and quality requirements are different for different paper grades, *the mechanical pulping category also includes processes with chemical* pretreatment (CTMP and CMP) and post treatment (bleached grades).

The stone groundwood pulp (SGW) and thermomechanical pulp (TMP) are the predominant mechanical pulps and are usually integrated with paper or board production. Chemi-thermomechanical pulp (CTMP) has increased its share of the global mechanical pulp production and bleaching of all those pulps has been growing in the last five years.

Manufacturing technology of mechanical pulping has progressed and developed in particular with the pulp quality and heat and energy recovery. The development of environmental control technology has been less obvious and the discharge of organic pollutants prior to effluent treatment have even increased in the last few years. This is due to the increase of bleaching with more powerful bleaching agents like hydrogen peroxide, which decrease the yield and increase the discharge of organic substances. However, there are a few CTMP mills with recovery systems that make the mills totally effluent free. These mills have had to meet these extreme requirements because of recipient limitations.

Since there is less dissolution of wood material in the (chemi-)mechanical pulping processes, they produce pulp at a high yield, normally over 88 %. This is why the pollution potential of mechanical pulping methods is considerably lower than with chemical pulping methods. The environmental impact from TMP and SGW is limited to effluents containing BOD (biochemical oxygen demand), suspended solids and some toxic substances found in the extractives in the wood. In the CTMP process a larger amount of organic material is dissolved from the wood which gives rise to larger emissions of BOD and/or COD than for TMP and SGW. The concentrations of dissolved substances are however not normally high enough to justify evaporation and incineration. On the other hand the BOD/COD levels are in most cases too high for discharge without external treatment. Emissions from mechanical pulping are shown in Figure 2.4.

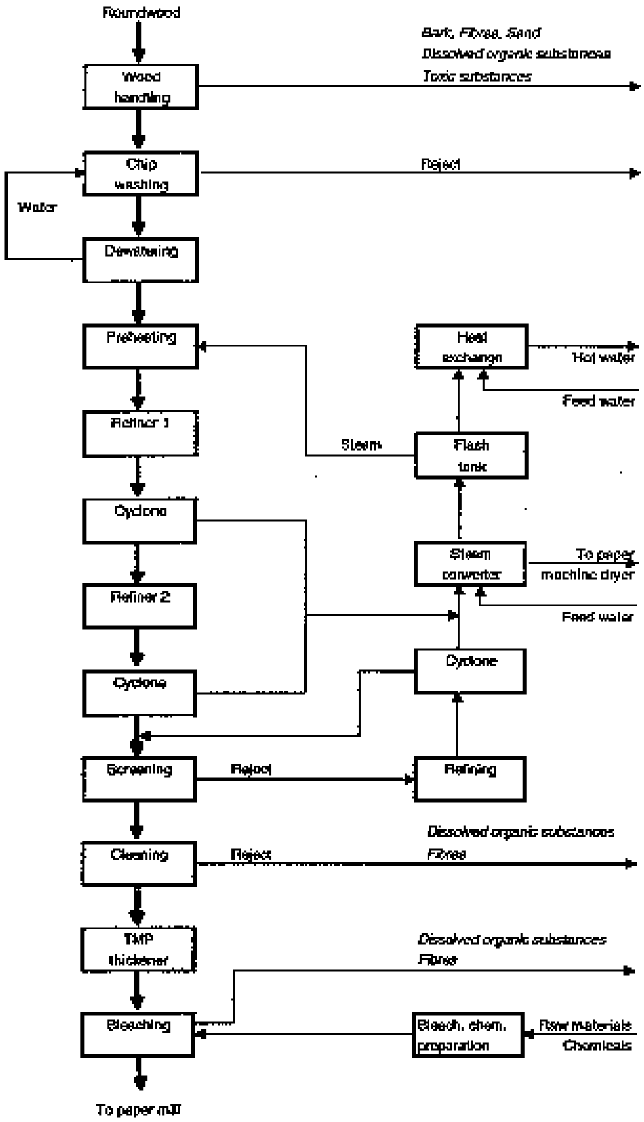
The SGW and TMP process give a yield of 94-98 % and the CTMP process gives a yield in the 88-95 % interval with an additional loss of 1-3 % during the pulp bleaching.

Thermomechanical Pulping (TMP)

A line diagram of a typical TMP process is shown in Figure 2.4. Wood is first chipped. Chips for mechanical pulping must not contain stones, sand, scrap metal or other hard contraries that may cause damage to the refiner plates. In most chip refining processes the chips are therefore washed to remove contraries before refining. This gives a wash reject as water effluent. After chipping and washing, the raw material is preheated with steam and fed into a disc refiner where fibres are ground between two discs together with a relatively small amount of water. Part of the organic substances of the wood are dissolved in water and discharged from the process either from the mechanical pulp plant or from the paper machine.

A large share of the comparatively high amount of electric energy required in refiner mechanical pulping is converted into heat, most of which eventually is consumed for evaporation of water contained in the chips. In many mills, a significant amount of the steam thus generated may be recovered, cleaned and/or heat-exchanged to produce clean process steam, e. g. for use in paper drying. After refining, the pulp is further diluted, screened and cleaned. After screening follows dewatering and possibly also drying or storage in a big pulp tower. The application of more mechanical energy instead of chemical dissolution leads to more pronounced fibre fragmentation and formation of fines. The significance of water in the mechanical pulping processes implies that fresh wood is to be preferred as raw material. If the wood for mechanical pulping has to be stored, drying should be prevented, e. g. through storage in water or sprinkling of log piles. This may require water collection in the wood yard to avoid discharge of organic substances.

Figure 2.4
The TMP process and emissions



Stone Groundwood (SGW) Manufacturing

The main difference compared to the TMP processes is at the beginning of the process. In the SGW-process 1-2 m long logs are fed into a grinding machine and forced against a grinding stone.

Chemithermomechanical pulping (CTMP)

The typical flow diagram of a TMP process illustrates fairly well also the main features of the CTMP process. The screening and cleaning operations and equipment are very similar to the TMP process. The CTMP process however includes a chemithermal pretreatment instead of a simple thermal one like in the TMP process. Caustic soda, sodium sulphite, hydrogen peroxide or another chemical solution is used to treat the wood chips prior to refining.

The chemical addition is made in order to decrease the damage of fibres in the process and to facilitate defibrillation. Unlike chemical pulping the lignin and hemicellulose compounds are not extensively lost in the process and consequently, the yield is fairly high. The amount of chemicals used in the CTMP process is far from sufficient to economically justify a recovery system for process chemicals.

The chemicals normally applied are sodium sulphite or hydrogen peroxide. Peroxide is always used together with an excess of sodium hydroxide and this sometimes is the case also when sodium sulphite is used, especially in pulping of hardwoods. The use of chemicals result in somewhat lower pulp yields for CMP and CTMP than for TMP. The larger amounts of dissolved organic wood substances result in more water emissions that have to be treated before discharge to the recipient.

Table 2.1 compares wood consumption and power demand for some of the pulping processes in modern mills.

Table 2.1
Typical wood and energy consumption in different pulping processes.

Process	Consumption	
	Wood, m^3sub/t	Electricity, kWh/ADt
Kraft pulp[a] (new mill)	5.0	- 200[c]
CTMP[b]	2.65	2000
TMP[b]	2.55	2100
DIP[b]	-	300 - 400
SGW[b]	2.45	1400

[a] Bleaching ODC(EO)DED
[b] For newsprint.
[c] Negative number; indicating a surplus of power available for export.

2.1.4 Semichemical Pulping

For some pulp qualities, the chemical pulp is unnecessarily expensive, while the mechanical pulps do not withstand the quality requirements. However a combination of chemical and mechanical treatment can be used to achieve a high pulp yield and still keep some quality properties of chemical pulp. Semi-chemical pulp can for this purpose be produced with the conventional methods for chemical pulps but with a lower chemical charge and/or shorter cooking time. The cooking will then be followed by a mechanical defibration. This can give so called "high yield" pulps with a yield of up to 70 % for sulphite and 60 % for kraft pulps.

A method that gives an even higher yield is the NSSC-method (Neutral Sulphite Semi-Chemical), where the cooking takes place in a neutral or slightly alkaline solution at a relatively high temperature. After the cooking, the softened chips are defibrated in a disc refiner.

The waste coking liquor presents a problem in semichemical pulping since it, due to the high yield, is low in organic and high in inorganic chemical content. To evaporate and burn it is therefore difficult and uneconomical. At some production sites where there is a kraft pulp mill, the cooking liquor from the semi-chemical pulp production is fed into a cross-recovery system with the kraft pulp mill. Alone, a neutral sulphite mill may increase the organic content of the spent cooking liquor by recirculating it, at some sacrifice of the pulp brightness.

Even if there are economic drawbacks it is of course possible to evaporate the spent liquors and burn the organic material in recovery furnaces. There are a number of separate recovery systems in operation for semichemical pulp mills. These may be based on indirect or direct evaporation. With indirect evaporation there are multiple effect evaporators or mechanical vapour recompression units being used. The furnaces or boilers being used are either such units that generate a smelt of inorganic chemicals or furnaces of fluidized bed types. The fluidized bed types are probably the most common units for semichemical pulping with two predominant systems in use being the Copeland reactor and the FluoSolids system. When operating with magnesium base, which is not the most common base for semichemical pulping, a complete chemical recovery can be accomplished through these reactors. When operating with sodium base, the lower melting point of the inorganic products makes it necessary to incorporate features which permit smooth processing and production of a dry pelletized inorganic sodium ash. The conditions are oxidative, which implies that the product consists of sodium sulphate, Na_2SO_4, and sodium carbonate, Na_2CO_3, which is not suitable for re-use as sulphite liquor. Thus, with these kind of systems the chemicals may only be recovered in the case of magnesium base. The heat that is recovered from the combustion depend on the pulp yield, but most of the steam is consumed in the evaporation. Thus, these recovery systems must primarily be considered as an environmental measure.

A recovery or incineration system of this kind should normally be evaluated versus effluent treatment systems. The most suitable solution from environmental points of view will vary from case to case depending on local situation. Water discharges and atmospheric emissions have to be evaluated against investment and operating costs. In general a lower pulp yield will favour evaporation and incineration, while a higher pulp yield will favour effluent treatment solutions. Closure of water systems will be beneficial for the emission control in either case.

2.1.5 Non-wood Fibre Pulping

Important non-wood plant materials used in the production of fibre for paper making belong to the following categories:

- Agricultural residues, such as bagasse, cereal straw and stalks.
- Natural growing plants, primarily grasses and reeds.
- Non-wood crops cultivated primarily for their content of fibres, which are used also in other products like textiles, strings and ropes.

The traditional pulping process for non-wood plants, applied since several centuries ago, is cold maceration with milk of lime, followed by leaching/washing and beating/stamping. Such processes are still used in very small operations. Also in more modern non-wood plant processing some of the pulping methods applied seem obsolete in comparison to those used in modern wood pulp production. Common pulping processes for the main types of non-wood plants are as follows:

- Refiner mechanical or chemimechanical pulping
- NSSC or soda semichemical pulping
- Kraft pulping also with bleaching
- Oxygen-alkali pulping (NACO process)
- Hot lime pulping

Different processes are more optimal for certain fibres than others.

Disposal of sludge from pretreatment of some non-wood plant materials e. g. straw or reeds may constitute a significant environmental problem. Also non-reburnable lime mud from non-wood based operations may have negative environmental impacts. Otherwise the principal differences between wood and non-wood pulping should be small with regard to emissions with environmental impact.

In practice, however, the situation is quite different due to the structural differences between wood and non-wood processing units respectively. Whereas the average wood-based chemical (kraft) pulp mill in a global perspective has a capacity of around 400 t/d, practically all non-wood based pulp mill are considerably smaller which often does not economically justify a chemical recovery system. The process systems are often open and the effluents are often sewered without any special treatment. Thus water pollution in reality is a very great problem in non-wood pulping.

2.1.6
Waste Paper Processing with Deinking

A modern waste paper plant with deinking is a sophisticated system – a combination of advanced equipment and chemicals, fulfilling high demands for performance, economy, product quality and environmental effects. Most of the equipment in the process is needed to remove foreign components, including ink particles, from the recycled fibre suspension. Because of differences in size and density, not only between fibres and impurities, but also between different types of impurities, different types of equipment are needed to separate all impurities from the pulp suspension. This is why a deinking plant has become relatively complicated.

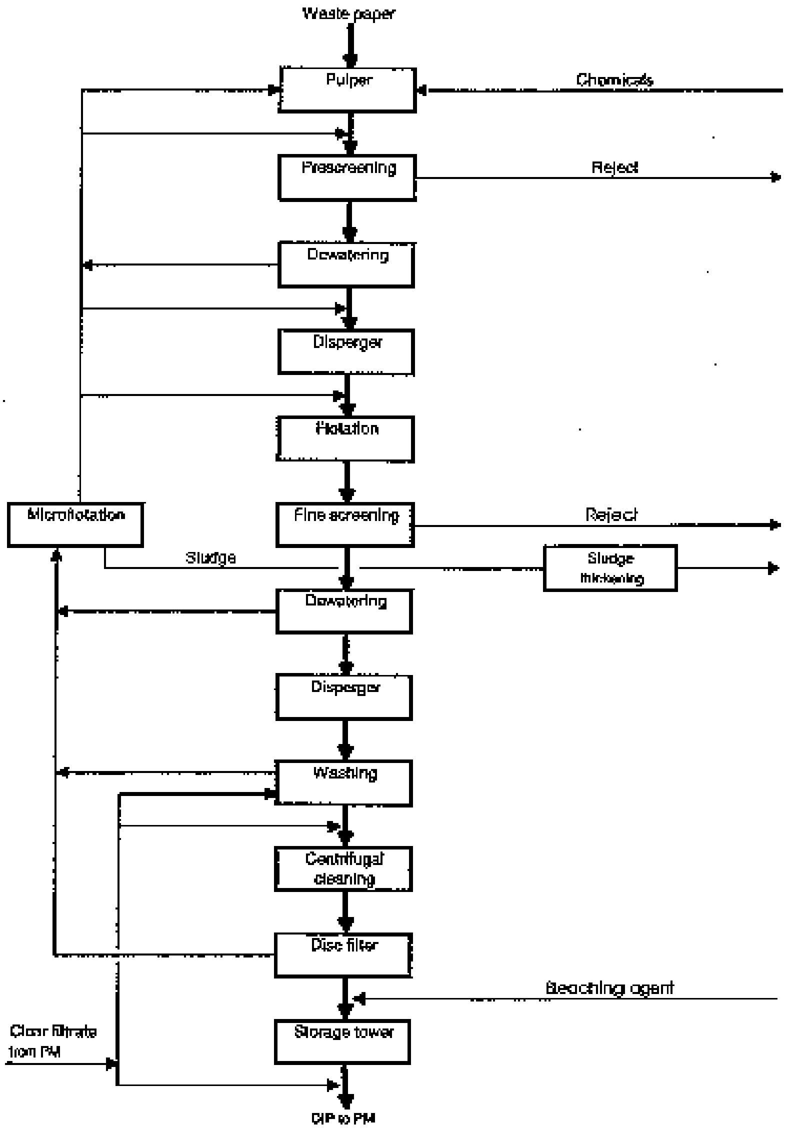
The main objectives of the deinking process are defibration, decontamination, deinking (which is a special case of decontamination) and reconditioning of the fibres, i. e. bringing the fibres as far as possible back to their original condition or to a condition suitable for the intended use of the recycled fibres (RCF).

A typical plant for production of deinked recycled fibres (DIP) includes the equipment and stages shown in Figure 2.5. The different steps or operations to fulfill the objectives may however vary from one case to another. Waste paper is normally delivered to the deinking plant in the form of bales kept together by metal wires or straps. The bales are opened by cutting the wires or straps which are collected and sold as metal waste. Occasionally, loose waste paper is also used. The fibres are then separated in a pulper and chemicals needed for the deinking process are added. Large foreign items, staples, paper clips, plastic foils and similar items are then removed in a prescreening process that may take place in several stages. The reject has to be deposited. After the fibres have been given some time to swell the pulp is dispersed. In this process remaining stickies, which originate from hot-melt glues etc., are disintegrated and remaining ink is removed from the fibres. Deinking is performed by means of flotation and/or washing. Ink sludge is removed and incinerated, or deposited.

Between and after different optional stages of flotation and washing, the pulp is screened, cleaned and dewatered. Centrifugal cleaning is done to remove heavier reject like sand and fine screening by means of pressure screens is done to remove stickies. Dewatering/thickening may be done by disc filters and screw presses to achieve the needed pulp consistency.

Before entering a storage tower the pulp is often bleached. If the waste paper processing is not integrated with a paper mill, but rather used to produce market RCF pulp, pulp drying and bailing of the deinked pulp will also be required in the processing line. In other cases the pulp is pumped to the paper mill.

Figure 2.5
Recycled fibre mill with deinking system.



Water from the dewatering stages is clarified in a micro-flotation unit. The white water is then reused in the process. The unit gives a sludge that is thickened and deposited or incinerated.

Characteristic properties of RCF

For the use of recycled fibres (RCF) in paper making it has to be noted that RCF exhibit certain distinct and fundamental differences in comparison with virgin fibres. For example:

- In most cases RCF have been subjected to varying degrees of mechanical treatment, primarily beating or refining but sometimes also quite intensive calendering and other mechanical stressing in primary production, and also in further converting and during the actual usage of the paper product.

- RCF have undergone drying at least once before, but often repeatedly.

- RCF may have been subjected to various ageing processes.

- RCF practically always represent a mixture of fibres both with regard to origin (wood species) and to further processing (pulping method).

Effluent Discharges from RCF Plants

The conventional discharge parameters of main concern are TSS (total suspended solids), BOD (biochemical oxygen demand) and COD (chemical oxygen demand). Typical values of these parameters are summarized in Table 2.2. The TSS, BOD and COD data in Table 2.2 are based on several sources, and it is clear that large variations exist between different plants. The differences are to a large extent caused by variations in RCF pulp quality. These data are also based on experience from relatively modern plants, with a high degree of closure of the water systems. Older plants may show considerably higher discharges, particularly effluent flows and TSS discharges.

Table 2.2
Discharges from deinking and non-deinking RCF pulp mills, before effluent treatment.

Discharge parameter	Unit	With deinking	Without deinking
Effluent flow	m^3/ADt	5 - 10	3 - 5
TSS	kg/ADt	10 - 50	3 - 10
BOD_5	kg/ADt	20 - 40	5 - 15
COD	kg/ADt	40 - 90	10 - 40

The above TSS values do not include the deinking sludge, sludge from internal white water clarification or other rejects.

Other discharge parameters of concern are heavy metals, certain types of organic compound, such as dioxins, chloroform and PCB, and toxicity. Metals originate from metal-containing printing inks but today the metal content in deinking sludge is typically lower than in paper mill sludges, and also lower than in municipal sludges.

2.1.7 Other Waste Paper Processing

Waste paper that does not have to be deinked is much easier to treat since the complicated part in the above mentioned process is the deinking itself. The qualities used are also much more standardised and less contaminated. Thus the included steps are more or less a pulper, a swelling tower for the fibres and cleaning equipment. Since there are no chemically complicated processes involved and the raw material is less contaminated, the process is neither very complicated from an effluent treatment point of view.

The recycled fibres of concern are for example white woodfree shavings from the envelope and printing industries and container waste from the packaging converting industry and from collection companies.

2.2 Pulp Bleaching Processes and Emissions

2.2.1 Bleaching of Chemical Pulps

The purpose of bleaching of chemical pulps is to remove lignin and impurities (non-fibrous particles and extractives) that remain in the pulp after the cooking and/or oxygen delignification stages. Certain pulp quality criteria such as brightness, brightness stability, cleanliness and strength have to be considered as well as the environmental influence that different bleaching chemicals might cause. The pulp quality criteria differ depending on the paper grade that the pulp is intended for. Examples of brightness requirements for different paper grades are presented in Table 2.3. In principle, to avoid wasting the papermaking potential of the furnish components, the brightness of these components should not differ markedly from that of the paper. All paper qualities do not need bleached pulps at all, such as most kraft liner and sack paper whose main quality aspects are strength properties rather than printability and brightness.

Bleaching of chemical pulp is mostly carried out in several stages and a number of different chemicals are used. In "classic" bleaching, chlorine-containing chemicals are used, primarily molecular chlorine (chlorine gas) and chlorine dioxide, together with caustic. The environmental pressure has however given rise to the use of other chemicals that are considered as being more environmentally friendly.

Table 2.3
Brightness ranges of some typical paper grades.

Grade	Brightness, % ISO
Copy paper	78 - 95
Continuous stationery	78 - 90
Coated wood-free	90 - 95
Coated wood-containing	68 - 80
Uncoated woodcontaining	66 - 74
Newsprint	58 - 70
Tissue	55 - 90
Fluff	70 - 90
Food-board	80 - 90

The following is a list of the most common chemicals used in pulp bleaching and the abbreviations used by the industry to denote the use of these chemicals in bleaching stages. Printing several letters between brackets shall be interpreted as a charge of these chemicals in the same bleaching stage.

C	Chlorine
D	Chlorine dioxide
H	Hypochlorite
E	Caustic soda
O	Oxygen
Z	Ozone
P	Hydrogen peroxide
A	Acidic treatment with SO_2 etc. (usually as activation between two alkaline stages)
Paa	Peracetic acid
Q	Chelating agent
Y	Dithionite
FAS	Formamidine sulphonic acid

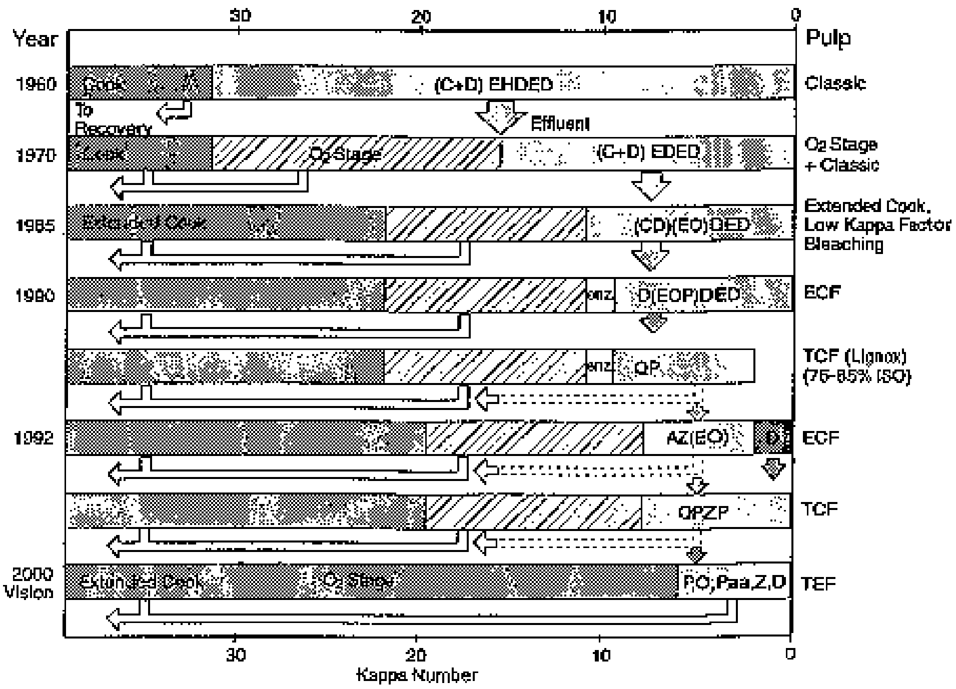
Pulps produced with different pulping methods and from different wood raw materials react differently to bleaching chemicals. Thus kraft pulps are generally more difficult to bleach than sulphite pulps and softwood pulps usually require higher chemical application in bleaching than hardwood pulps do.

Bleaching development

New pulping and bleaching technology combined with more stringent effluent regulations, influence from environmental pressure groups and new market demands have had a considerable influence on the modern bleaching practices. Consequently, new bleaching processes are used and the consumption of different bleaching chemicals has been changed, Figure 2.6. There has been a dramatic decrease in the consumption of molecular chlorine in several countries and a steady increase in the consumption of oxygen and hydrogen peroxide. Chlorine dioxide is probably the most important bleaching agent and was until recently the only option for bleaching of kraft pulps to full brightness (90 % ISO) at preserved fibre strength.

ECF (elemental chlorine-free) bleaching means that molecular chlorine has been completely replaced by chlorine dioxide. ECF bleaching usually also involves the use of oxygen and hydrogen peroxide. In TCF (totally chlorine-free) bleaching no chlorine-containing chemicals at all are used. Available chemicals for TCF bleaching are e. g. oxygen, hydrogen peroxide, ozone and peroxy acids. TEF refers to totally effluent free bleaching, which implies a closing of the effluent loop of the bleach plant. TEF bleaching has not yet been realized and today it is not clear whether this will be possible at all at reasonable costs.

Figure 2.6
Schematic illustration of the development of delignification and bleaching of softwood kraft pulp.



The steps towards ECF bleaching have consisted of successive modifications of the traditional chlorine bleaching, such as

- Reduced kappa number before bleaching
- Improved washing before the first bleaching stage
- Decreased kappa factor and increasing share of chlorine dioxide in the first bleaching stage: (C+D)
- Elimination of hypochlorite (H)
- Powerful extraction stages through oxygen and peroxide reinforcement, increased temperature and pressure: (EOP)
- Medium consistency (MC) technology and efficient chemical mixers
- Improved process control

For mills with oxygen delignification, the change from classic to ECF bleaching was easy, provided the chlorine dioxide generation capacity was sufficient. This conversion was most rapid and complete in the Nordic countries. In other parts of the world, classic bleaching is still quite extensively used - in some mills in parallel with ECF bleaching.

ECF bleaching allows production of kraft pulps that meet the highest requirements with respect to strength, brightness, brightness stability, cleanliness, etc. Since chlorine dioxide is more expensive than molecular chlorine, ECF bleaching means an increase of the production cost compared to classic bleaching.

Many mills, whether they use classic or ECF bleaching, also produce TCF pulps in campaigns by final bleaching with only hydrogen peroxide (LIGNOX process). A low to moderately high brightness (about 85 % ISO) can be achieved by final bleaching with only hydrogen peroxide provided the pulp has a kappa number not higher than that corresponding to oxygen delignification. Under favourable conditions, an even higher brightness can be achieved, but at a high cost.

The most recent additions to the group of chlorine-free bleaching chemicals, are peracetic acid and peroxymonosulphuric acid ("Caro's acid", H_2SO_5), which are alternatives to ozone in combination with alkaline peroxide stages. Also enzymes can be used both in ECF and TCF bleaching. Enzymes can facilitate the change from classic to ECF bleaching in mills operating with a high kappa number of unbleached pulp or have too small a chlorine dioxide generation capacity. In TCF bleaching with peroxide, enzymatic treatment may be a cost effective tool for attaining a higher final brightness.

Dioxin

The discovery that poly-chlorinated dioxins and furans were formed in the classical bleaching processes was of big importance for the development of bleaching technology between 1985 and 1990. In many countries the classical bleaching processes are still in extensive use. As a background to this development this section about dioxins and furans is included.

The harmfulness of dioxins differs with the different isomers in the group. Two of the most toxic substances are considered to be 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzo-furan (2,3,7,8-TCDF). These substances can be found in pulp and in effluents from bleach plants using chlorine in classical bleaching. Dioxins are regarded as acutely toxic in higher concentrations. For example it has been shown that 2,3,7,8-TCDD at a dosage of 10 µg/kg body weight causes malfunctions in the liver of rats. However, the main problem with dioxins is probably not their acute toxicity, since the concentrations in the environment probably are too low to cause that kind of harm, but the dioxins are also regarded as carcinogenic. Thus, in animal tests chlorinated dioxins have been shown to induce tumours. It has for instance been reported that rats have developed tumours in the liver, lungs and other organs after long exposure to 2,3,7,8-TCDD. Dioxin are lipophilic and may accumulate in the tissue of animals. It also seems that humans have the poorest ability among mammals to degrade dioxins. There are reports of half-lifes up to seven to eight years for dioxins in human tissue.

The reduction of dioxin formation in the pulp industry through development of bleaching technology is related to the efforts to reduce the AOX discharges from bleach plants. Quite early when studying modifications to classical bleaching it was found that when the overall AOX formation is reduced the dioxin formation is reduced much faster, cf. Figure 2.7.

The polychlorinated dioxins are formed from dissolved lignin compounds in the presence of chlorine species. An important matter in order to minimize the formation of dioxins is to minimize the presence of chlorine and the dioxin precursors. A low kappa number and a well washed pulp before the bleaching reduces the dioxin precursors present in the pulp. There is a significant reduction of dioxin formation when molecular chlorine is substituted (replaced) with chlorine dioxide. Already at substitutions of 70 % with chlorine dioxide, the dioxin formation becomes below background level. Another measure is to decrease the chlorine charge factor in the first bleaching stage below a value of 0.15 % molecular chlorine on the pulp per kappa number (chlorine multiple), the amount of dioxin present in the pulp and the effluent will be at, or below, background level.

Figure 2.7
Total formation of PCDDs and PCDFs and AOX in total mill effluent versus molecular chlorine multiple.

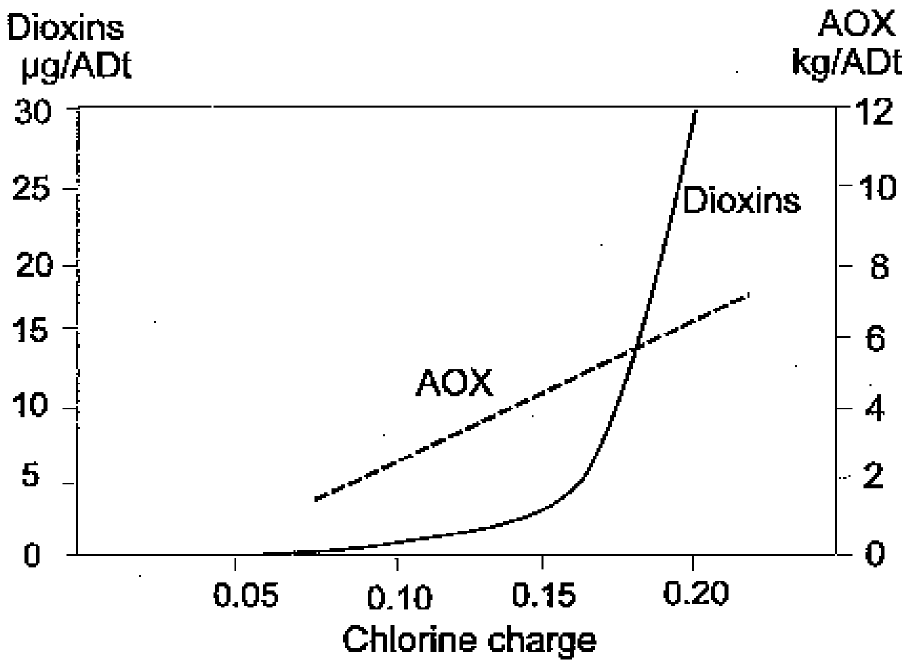


Table 2.4 shows some example of dioxin levels in pulps and effluents produced through different bleaching sequences.

Table 2.4
Example of dioxin levels for different bleaching sequences and detection limits for some substances.

Bleaching	Dioxin (toxic equivalency factor)	
Sequence	in pulp, µg/ADt	in effluent, µg/ADt *pg/kg water*
C+D EO H D E D	10 - 30	5 - 10 *40 - 80*
O DC EOP D E D	< 0.1	0.05 - 0.5 *0.3 - 3*
O D EOP D E D	0.02	
Detection Limits for Compounds:		
TCDF	0.002	
TCDD	0.004	

Thus, when applying ECF bleaching without any molecular chlorine (Cl_2) being used, the dioxin formation is at or below the detection level. The AOX levels are also reduced considerably as discussed below (Table 2.5). In TCF bleaching, by definition no chlorine compounds are being used for bleaching and there is no dioxin formation and no AOX formation.

At the moment, it is far from clear that TCF bleaching should be considered as better from an environmental point of view than ECF bleaching. TCF bleaching may facilitate a closure of the bleach plant effluent side in a better way than ECF bleaching, but there are development work going on for both cases and no final conclusions can yet be drawn. It seems that TCF bleaching may produce more COD (from degradation of carbohydrates), in particular if ozone is being used. The use of chelating agents in TCF bleaching will result in more nitrogen in the TCF effluents and these agents (like EDTA) do not appear to be degraded in activated-sludge treatment. Residual peroxide in untreated effluents results in acute toxicity of the waste water (to water fleas).

Bleach Plant Effluents

In the bleach plant, about 40-50 kg of organic substances (mainly lignin) are dissolved per ton of pulp and end up in the effluent. A traditional bleach plant for chemical pulp is open, i. e. the spent bleaching liquors are discharged as waste water (mostly to effluent treatment) instead of being recycled to the chemical recovery. A minor part of the dissolved organic material is chlorinated when chlorine-containing bleaching chemicals are used. Whether the pulp is bleached with chlorine-containing chemicals or not, the dissolved organic substances contribute to the effluent load. Of the chlorine used in the bleach plant, about 90 % ends up as common salt (chloride) and to some extent as chlorate and about 10 % or less, becomes bound to the organic material. This organically bound chlorine is roughly equal to the group of substances denoted called AOX (adsorbable organic halogen).

AOX is a measure of one important group of bleach plant effluents that are harmful to the environment. The major part of the material that is discharged with bleach plant effluents is however non-chlorinated organic material, even in traditional chlorine bleaching. Among the oxygen-consuming substances, some fall under the measure of BOD (biochemical oxygen demand) while others are chemically degradable and are called COD (chemical oxygen demand). The BOD level of the effluent indicates the amount of easily biodegradable material. The material that is more difficult to degrade by biological processes is indicated by the difference between the COD and BOD values. The organic material consists mainly of lignin and carbohydrate residues and their degradation products. In addition there are small amounts of extractives.

Bleach plant effluents may also cause disturbances in aquatic systems due to the presence of TSS (total suspended solids), nutritive salts (nitrogen, phosphorus), coloured substances and all kinds of toxic substances of which most fall under the AOX measure. The suspended solids come from all parts of the mill and contain fibres, flocculated wood substances and inorganic particles such as sand.

Table 2.5 shows the influence of process alternatives on the bleach plant emissions from bleaching of softwood kraft pulp. A low kappa number after cooking and oxygen delignification, well washed pulp and complete replacement of molecular chlorine with chlorine dioxide (ECF) results in an AOX level of 0.5 kg/ADt, or lower. This corresponds to a 90 % reduction of the AOX from traditional chlorine bleaching (Sequences 1 and 2 in Table 2.5).

The COD load in bleach plant effluents is strongly related to the kappa number of the pulp prior to the bleach plant. The COD load from a kraft mill will, apart from the contribution from the bleaching effluent, also have contributions from other sources such as wood room (debarking) effluents, evaporation condensates and carry over of black liquor residues (dissolved organic material) with unbleached pulp. In TCF bleaching the emissions of organic substances are similar to those of ECF bleaching, except that no chloro-organic compounds are formed in the TCF alternative.

Table 2.5
Raw effluent loads from bleaching of softwood kraft pulp for different bleaching alternatives.

Decreasing order of use of chlorine chemicals	Kappa number	COD, kg/ADt	AOX, kg/ADt
Classic sequences:			
1. CEHDED	32	70-80	8-9
2. O(C85+D15)(EO)DED	20	45-55	3-5
Increasing ClO_2 substitution:			
3. O(D30C70)(EO)DED	18	40-50	2-3
4. O(D50C50)(EOP)DED	16	40-45	1.5-2
ECF sequences:			
5. OD(EOP)DD	16	40-45	0.5
6. OD(EO)D(EP)D	8-10[a]	40	0.2-0.3
TCF sequence:			
7. OZ(EOP)P	8-10[a]	40	n. d.

[a] With extended delignification in cooking.
n. d. = not detected.

The different chlorinated compounds in bleach plant effluents are often divided into low and high molecular mass fractions for characterisation purposes. About 20 % of the organically bound chlorine found in the effluent from conventional chlorine bleaching is associated with low molecular mass material. The major part of the low molecular mass fraction consists of relatively water soluble substances which are easily degraded before or during biological effluent treatment. Such compounds are thus of minimal environmental significance. Examples of compounds in this group are chlorinated acetic acids and chlorinated acetones. The environmentally harmful group of compounds represented by non water soluble neutral organic compounds constitutes only some 1-3 % of the AOX. The high molecular mass fraction constitutes the major part of AOX, about 80 %. This material is characterised by relatively high water solubility and low chlorine content.

Other variables with environmental significance are the degree of chlorination or substitution (expressed as number of chlorine atoms in the molecule or as the carbon-to-chlorine ratio), tendency to accumulate in living organisms (bioaccumulation, in fatty tissues) and persistence to degradation.

Among the chlorinated components, interest has been focused on the following compound groups:

- dioxin, which is a simplified notion of a group of several highly chlorinated dibensodioxins and dibensofurans (3-4 chlorine atoms per molecule)
- other chlorinated phenolic substances
- chloroform
- chlorinated acetic acids

Formation of polychlorinated compounds, such as dioxin, in bleaching is easy to avoid by reducing the use of molecular chlorine (Cl_2). In BCF bleaching the formation of highly chlorinated compounds is minimal and often below detection limits.

Relatively high amounts of polychlorinated phenolic substances are formed in conventional chlorine bleaching, up to 100 g/ADt, but the amount can be below the detection limit in effluents from ECF bleaching.

In chlorine dioxide bleaching of chemical pulp, chlorine dioxide is partly converted to chlorate, which in aquatic environments is toxic towards bladderwrack and other brown algae. The amount of chlorate formed is typically 1-6 kg/ADt. Elimination of chlorate requires some kind of effluent treatment. Chlorate is effectively eliminated by conversion into chloride in anoxic (anaerobic) zones of biological effluent treatment plants, e. g. in a section before aeration in aerated lagoons or in lagoons specifically designed for chlorate conversion.

Relatively large amounts of chlorinated acetic acids are formed during bleaching. Also chlorine dioxide contributes to the formation of chlorinated acetic acids. Some of these substances correspond more to the chlorine charge used than others. The chlorinated acetic acids are of low environmental significance since they are easily degraded in biological effluent treatment.

Important Bleaching Chemicals and Resulting Effluents

Chlorine

Chlorine can be added to pulp as a water solution or as pure chlorine gas, commonly a combination of both is used. Mixing is important for achieving a homogeneous bleaching result. Traditional chlorine bleaching takes place at a low pulp consistency to allow a sufficient amount of chlorine to be dissolved relative to the amount of pulp. Chlorine is added to a static or dynamic mixer followed by an upflow bleaching tower. Chlorine reacts readily at low temperature, and in pure chlorine bleaching high temperature should be avoided since it causes excessive degradation of the cellulose and loss of pulp strength as a consequence.

More recent developments in chlorine bleaching of chemical pulp involve the use of dynamic, high-shear mixers at medium consistency. This gives a more controlled and even chlorination, resulting in decreased consumption of chlorine.

An advantage of chlorine is its ability to delignify and brighten chemical fibre very selectively, and to remove colour from dyed fibre and destroy contaminants. Because of its strong delignifying action, chlorine is not suitable for bleaching of mechanical fibre. Delignification of mechanical fibres means of course a loss of yield, but the main factor that makes chlorine unsuitable for mechanical fibre is the yellowing that it induces. Hypochlorite also causes yellowing of mechanical fibres.

The main drawback associated with chlorine as a delignifying and bleaching chemical is the formation of chloro-organic compounds. Especially polychlorinated, lipophilic and persistent compounds are considered environmentally harmful due to their high toxicity and high probability of bio-accumulation. The use of chlorine involves the risk of dioxin formation.

Chlorination is always followed by an alkaline treatment, either alkali extraction stage or other bleaching stages, most commonly hypochlorite. For the highest bleaching requirements, chlorination is followed by alkaline extraction and then hypochlorite.

Chlorine Dioxide

Chlorine dioxide has the highest selectivity among technical bleaching chemicals, but it is not as potent as molecular chlorine in prebleaching. Consequently, when chlorine is replaced by chlorine dioxide, the loss in bleaching power has to be compensated for in the subsequent stages. Bleaching with only chlorine dioxide in the first bleaching stage means that the total charge of effective chlorine has to be increased and oxygen and hydrogen peroxide have to be more extensively used in the extraction stages.

High charges of chlorine dioxide may lead to loss of viscosity, but for oxygen delignified pulp with a reasonably high starting viscosity, elemental chlorine free (ECF) bleaching will result in full brightness and excellent pulp strength.

Conventional ECF sequences applied on conventional kraft pulp (processed without modified cooking) will result in an AOX load of 1 kg/ADt or lower. Considerable decreases are possible with decreased kappa numbers in the cook and by optimisation of the chlorine dioxide distribution between the stages. Decreased emission levels may be attained by reducing the chlorine dioxide charge in the first bleaching stage and by not washing the pulp between the chlorine dioxide stage and the first extraction stage.

Hypochlorite

Hypochlorite is used in a single stage (H) or in combined sequences with chlorine (CH) and alkali extraction (CEH) for bleaching of chemical fibre. Although good mixing gives a favourable bleaching result in hypochlorite bleaching, mixing is not as sensitive as with chlorine. An upflow tower is not required, bleaching can take place in a chest or a downflow tower. Hypochlorite bleaching is carried out under alkaline conditions and when a hypo stage is preceded by a chlorine stage alkali (NaOH) is added after the chlorination without prior washing. Residual chlorine is then converted into hypochlorite.

Hypochlorite alone has a strong ability to remove colour from dyed fibre. Because of the yellowing that it induces it is not suitable for high shares of mechanical fibre in the waste paper furnish.

A characteristic of hypochlorite bleaching is the formation of relatively large amounts of chloroform besides other chloro-organic compounds.

Ozone

Ozone is a powerful oxidising agent and it can be applied to practically all types of pulp, but its high cost and rather poor selectivity in practical bleaching processes constitute a limitation for its use. High brightness levels are possible at a very low consumption of chlorine dioxide. Like with other non-chlorine based bleaching chemicals, it is in principle possible to recycle the washer filtrates to chemical recovery.

Ozone is produced on site in special generators through silent electrical discharge in a gas stream containing oxygen. Ozone quantities required for pulp bleaching, are most economically produced from oxygen, especially when there are several positions for consuming a part of or the whole excess oxygen at other points in a pulp mill. Different systems for recycling excess oxygen have been developed. In short loop systems, ozone and oxygen are separated directly after the ozone generator and the excess oxygen is fed back to the input side of the generator making it possible to increase the ozone concentration.

Enzymes

Among the several types of biological treatment designed to facilitate bleaching, the use of enzymes seems to be most promising.

Under optimum conditions for enzymatic treatment and following peroxide bleaching, brightnesses of 82-87 % ISO can be reached for both pine and birch kraft pulp. Some yield loss has occasionally been reported.

Since treatment with enzymes normally can be carried out in available equipment there is no need for extra investments. The enzyme treatment is usually applied on washed pulp after oxygen delignification.

Enzymes are produced by fermenting selected micro-organisms. Due to some incremental yield loss caused by the presence of cellulases, the wood cost per ton of pulp will increase. The yield loss will also increase the BOD and COD load of the untreated effluent.

Peroxide

Oxygen-delignified softwood kraft pulps can be bleached to 75-85 % ISO and hardwood pulps up to about 87 % ISO. With sulphite pulps, which generally are easier to bleach than kraft pulps, brightnesses of 89-90 % ISO are produced or even up to 92 % ISO.

The high brightness levels after peroxide bleaching require a high peroxide charge which means a considerable cost. It is also possible to produce fully bleached softwood kraft pulps by final bleaching with chlorine dioxide after the peroxide stage. The AOX level will be low, below 0.5 kg/ADt, but the cost of chemicals is high due to the high consumption of peroxide and chlorine dioxide.

2.2.2 Bleaching of Mechanical Pulps

The brightness of unbleached mechanical pulp depends on the wood species and to some extent on the pulping process. A typical brightness of unbleached mechanical pulp is 55-60 % ISO. Stone groundwood pulp from the same wood species has generally a slightly higher brightness than TMP. In many cases, like in newsprint manufacturing, the 55-60 % ISO brightness is sufficient, but with some other grades, like tissue or writing paper, the pulp may require some additional bleaching.

Since lignin is not removed during the defibration mechanical pulps are bleached with lignin preserving chemicals. Using lignin removing chemicals, as in the bleaching of chemical pulps, would be devastating to the yield. Chemicals like dithionite, hydrogen peroxide or a combination of them, are used depending on the required brightness level (paper quality). Should only a slight increase in brightness be required, dithionite is generally used, since it does not dissolve organic matter and it is rather inexpensive to use. When the target brightness is above 70-75 % ISO, it is necessary to use hydrogen peroxide or bleach in two stages with peroxide and dithionite.

Many hardwood based (chemi-)mechanical pulps respond better to peroxide bleaching than softwood pulps. Thus, hardwood (chemi-)mechanical pulps may be produced at a higher maximum brightness (≈ 85-87 % ISO) than attainable for the best softwood grades (maximum 80-82 % ISO).

2.2.3 Bleaching of deinked pulp

The main factors that determine the need for bleaching are the composition of the waste paper furnish, the performance of deinking and washing operations and the end use of the deinked pulp.

The increased use of recycled fibre has resulted in a shortage of high quality, economically attractive secondary fibre. The increasing share of unsorted and mixed grades of waste paper impairs the quality of available secondary fibre. This represents a challenge to producers of medium to high brightness deinked pulp, especially when chlorine-containing chemicals cannot be used. Chlorine and hypochlorite are often used in bleaching of deinked pulp to high brightness levels, but for the same reasons as with virgin chemical pulp, chlorine-containing chemicals will probably cease to be used. The future lies with chlorine-free bleaching also for recycled fibre.

Oxidative, chlorine-free bleaching chemicals include primarily oxygen, hydrogen peroxide, and ozone. The oxidative chemicals can be supplemented with reductive chemicals such as hydrosulphite (dithionite) and FAS (formamidine sulphinic acid). All of these chemicals can be used to bleach chemical fibre. Peroxide, ozone, hydrosulphite and FAS are also suitable for mechanical fibre. For colour stripping of dyed fibres, the reductive chemicals (hydrosulphite and FAS) and ozone can be used.

Bleaching of RCF differs from bleaching of virgin fibres in many respects. Some general differences are:

- Waste paper contains different fibres (mechanical and chemical, hardwood and softwood)
- Brightness-reverted (aged) fibre is difficult to rebleach

- Residual ink, colorants, fillers and metal contamination interfere with the bleaching reactions

Because of these differences the brightness gain in bleaching of RCF is lower than that obtained in bleaching of virgin fibre.

Because of the presence of impurities, efficient washing and cleaning stages and proper use of chelating agents are important for optimum in bleaching of RCF. Metals and ink often follow the fines, so it is important to establish a proper balance between yield and bleach response.

Brightness Requirements

The brightness requirements on deinked pulp depend on the waste paper furnish and on the type of final product. The brightness problem is further complicated by the fact that many waste paper furnishes contain both mechanical and chemical fibres, which may also be dyed. Table 2.6 shows typical waste paper compositions and brightness requirements of deinked pulp for some end products.

To meet the comparatively low brightness requirements for newsprint and tissue, addition of hydrogen peroxide to the pulper is often sufficient. For high brightness requirements, multistage bleaching including both oxidative and reductive bleaching chemicals is required.

Table 2.6
Waste paper furnish compositions and brightness requirements of deinked pulp.

End product	Brightness, % ISO	Raw material
Newsprint	55 - 60	Old newspapers (ONP), old magazines (OMG)
Tissue	45 - 80	ONP, practically all but unbleached waste paper, less magazines
Magazine paper	(65) - 75	OMG, computer printouts (CPO) and other office waste (OW)
Wood-free printing and writing paper	70 - 80+ up to 85	OW, CPO, pulp substitutes and pre-consumer waste

Deinking of waste paper that contains mechanical fibre (for instance newsprint, magazines, certain grades of book paper and computer printouts) with hot alkaline solutions results in some darkening or yellowing of the pulp. This is caused by formation of chromophores in the lignin under alkaline conditions. To counteract the yellowing, hydrogen peroxide is added to the pulper. For a significant increase in brightness, post-bleaching under optimal conditions is required.

Upgrading of unbleached chemical fibre from for instance old corrugated containers (OCC) to bleached pulp represents a special case. Both delignification and final bleaching are required, so the bleaching process resembles bleaching of virgin chemical pulp.

2.3 Pulp Mill Emission Control

Among the possibilities to control effluent discharges with technology for industrial operation, the following main in-plant control methods can be mentioned to reduce emissions to water:

- improvements in wood handling to reduce effluent discharges
- extended delignification with modified cooking
- extended delignification with an oxygen delignification stage
- improved washing and closure of screen rooms
- replacing the elemental chlorine with chlorine dioxide (ECF pulps)
- production of entirely chlorine-chemical-free pulps (TCF pulps) (with higher chemical and operating costs and inferior pulp quality compared to ECF pulps)
- condensate and liquor spill handling

To reduce emissions to the atmosphere, the following technologies may be mentioned:

- collection and incineration of strong malodorous gases (TRS-gases of HCLV nature (high concentration, low volume)) in lime kiln or in dedicated incinerators. Back-up system is required to guarantee a high efficiency
- collection and incineration of weak malodorous gases (TRS-gases of LCHV nature (low concentration, high volume)) in bark boiler or in recovery boiler
- removal of solid particulates (TSP) from flue gases by electrostatic precipitators (ESP) or by scrubber systems. ESPs are applied to recovery boilers, to bark boilers and to lime kilns

- removal of acidic gases (mainly sulphur dioxide) by scrubbers with alkaline liquors

- reduction of NO_x formation either through modifications to the combustion chamber or through injection of reducing agents

- improved lime mud washing to reduce emissions from lime kiln

Towards the Effluent-Free (TEF) Bleach Plant

Reducing or even eliminating bleach plant discharges has been a goal for the pulp industry for a long time. Some recycling of filtrates has been accomplished but the problem with chloride has made it difficult to reach the ultimate solution, the totally effluent free bleach plant (TEF).

Strictly speaking a totally effluent free mill is not achievable nor is it necessary. Certain emissions and levels can be in harmony with the environment on a sustainable basis. Provided sufficient dilution, BOD and COD emissions as such do not have to be harmful. Carbon dioxide and metals in ashes from pulp production can be part of a greater loop that includes the forests. But emissions of acid compounds (SO_2 and NO_x) into the atmosphere are difficult to accept.

TEF is here used to designate a mill with no bleach plant effluent (sometimes also referred to as closed loop bleach plant). In a modern conventional bleached pulp mill, the bleach plant is the largest emission source.

The basic requirements for recycling of spent bleaching liquors (washer filtrates) are:

- Low enough volumes of recycled liquors so they can be handled in other parts of the mill

- The recycled liquors must not be corrosive (requiring a low content of chloride ions)

- Control of the chemicals balance in the mill

- Removal of metals (apart from sodium) and other non-process substances that are introduced with the wood

The need for reducing the bleach plant effluent volume is indicated by comparing the effluent from a modern ECF bleach plant, which is about 20 m^3/ADt, with the about 8 m^3/ADt of brownstock washer filtrates sent to the evaporation and chemical recovery.

By treating the washer filtrates from ECF bleaching, both the volumes and chloride content can be decreased. Evaporation and membrane filtration are examples of such treatment methods being under development. A TEF bleach plant can therefore be realised from ECF bleaching, not only from TCF. In designs based on direct recycling of the bleach plant filtrates without application of any separation stages ("kidneys"), there will be a build-up of substances introduced with the wood and chemicals. Independent of the bleaching processes, chloride is also introduced with the wood to some extent.

In a modern ECF bleach plant the washer filtrate volumes are reduced by internal recycling. Any further reduction requires more efficient washers in the bleach plant, as for instance presses, so that less wash water is needed. Still additional evaporator capacity would be needed for the mill.

2.4
Paper Mills and Emissions

2.4.1
Technical Description of Different Paper and Board Manufacturing Processes

Paper and board manufacturing processes can take place at the same site as pulp production (integrated mills) or separately at a site of its own (non-integrated mills). When paper is manufactured on the same site dewatering and drying of pulp can be avoided between pulp and paper manufacturing. The following basic units are related to almost all types of paper and board machines. Figure 2.8 gives a basic illustration of these units, but also includes the white water system, for recirculation of fibres and water, and the boiler for production of steam for the dryer rolls. A paper mill may be divided into

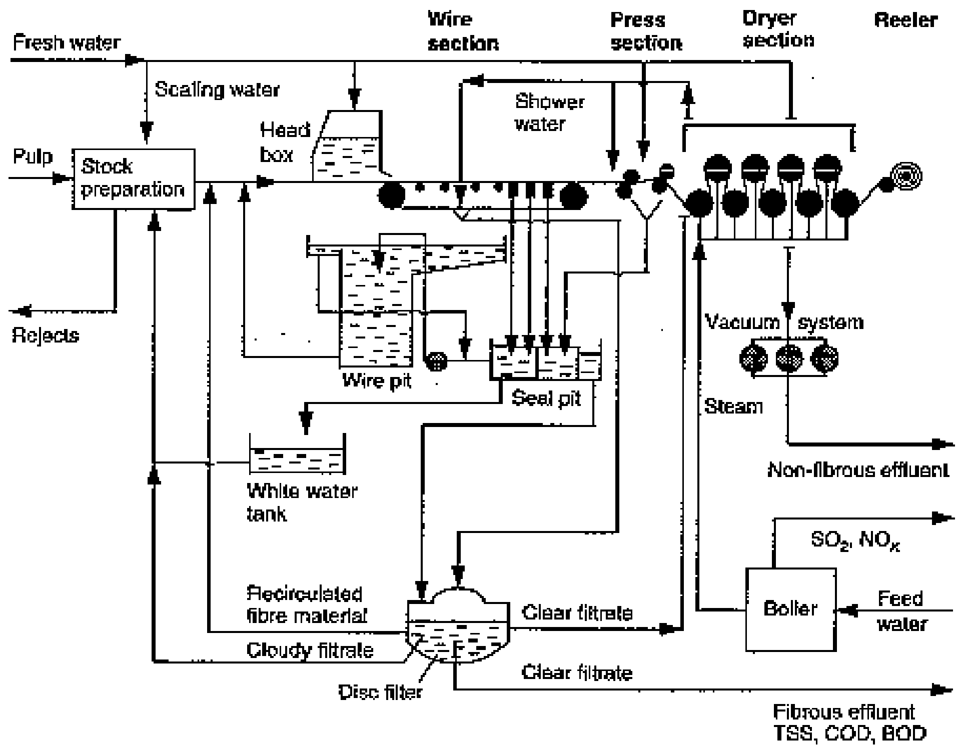
- Stock preparation

- Paper or board machine including
  - Wire section
  - Press section
  - Dryer section
  - Reeler

Stock Preparation

The stock preparation unit contains equipment to beat, clean, mix and dilute the paper furnish. At an unintegrated mill the dried pulp first has to be dissolved, a step that is not necessary at integrated mills where the pulp comes as a slurry. In the last case water is added to the system together with the pulp. This thus brings excess water to the system that has to be removed to keep the water balance. Chemical pulp has to be beaten in a refiner to enlarge the fibre bonding surface. Different types of pulp are then mixed, in some cases also together with clay particles, "fillers", to achieve the appropriate fibre furnish, Figure 1.1. Chemicals such as retention aids, that binds fines and filler particles to the fibres, are added. Pigments to colour the fibres might also be added as well as chemicals to decrease the biological activity in the system. Centrifugal cleaners are used to separate heavy particles and shives from the pulp and pressure cleaners are used to remove small particles and debris.

Figure 2.8
The paper production process, including white water system.



Wire Section and White Water System

Before entering the headbox the stock is diluted with recirculated water to achieve a dry content of around 1 %. The purpose of the headbox and the preceding piping is to transform the stock flow from a circular cross section to a flow of several meters width (a paper machine can be up to 10 meters wide) with an even pressure and a uniform fibre and particle content. The flow from the headbox hits an endless wire, where dewatering of the stock starts instantly. Thus a flow of water containing a lot of both fines and filler particles, but also some fibres, drains through the wire and ends up in the wire pit. This flow is recirculated in what is commonly called the short circulation. A circulation that is essential for the economy of the process. An overflow from the wire pit together with the water that is drained towards the end of the wire is entering a longer circulation that contains a disk filter, cleaning it from fibres and particles that will be recirculated. Excess flow from the disc filter enters the effluent to keep the water balance and to bleed the system of unwanted substances that do not leave together with the paper.

Press Section

There is only a limited amount of water that can leave the stock through the wire. The dryness is around 20 % when entering the press section, where further water is forced out of the paper by physically pressing it between two rolls. Press felts pass in between the rolls and the paper on both sides. In the press, the fibres are also pressed into physical contact with each other. After the press section, the dryness has increased to around 40 % up to about 50 %.

Dryer Section

Most of the remaining water is evaporated, and fibre-to-fibre bonds are developed in the dryer section, where the paper gets into contact with steam heated metal cylinders. In the case of an unintegrated paper mill the steam is produced in a boiler. A paper machine that is integrated with a pulp mill can use the excess steam from the bark or recovery boilers in the case of chemical pulp production (Figure 2.1) and the steam from the refiners in the case of TMP production (Figure 2.4).

Additional Equipment

In addition to the basic units there is often additional units depending on the paper and board grade. Most common optional units are as follows:

- Calenders (on- or off-machine types)
- Winders and rewinders
- Coaters (on- or off-machine types)
- Coating emulsion preparation
- Finishing and roll wrapping equipment
- Roll core handling systems

Different paper and board grades are manufactured from different raw materials with machines which are designed for each paper or board grades.

2.4.2 Water Discharges Before External Treatment

The following types of discharges can be noted:

- Waste water (effluent) discharge
- Suspended solids (TSS) emissions before and after primary treatment
- BOD and COD discharges after primary treatment.

The waste water discharges are of basic importance since it has influence on the discharges of other pollutants (particularly suspended solids), and a great significance for the design of effluent treatment plants. Typical discharge data for various paper production categories are summarized in Table 2.7. A main part of the TSS discharged to primary treatment will be removed there, giving rise to sludge which has to be handled, dewatered and finally disposed of. The TSS data before primary treatment show large variations. These data reflect the differences in system closure and in the internal fibre recovery. Also the TSS data after primary treatment show variations. These reflect the differences in system closure but also, varying TSS properties between the mills, due to process differences.

It is not relevant to specify the BOD and COD discharges before primary treatment, for two reasons. First, the variations are very large, due to the variations in TSS discharges and the variations in the specific BOD and COD of the TSS. Secondly, the aim of the primary treatment is to remove TSS, and further removal of BOD and COD shall be made by other methods (biological or chemical). This means that the relevant data are the BOD and COD discharges after primary treatment.

The BOD and COD discharges from the paper mill originate from:

- Organic matter, carried over in the pulp from the integrated pulp mill or included in the purchased pulp. This amount is normally more important in the case of an integrated mill.

- Organic matter, dissolved from the pulp in the refining ahead of the paper machine. This amount is generally higher for high yield (mechanical) pulps than for low yield (chemical) pulps. This amount - generally referred to as "generated in the paper mill" - normally corresponds to appr. 1-5 kg BOD/t paper and appr. 2-10 kg COD/t paper. These are also the dominating BOD and COD discharges from a non-integrated paper mill.

- Organic matter, originating from chemical additives in the paper mill. This amount is normally of minor significance in terms of BOD and COD.

The degree of system closure normally has only a minor influence on the BOD and COD discharges. In the case of very high degrees of closure, i. e. very low white water discharges, a significant reduction of the BOD and COD discharges can be reached. In these cases the corresponding "removed" BOD and COD amounts will be carried over to the finished paper.

Significant differences between discharges from the various paper production categories cannot be identified. In Table 2.7 indicative specifications for the different categories have been presented. There are large variations also within each category.

The discharge data given here refer as far as possible to non-integrated paper production. For integrated paper production, particularly the BOD and COD emissions will be very much influenced by the type of pulping production as well as by the internal pollution control at the pulp mill. In paper production integrated with recycled fibre utilisation, the recycled fibre processing will influence the emissions.

Table 2.7
Water discharges from paper mills

Production category	Effluent, m^3/t	Suspended solids, kg/t		BOD_5, kg/t	COD, kg/t
		Before	After	After	After
			Primary Treatment		
Newsprint	12 - 24	appr. 30	-	-	-
Printing & writing, uncoated	7 - 90	30 - 50	0.3 - 8	1 - 13	2 - 20
Printing & writing, coated	8 - 50	10 - 40	0.5 - 4	1 - 20 (norm. 1 - 2)	2 - 40 (norm. 2 - 7)
Packaging	-	-	~ 5	-	-
Paper board	8 - 20	-	1 - 3	~ 2	3 - 10
Liner & fluting	10 - 20	5 - 70	1 - 3	-	-
Tissue	20 - 50	~ 30	0.3 - 2	2 - 3	3 - 5
Special	10 - 400	20 - 100	0.1 - 6	0.3 - 6	1.5 - 8

Chemical Additives

Some comments may be given to other environmental concerns as to the additives in paper mills. The judgement of the potential environmental risks are based primarily on known properties of each chemical as such. In order to estimate the actual effects in receiving waters it is necessary to have a knowledge of the properties of the chemicals with respect to for instance the retention in the paper, the degradation or other transformations in the paper machine system, and the degradation or removal in the effluent treatment plant.

A typical classification of the additives that is used in some countries may be summarised as follows:

Insignificant environmental risks

- Fillers
- Dry strength agents (modified starch products)
- Dye fixation agents
- Retention aids
- Resin dispersion agents
- Complexing agents

Low environmental risk, but not generally negligible

- Hydrofobation agents
- Wet strength agents
- Dyes
- Optical whitening agents
- Defoaming agents
- Slimicides
- Tensides

There may be large variations within each group of chemicals and for some of the chemicals in use the knowledge to make an environmental risk evaluation is limited. As examples, knowledge of retention and emissions of defoaming agents and of hydrofobation and wet strength agents is insufficient. Knowledge of degradation products of dyes is limited.

Sources of Water Discharges

Different types of waste water discharged from a paper machine comes from different parts of the machine:

- Pulp is cleaned ahead of the paper machine for the removal of impurities, like bark particles, shives and sand. Centrifugal cleaners and screens are used. The rejects from the cleaners contain the impurities and also some valuable fibres, suspended in water. The rejects are usually discharged to the combined effluent, but may also be discharged directly to the sludge dewatering.

- The white water is the water which is used for transporting the pulp from the pulp mill to the paper mill inlet, the head box, where more water is added for dilution, and further to the paper machine wire. This water is drained off at the wire, to the main part, and then finally removed from the paper in the press section and the drying section of the paper machine. The white water also contains the spent shower water, from the cleaning of wires, felts etc. The main part of the white water (in a modern mill) is recycled within the paper machine, as dilution water and as shower water. An excess of white water is however discharged to the effluent. This water usually passes through a fibre recovery unit, before the discharge.

The amount of white water excess depends on the degree of recycling, or degree of closure, in the paper machine. The higher degree of closure, the lower is the amount of white water excess. This amount is usually expressed as m^3 per ton of paper. The white water excess contains the main part of the continuous discharges of TSS and of dissolved organic substance (normally expressed as BOD and COD).

- The temporary and accidental discharges are such discharges which are not directly connected to the process or which occur intermittently. Examples of such discharges are over-flows of white water or pulp from tanks or other equipment, with a poor level control, spent wash water from cleaning of equipment and flushing water from flushing of floors etc. These discharges tend to contain an increasing share of the total discharges, as the degree of closure in the paper mills are being increased.

- The spent cooling waters, as well as the spent sealing waters from the vacuum system and other equipment, are generally clean, i. e. fibre-free. These waters may be recycled to some extent. Clean cooling waters should be separated from the other effluents, in order to minimise the load on treatment plants.

2.4.3 Atmospheric Emissions

The atmospheric emissions from paper mills originate primarily from various types of power plants. The paper mill itself does not normally give rise to any significant atmospheric emissions. An exception to this rule are the special paper mills which utilise organic solvents in the production for various purposes. Such solvents may give rise to atmospheric emissions.

Emission Data for Power Plants

Typical emission data for various boiler types with respect to particulates, sulphur dioxide (SO_2) and nitrogen oxides (NO_x), from solid fuel boilers and oil, gas and coal fired boilers, all of which may be operated at paper mills are summarised in Table 2.8.

Table 2.8
Atmospheric emissions from boiler plants at paper mills.

Plant type	Particulates		SO_2	NO_x, as NO_2
	mg/m³n	kg/t steam		
Solid fuel boilers			< 20 mg/m³n	75-100 mg/MJ
- Cyclone/Multicyclone	50 - 250[a]	0.06 - 0.9		
- Electrostatic precipitator	5 - 100[b]	0.01 - 0.1		
Oil-fired boilers[c]	15-100	0.01-0.17	Depending on sulphur in oil	150-250 mg/MJ
Gas-fired boilers[c]			< 50 mg/m³n	100-250 mg/MJ
- LPG	< 5	-	-	
- Producer gas	10 - 60	-	-	
Coal-fired boilers	Appr. same as solid fuel boilers	-	Depending on sulphur in coal	150-450 mg/MJ
Total from paper mill	**-**	**-**	**0.02 - 6 kg/t of paper**	**0.1 - 2.4 kg/t of paper**

[a] Up to 500 mg/m³n.
[b] Normally 50-100 mg/m³n.
[c] No collector for solid particulates (TSP).

Emissions of Volatile Organic Compounds

This problem is related to a relatively small number of special paper mills of different types, which utilise organic solvents and other volatile organic compounds in the production. These mills are normally relatively small units. Examples of operations where such compounds are used are the following:

- Printing operations
- Coating of paper with organic solvent based coating materials
- Preparation of filter papers with resins

Examples of volatile organic compounds (VOCs) which can be emitted to the atmosphere from such operations are the following:

- Methanol
- Acetone and other ketones
- Phenol
- Formaldehyde

Such compounds can be emitted either from the sections of the paper machine where the printing, coating etc. operations are performed, or from areas in the mill where the different chemicals are handled. VOC emissions may be a working environment problem as well as an atmospheric emission problem.

2.4.4 Waste Generation

Various types of waste, such as rejects and sludge, are generated at paper mills. Rejects are generated by cleaning of the pulp furnish before the paper machine headbox. The rejects contain various impurities, like shives, bark, sand etc., and also some good fibres. The dry solids content is generally around 1-2 %. The rejects are normally led to the effluent stream. In the case of an integrated mill, some rejects may be recycled to the pulp mill. Most of the reject solids will end up in the sludge from effluent treatment.

Sludge from effluent treatment represents at many mills, particularly non-integrated paper mills, the largest waste volume. The sludge may be of different types:

- Primary sludge, from primary clarification. It is generated at most mills. It consists primarily of fibre material and of inorganic material at mills using fillers.

- Biological (secondary) sludge at mills using biological effluent treatment. It contains a high proportion of organic material.

- Chemical (tertiary) sludge at mills using chemical effluent treatment (chemical flocculation). The distribution of organic/inorganic material varies depending on the type and amount of chemicals used for flocculation.

2.5 Paper Mill Emission Control

2.5.1 Water Pollution Control

The main principles for process internal control measures in papermaking are:

- Reduction of fresh water consumption, recycling of process waters.
- Reduction of fibre and filler losses from the process to the recipient.
- Separation of uncontaminated waters from contaminated waters in the process.

The first two types of measures above are called "system closure". The system closure often results in advantages in pollution control but drawbacks in the papermaking process.

The advantages of system closure are:

- Lower fresh water consumption resulting in lower volumes to external effluent treatment: Effluent treatment can thus be built with smaller hydraulic capacities and lower investment costs. Contaminants are more concentrated in the effluent, which often contributes to higher removal effectiveness.

- Lower costs of raw water: Savings in raw material costs due to lower losses of fibre and fillers can be achieved and also lower energy consumption due to less cold fresh water added to the process.

- Higher temperatures in process white water system: Faster dewatering on the paper machine wire due to lower viscosity of the water. Faster dewatering results in lower steam consumption in the dryer section. The faster dewatering can also be utilised to increase the production speed.

The drawback of system closure is the build-up of suspended solids as well as dissolved organic and inorganic substances in the white water system. The build-up may result in some of the following negative effects:

- Increased biological growth in the system, resulting in slime problems causing web breaks and production losses.

- Product quality problems: lower brightness and decrease in some strength properties.

- Increased consumption of many process chemicals: sizing agents, retention aids or biocides.

- Corrosion problems, for instance from build-up of chloride ions.

- Clogging of pipes, shower nozzles, wires and felts with fibres and fine suspended solids, causing interruptions in the production.

These effect can however be reduced through several measures such as changing the chemical condition to reduce both the biological and chemical deposits and decrease the corrosion problems. The retention can be increased by more use of retention aid. Efficient cleaning and screening of the pulp becomes more crucial with increased system closure. Membrane filtration is also an option to reduce the concentrations of substances building up in the system. Some measures are definite prerequisite for increasing the system closure.

Reduction of Fresh Water Consumption

The fresh water consumption can be reduced by recycling the white water in as many positions as possible, generation of clarified water from white water as a substitute for fresh water, and generation of fresh water by purification of clarified white water.

The following positions in the process are of special interest when reducing fresh water consumption by recycling:

- Dilution of fibre raw materials and fillers
- Dilution of process chemicals
- Dilution of process chemicals for coating colours and surface sizing
- Shower water system
- Vacuum system
- Sealing water for pumps and agitators
- Recycling of white water from paper mill to pulp mill in integrated mills

The white water contains relatively high amount of fibres and other suspended solids, and cannot be reused without clarification. There are several methods for the clarification of white water. The obtained clear filtrate is used as a substitute for fresh water in the paper machine system. The separated fibre and filler material is reused as raw material in the process. White water may be clarified by filtration, flotation or sedimentation.

Water purification can be achieved through evaporation or membrane filtration. Technologies which however not can be generally applied in full-scale practice in paper mills with current technology due to operating problems and high costs. However, the technology for fresh water generation can also be used to reduce the fresh water needed in an existing mill without having the target of closing the mill completely. There are today very few installations, most of which are pilot installations. These technologies, including the closed cycle paper mill, will probably reach technical application during the second half of this decade.

During the last few years a lot of research has been carried out on the possibility of closing completely the process water flows in the paper mill. This would result in a mill with no effluent and only solid waste, which in most cases could be burnt in the mill. The prerequisite for succeeding with the totally closed cycle mill concept is that the dissolved organic and inorganic materials (salts), not retained in the paper can be removed from the process waters before unreasonably high levels are built up. Another problem is that pure or almost pure water will be needed in some positions of the process also in the future. If this water is taken from external sources, the same amount of water must be discharged from another part of the mill to keep the mill in balance. The solution to the problems is a nearly complete separation of all colloidal and dissolved material from the water. The remaining water is used as fresh water and the residuals contain all the contaminants, which have to be removed from the process.

Reduction of Fibre and Filler Losses from the Process to the Recipient

The following areas are of interest when reducing the losses of fibres and fillers to the recipient:

- Retention of fibres and fillers in paper forming
- Fibre recovery units for excess white water
- Reject handling and reject cleaning
- Accidental discharges
- Handling of coating colour discharges

The reason why the excess water from the paper machine process is contaminated with fibres and fillers is that part of the material is slippering through the holes in the wire when the paper web is dewatered. The retention, the amount of material retained on the wire, is less than 100 %. If the retention is increased, the consistency of the white water is reduced. A cleaner white water to the fibre recovery unit results in less material in the clear filtrate to external treatment. The retention varies much between different paper qualities but is in general between 50 and 90 %. The retention is usually lower for mechanical pulps (which contain large amounts of fine material) than for chemical pulps. The retention depends on several machine settings, e.g. machine speed, paper basis weight and consistency in the headbox. Changes in these machine settings can, in general, not be made without affecting paper quality or productivity. The best way to increase the retention without affecting quality and productivity too much is to utilise chemicals, retention aids. Retention aids are usually polyelectrolytes. The smaller particles are bound to the larger fibres with electrostatic forces during dewatering of the paper web. An effective retention aid can increase the retention by 10-15 % units.

The excess water leaving the paper machine system should be clear filtrate to reduce fibre and filler losses. In a non-integrated paper mill, this water is led to the effluent treatment or to fresh water generation. If the paper machine is integrated with a pulp mill, the excess clear filtrate is used as a substitute for fresh water in the pulp mill. The fibre and filler materials recovered in the clear filtrate generation are pumped back to stock preparation, where they are mixed with incoming raw materials. Fibre recovery is made in the same process step as the generation of clarified white water.

Some of the fibre material in the incoming pulp is not suitable for paper-making and has to be sorted out. There may also be contaminants, such as bark, plastic, sand, biological slime and unseparated fibres (shives), which have to be removed. In a modern paper machine system 0.5-1 % of the incoming raw materials is rejected. This rejected material is often led to the effluent treatment. The reject rates may be decreased by either increased number of cleaning stages for the rejects or recirculating the rejects to pulp mill To decrease the load on the external treatment the rejects can also be dewatered and burnt as sludge.

Upsets in the process resulting in overflows of pulp and white water to sewer channels are part of the normal operation of the mill. These can however be reduced by the following measures:

- White water system design and control
- Broke system design
- Improved training and motivation of the operators
- Sewer recovery system

If coated paper grades are produced it is common to have a separate sewer for the collection of coating colour discharges. The main motive for introducing such a system is that greater amounts of accidental discharges of coating agents can result in severe disturbances in the effluent treatment plant. Furthermore, if the sludge from the treatment plant contains coating components, it might obstruct the sludge dewatering properties and eventually the incineration of the sludge. Recirculation of coating colour back to the coating kitchen has until recently been considered impossible. The reason for this is that the coating process is extremely sensitive to contaminants, which easily can enter the system during recirculation. However, with the membrane filtration technology very good results have been obtained in coating colour recycling.

Separation of Uncontaminated Waters from Contaminated Waters in the Process

Some of the water involved in the papermaking process is not in direct contact with the fibre suspension and is thus not contaminated with solids or dissolved substances. These waters are typically cooling waters from e. g. refiners, paper machine drives, hydraulics and compressors.

After primary use these waters can by utilised in the following ways:

- Discharge to the recipient
- Used as fresh warm water in the process
- Reused as cooling water in positions where cooling water temperature can be higher, or reused after cooling.

Regarding direct discharge to the receiving water, it is important that uncontaminated waters should be discharged via a separate sewer system with no connection to the effluent treatment system. Otherwise the effluent treatment system will carry an unnecessary load of uncontaminated water resulting in lower treatment efficiency or higher investment costs. If the cooling water is used as fresh warm water, this water should be taken from positions where there is no risk for oil spill. The system could also be equipped with oil separation units and oil alarms.

2.6 Emission Sources

In Section 2.1-2.5 the processes and emissions are described in general terms. In this section, Section 2.6, the main sources of atmospheric and water emissions from pulp and paper mills are summarized. Actual emission levels are presented in Chapter 6 and 7.

In Table 2.9 the sources of major emissions to the atmosphere from pulp and paper industries are summarized for the kind of industries/processes included in the present study.

Table 2.9
Main sources of atmospheric emissions

Process	Solid particulates, TSP	Sulphur dioxide, SO_2	NO_X	Malodorous gases, TRS	Chlorine compounds
Kraft	Recovery boiler Bark boiler Power boiler Lime kiln	Recovery boiler Incineration furnace (Bark boiler) Power boiler Lime kiln	Recovery boiler Incineration furnace Bark boiler Power boiler Lime kiln	Digester plant Evaporation Condensates Non-condensibles Misc. tanks (Lime kiln)	Bleach plant Chlorine dioxide generation
Sulphite	Recovery boiler Bark boiler Power boiler	Recovery boiler Liquor preparation (Incineration furnace) (Bark boiler) Power boiler	Recovery boiler (Incineration furnace) Bark boiler Power boiler	Digester plant	Bleach plant Chlorine dioxide generation
Semi-chemical	Bark boiler Power boiler	Liquor preparation (Bark boiler) Power boiler	Bark boiler Power boiler	-	-
Mechanical	Bark boiler Power boiler	Bark boiler Power boiler	Bark boiler Power boiler	-	-
RCF/DIP	Power boiler	Power boiler	Power boiler	-	-
Paper production	Power boiler	Power boiler	Power boiler	-	-

In Table 2.10 the sources of major emissions to water from pulp and paper industries are summarized for the kind of industries/processes covered by the present report.

Table 2.10
Main sources of water emissions.

Process	TSS	BOD	COD	AOX
Kraft	Wood handling Screening Cleaning Bleaching	Wood handling Condensates Screening Cleaning Bleaching	Wood handling Condensates Screening Cleaning Bleaching	Bleaching
Sulphite	Wood handling Screening Cleaning Dewatering Bleaching	Wood handling Condensates Screening Cleaning Dewatering Bleaching	Wood handling Condensates Screening Cleaning Dewatering Bleaching	Bleaching
Semichemical	Wood handling Washing Dewatering	Wood handling Washing Dewatering	Wood handling Washing Dewatering	-
Mechanical	Wood handling Screening Cleaning Bleaching	Wood handling Screening Cleaning Bleaching	Wood handling Screening Cleaning Bleaching	-
RCF / DIP	Screening Cleaning Flotation	Screening Cleaning Flotation	Screening Cleaning Flotation	-
Paper production	Screening Cleaning White water	Screening Cleaning White water	Screening Cleaning White water	-

3
EXTERNAL EFFLUENT TREATMENT

3.1
Introduction

3.1.1
Main Treatment Methods

The treatment methods which are used by pulp and paper industries can be assigned to the following main groups:

Group 1 Technically proven and established methods, which are in general use today at modern plants, and which obviously do not entail excessive investment and/or operative costs.

Group 2 Technically proven and established methods, which are used only to a limited extent today.

Group 3 Emerging technology at its early stage under development, but that will likely find a use in the future.

These groups can be summarized as follows.

Group 1 includes the primary treatment for suspended solids removal and the biological (secondary) treatment, by aerobic methods, for removal of organic matter.

Primary treatment, and also a number of pre-treatment methods like screening and neutralization, are extensively used in the pulp and paper industry. The purpose is often pre-treatment ahead of biological treatment, but in many cases it is the only effluent treatment. Primary treatment, with the methods used today, is expected to be of great importance also in the future.

Aerobic biological treatment is the fundamental method to be used for the removal of oxygen consuming organic matter, and also for the removal of specific organic compounds including toxic compounds and to some extent chlorinated organic compounds. The most important methods are the activated sludge and the aerated lagoon methods, which are extensively used for most of the present types of pulp and paper mill effluents.

Group 2 includes the trickling filter and the submerged biological filters, which are aerobic biological methods, the anaerobic biological methods, and chemical flocculation.

The main applications of the filter methods are either in cases when only limited treatment efficiencies are required or as a pre-treatment stage ahead of some other biological treatment.

The anaerobic methods can, with the present technology, be used only for certain types of effluent, mainly those with a high concentration of organic matter, with a limited amount of toxic substances and with a limited amount of sulphur compounds. With these restrictions, the advantage of the anaerobic treatment being the lower operating costs compared to the aerobic methods must be pointed out. An increased use is expected in the future, due to lower water consumptions, higher organic concentrations and higher energy costs.

Chemical flocculation is extensively used in some countries, like Sweden and Japan, but to less extent in most other countries. The main reasons for its application are either the removal of phosphorus, which is common in Sweden, or the complimentary removal of COD after biological treatment, which is common in Japan. In certain cases chemical flocculation can be used as the only treatment in connection with primary treatment when a limited treatment result is required. A future increased application can be expected, in cases where high COD removals are required.

Group 3 includes methods which are presently in a development stage, or which are used only at a very limited extent. This group includes two sub-groups represented by new technology for aerobic and anaerobic biological treatment and by various physical-chemical treatment methods. These methods are not expected to find an extensive use in the near future, but possibly on a long-term basis.

New technology for aerobic treatment aims at reducing costs and at finding methods which have a larger operation stability than the current methods, like the activated sludge method. New technology for anaerobic treatment aims at finding new application areas and at increasing operation stability.

The use of physical-chemical methods aims primarily at removing substances which can not be removed by biological treatment, or at reaching extremely good treatment results. Methods in this group are primarily membrane filtration, evaporation and various adsorption methods (like the use of activated carbon).

The question of sludge handling requires attention. Many treatment methods produce significant amounts of sludge, which is a solid material with a high content of water. There are three types of sludge from pulp and paper industries being "fibre" sludge and "biological" sludge with a high content of organic matter, and "chemical" sludge with a high ash content. The present methods for handling the sludges are primarily reuse of some fibre sludge and landfilling or incineration for fibre/biological/chemical sludge. But other methods will probably find increasing use, like using sludge for improving poor soil quality or application of sludge on farm land.

3.1.2
Effluent Emissions and Treatment Methods

In the modern pulp and paper mills internal measures are normally applied, in order to minimize the discharge of polluted waste waters. But the technology of today does not allow a complete closure of the mill water systems, although the totally closed mill concepts are under development. In the normal case the pulp and paper mills will always discharge a polluted wastewater, or effluent, which has to be treated before discharge to the receiving water.

The purpose of the effluent treatment is to remove a number of different components, emissions, generally characterizised by some of the groups mentioned in Chapter 1.

It is to be noted that the requirements of today, regarding the removal of these components, differ between the various pulp and paper producing countries. However, requirements regarding suspended solids, organic matter (biodegradable and total) and chlorinated organic matter are applied in most of countries today. It shall also be noted that effluent treatment methods are well developed for the removal of most of these components. There are large differences, however, as to what extent the available methods are utilized.

In summary, the following treatment methods are available:

- *Suspended solids*: Mechanical or Primary treatment.
- *Organic matter, biodegradable*: Biological (or Secondary) treatment.
- *Organic matter, non-biodegradable*: Biological treatment and/or chemical flocculation. Possibly membrane filtration.
- *Toxic matter*: Biological treatment, chemical flocculation.
- *Chlorinated organic matter*: Biological treatment, chemical flocculation.
- *Coloured matter*: Chemical flocculation. Possibly membrane filtration.
- *Acids* and *alkali*: Neutralization with alkali or acid.
- *Chlorate*: Biological treatment, under anoxic (virtually oxygen free) conditions.

- *Phosphorus*: Chemical flocculation and to some extent by biological treatment.

- *Nitrogen:* Methods are not well developed today for pulp and paper mill effluents.

Most of these methods, i. e. the mechanical, biological and chemical methods, produce a solid water-containing residue called a sludge. This sludge always has to be further handled and finally disposed of.

Figure 3.1 shows an example of a complete treatment plant for pulp and paper mill effluents.

3.2 Pre-Treatment

Pre-treatment is carried out ahead of other treatment plants, in order to facilitate the treatment process. The following methods are the most important ones:

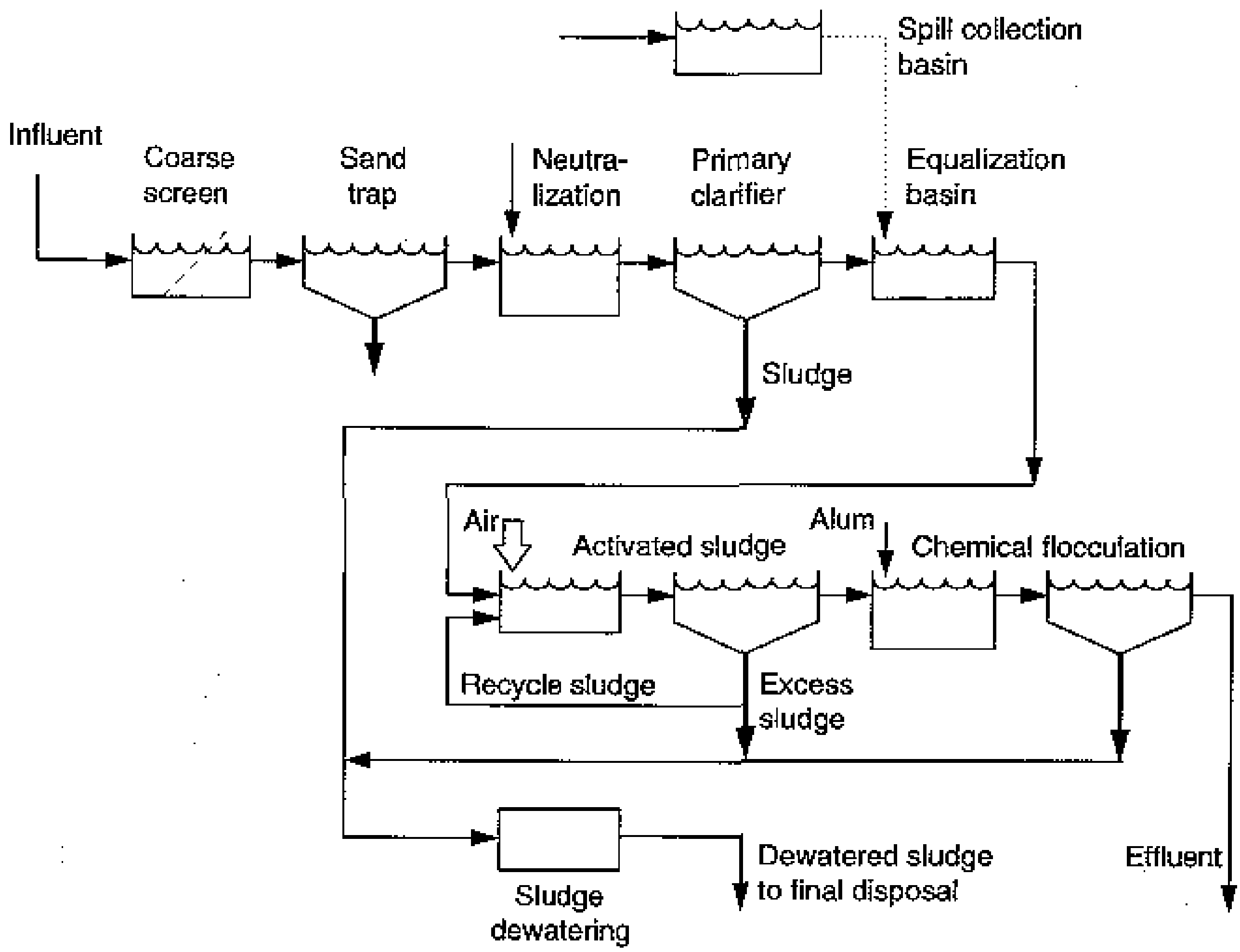
Coarse screening and sand removal is carried out in order to remove larger objects and sand, which may cause damage to the subsequent equipment.

Neutralization is carried out for adjusting extreme pH values to about 7. Highly acid or alkaline effluents may disturb biological treatment processes, cause corrosion to equipment or may be toxic to water living organisms.

Temperature control, generally cooling, may be necessary for high temperature effluents, which may disturb biological treatment processes. Such processes generally require a temperature below 40°C.

Equalization and spill collection may be required for effluents with large variations as regards flow and content of pollutants. Such variations may disturb the function of the subsequent treatment processes.

Figure 3.1
A complete treatment plant for pulp and paper mill effluents with primary, secondary and tertiary stages.



3.3
Primary or Mechanical Treatment

3.3.1
Mechanical Methods

Primary treatment means the first stage of a treatment sequence. Primary treatment is generally carried out by mechanical means, hence the term mechanical treatment. The following three methods are used:

- Sedimentation
- Flotation
- Filtration

of which sedimentation is by far the most common.

Primary treatment is always a first stage ahead of biological treatment plants. The reason is that suspended solids in larger amounts will disturb the biological process, for instance by taking up volume, which should be reserved for the biological sludge, by settling into sludge deposits or by causing clogging problems.

In many pulp and paper mills primary treatment is still the only effluent treatment. Effluents from about 15 % of the total world capacity of pulp and paper (excluding non-wood pulping) are still being discharged without any external treatment at all. For non-wood pulping, more than 90 % of the mills discharge the effluents untreated.

A mechanical treatment stage, particularly sedimentation, and to some extent also flotation, is also an important part of biological treatment as well as chemical flocculation plants.

Primary treatment for the removal of suspended solids is the basic effluent treatment to be applied at pulp mills. The purpose of the primary treatment as the only treatment is to reduce TSS discharges to the recipient, or as a pre-treatment ahead of biological treatment; to protect the biotreatment from high TSS loads which may disturb its function.

Primary treatment by sedimentation is a well established method and extensively used. Flotation and filtration may be interesting alternatives for special applications (e. g. in cases of area limitations).

At present, most pulp and paper mills in developed countries are equipped with primary treatment alone, primary and chemical treatment, or primary and biological treatment. Primary treatment must be regarded as a minimum requirement for all pulp and paper mills and biological treatment should be standard for most mills with higher BOD discharges (for instance above 2500-5000 t BOD/a from the processes) and sensitive recipients.

3.3.2 Sedimentation

Sedimentation relies on gravity forces, the suspended particles are allowed to fall or settle to the bottom in the treatment plant. This requires the particles to have a density higher than that of water, which is also the normal case. Also a certain minimum size of the particles is required, the finer particles will settle too slowly for practical use or not settle at all. This means that a complete removal of suspended solids is normally not possible in practice.

The sedimentation is carried out in sedimentation basins, also called clarifiers. These can be made with a circular or rectangular shape. The choice between these two is often determined by the local situation.

The particles, settling to the bottom, form a sludge, which has to be removed from the clarifier. This is achieved by pumping, in circular clarifiers in combination with bottom scraping. The sludge is normally low in dry solids (DS) content, approximately 1-2 %, and has to be dewatered before final disposal (cf. Section 3.8). In some mills the sludge from the primary clarifier is reused in the production process. This may only be practised when the fibre content in the sludge is high and when a reuse is feasible with respect to product requirements.

The result of the primary treatment depends on the effluent properties, but also on the degree of internal fibre recovery, which is carried out in the pulp or paper mill. For suspended solids (TSS) the removal rate may be within 50-90 %. For settleable solids the removal will normally be higher, approximately 90-95 %. TSS values after the primary sedimentation may be in the range of 30-200 g/m^3, while the specific discharge is typically approximately 4-5 kg/ADt in pulp mills and 1-5 kg/t of paper in paper mills.

Primary treatment will also in many cases give a BOD and COD removal, depending on the specific properties of the effluent. BOD removals may be within 0-30 % and COD removals within 0-50 %.

3.3.3 Flotation

This process is also referred to as dissolved air flotation (DAF) or microflotation. It is rarely used for primary treatment. More common applications are for internal fibre recovery in paper mills and for TSS removal after chemical flocculation.

Flotation also relies on gravity forces, but the particles are allowed to float to the surface, where the sludge is formed. This is achieved by adding small air bubbles of micro-size to the particles, thus giving them a density lower than the water density.

The main advantages of flotation, relative to sedimentation, are a smaller space demand and the possibility of achieving a higher DS content of the sludge (approximately 3-5 %). The disadvantages are a higher electric power demand and a larger sensitivity to flow and quality variations of the incoming effluent.

The most important application of flotation in pulp and paper mill effluent treatment is as the separation stage in chemical flocculation (cf. Section 3.7).

3.3.4 Filtration

Filtration is rarely used for primary treatment, although increasing use has appeared during the last few years. The applications are mainly to be found in paper mills. The type of filter used in paper mills is a rotating, gravity drum filter with a fine-mesh filter cloth as the filter medium.

The main advantage, compared to sedimentation, is a considerably smaller space requirement. This means that the most interesting application of filtration for primary treatment is when space is a limiting factor.

3.4 Secondary or Biological Treatment

3.4.1 General

The term "secondary" refers to the fact that this treatment is normally a second stage, after the primary treatment, which removes suspended solids. In the following the term "biological" treatment is used.

The main purpose of biological treatment is the removal of organic matter. The process basically works as the natural self-purification in the water courses, but under controlled conditions and within a limited volume. Living micro-organisms utilise organic material in the effluent as an energy source and as raw material for building up new cells. The organic matter is transferred into a solid material, the biological sludge. The net growth of sludge is removed from the system.

An important effect of the biological treatment is in many cases toxicity removal, due to the fact that certain toxic substances are organic and biodegradable, particularly resin compounds and fatty acids. However, the toxicity must not be too high since that may destroy the bacterial population in the treatment system.

The main type of microorganisms in a biological treatment plant is bacteria. Other types are present as well, like funghi, algae, protozoa and higher forms of organisms.

Two main types of biological treatment are used:

- *Aerobic treatment*, with microorganisms requiring oxygen.
- *Anaerobic treatment*, with microorganisms working in the absence of oxygen.

The aerobic treatment is the most commonly used; it has been applied in the pulp and paper industry for many years. The operating costs of aerobic treatment are rather high. For this reason the anaerobic treatment has been developed. The lower operating costs of this method are mainly due to lower electric power demand and the formation a combustible gas (methane) which can be used as a fuel.

Common to both the aerobic and anaerobic methods is that a number of conditions must be fulfilled, which are related to the optimal living conditions for the microorganisms. These are mainly the following:

- Suitable pH value, around 7, but 6-8 is mostly acceptable.
- Optimum temperature range, approximately 20-35 °C .
- Toxic compounds present in sufficiently low amounts.
- Settleable solids virtually not present.
- Nutrients, i. e. nitrogen and phosphorus compounds, available in sufficient amounts.

All biological processes are susceptible to various disturbances, which may reduce, or even eliminate, the treatment efficiency. Reasons for such disturbances may be that some of the above mentioned optimal conditions are not fulfilled, or that some other process conditions are disturbed. Bacterial growth may be inhibited by toxic materials above certain concentrations. In most cases, a microbial population can acclimate to the presence of a toxicant and learn to tolerate a higher concentration without inhibition.

The efficiency of a biological treatment is generally measured as the removal rates for BOD and COD. Typical values are for example 90 % BOD removal and 40 % COD removal. The COD removal percentage is always lower than the BOD removal, since the COD value is a measure of the total organic substances, including bio-degradable as well as non-degradable substances, while the BOD value is a measure only of the bio-degradable substances.

The COD/BOD ratio of untreated effluents varies within a range of approximately 2.0 - 4.5. The higher this ratio, the lower the percentage of COD removal at a given BOD removal.

3.4.2 Aerobic Methods

The aerobic methods utilize microorganisms which require oxygen for their metabolic processes. The main final products of the aerobic degradation of organic substance are carbon dioxide (CO_2), water (H_2O) and sludge (= excess of microorganisms).

Aerobic biological treatment involves rather high operating costs. These include mainly the following items:

- Electric power for aeration, pumping and mixing
- Chemicals for pH control, nutrient dosage and sludge conditioning (before dewatering)
- Sludge disposal (like landfilling or incineration).

Development efforts on biological treatment aim, to a large extent, at minimizing these operating costs.

There are few limitations in the applicability of aerobic biological treatment to various pulping effluents. Problems can arise with effluents with a high content of toxic substances or with very high concentrations of organic matter. These problems can be solved in most cases, for instance by detoxification through chemical flocculation and by a suitable plant design. In the case of very high organic content, pre-treatment with anaerobic biology may be advantageous.

Two methods are in a dominant position, as regards the treatment of pulp and paper mill effluents being aerated lagoons and the activated sludge methods. Other methods, used to a smaller extent, are the trickling filter and various forms of submerged biological filters.

Aerated Lagoon

Process Technology

The aerated lagoon has a large volume, giving detention times in the range of approximately 3-10 days. The microorganisms grow in suspension in the bulk of liquid, reaching a rather low concentration. This means a low reaction rate, which explains that a rather long detention time is required.

Oxygen is provided by means of some type of mechanical aeration equipment, acting either in the water surface (surface aerator) or at the bottom (bottom aerator). The latter type is always combined with a blower or compressor for provision of the air. The aeration also has the very important function of mixing.

An aerated lagoon is often succeeded by a sedimentation basin, sometimes only in the form of a quiescent zone within the lagoon. The purpose of this is to achieve settling of excess biological sludge. However, many mills have experienced that the sludge settling is not very efficient.

A nutrient dosage is often not required, but the nutrients naturally present in the effluent may be sufficient for the required treatment result.

The temperature is an important parameter. Due to the large surface area of a lagoon, the cooling of the effluent can be considerable, particularly during winter operation in cold climates. This will reduce the treatment efficiency during winter.

Advantages are the low susceptibility to various disturbances and consequently the rather high operational stability. Relatively low operating costs are achieved through the low chemical demand and the low sludge production. Disadvantages are the low or moderate treatment efficiencies, which may differ between summer and winter operation in cold climates, and the large area demand.

Treatment Efficiencies

Treatment efficiencies are variable, depending on effluent type, plant design and operating conditions. Typical values are a 40-90 % BOD removal (normally 65-75 %), 10-50 % COD removal (normally 20-30 %) and 20-50 % AOX removal (normally 20-30 %). The removal of acute toxicity to fish is generally very efficient in aerated lagoons.

Acute toxicity (i.e. causing the death of fish according to standard a test) is mainly caused by resin and fatty acids, which normally occur in pulp mill effluents. These compounds are easily biodegradable, which explains the toxicity removal. In lagoons with a good function, i. e. with BOD removals of 70-90 %, the toxicity removal may be up to 100 %, which means that no toxicity can be detected in the treated effluent, when using standard toxicity tests. Chronic toxicity, represented for instance by reproduction disturbances in fish, is also efficiently reduced.

The removal of TSS in aerated lagoons is generally not very efficient due to the formation of micro-organisms with poor settling properties. In fact increased TSS discharges have been observed for many lagoons.

The reduction of chlorate in aerated lagoons may be very efficient, provided that zones with low oxygen concentration exist. Reductions of 90 % or higher have been experienced.

The removal of nutrients, i. e. nitrogen and phosphorus compounds, is generally low in aerated lagoons. The nitrogen discharge sometimes increases by some 5-10 % or more, which has been explained by the presence of nitrogen fixing bacteria.

Applications

Aerated lagoons are mainly used when the required treatment results are only moderate. Another application is to use the lagoon as a second stage in a two-stage treatment plant, with some other type of biological treatment as the first stage.

Aerated lagoons are extensively used for pulp and paper mill effluents, particularly in North America and Sweden.

Activated Sludge

Process Technology

The activated sludge plant consists of two main units, the aeration basin and the clarifier (sedimentation basin). In the first stage, the aeration basin, the effluent is treated with a culture of microorganisms (the activated sludge), which is present in a high concentration. The retention time is much shorter, compared to the aerated lagoon, approximately 8-24 h.

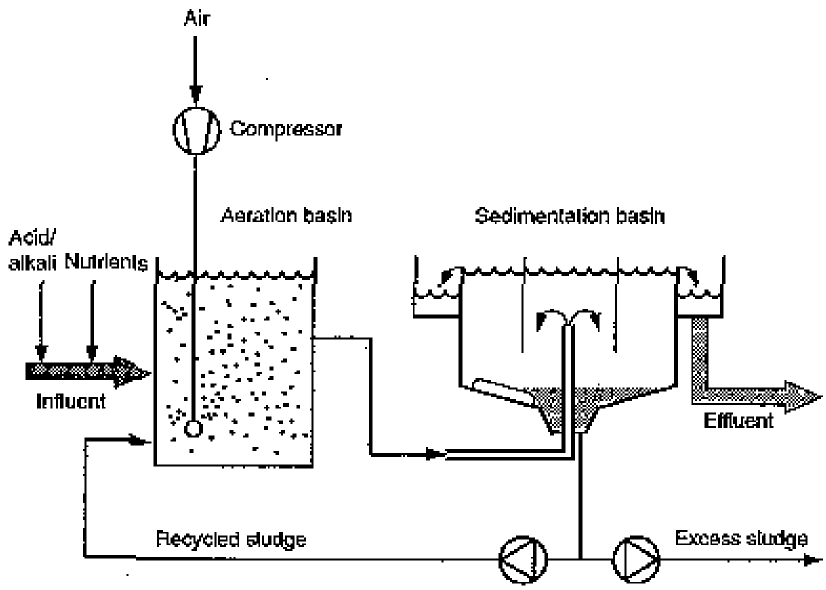
The sludge is separated from the water in the clarifier. The main part of the sludge is recirculated to the aeration basin, which is necessary for keeping the high sludge concentration. A small part of the sludge, corresponding to the net growth, is removed from the system as the excess sludge.

Oxygen and mixing is provided to the aeration basin by a mechanical aeration equipment. Various types of surface aerators and submerged turbine aerators, furnished with air from blowers or compressors, are used for activated sludge plants.

The principle of the activated sludge process is shown in Figure 3.2.

A large number of different process and plant designs exists for the activated sludge process. These variations include the aeration basin, the clarifier, the aeration equipment, as well as the sludge recirculation. One special process design is the pure oxygen activated sludge, where pure oxygen, or oxygen enriched air, is used instead of air. This has been applied for bleached kraft and sulphite mill effluents. There are certain design and other advantages in this process, but the economy should be analyzed and compared with the conventional process in each case, when the oxygen process is considered.

Figure 3.2
Activated sludge plant.



Nutrient dosage has normally been required and practised at activated sludge plants. However, during the last years it has been demonstrated in Finland and elsewhere, that the nutrient dosage in activated sludge treatment of pulp mill effluents can be considerably reduced. This will reduce costs and as well as nutrient discharges.

The risk of temperature decrease during winter operation in cold climates is much less, compared with the aerated lagoon, due to the smaller volume and smaller surface area. On the other hand, there may be a risk of reaching too high effluent temperatures, above 40°C, particularly in modern mills with low water consumptions, and in countries with warm climates. In such cases cooling of the effluent ahead of the activated sludge plant is required.

Advantages of the activated sludge process are the potential of high - very high treatment efficiencies, the possibilities to control the process (particularly the oxygen consumption), and the relatively low surface area demand. Disadvantages are the relatively high susceptibility to disturbances and consequently high risk of operational instability, and the high operative costs.

Poor sludge settling properties of the sludge is a common problem. A recent measure for improving sludge settleability is the installation of a so-called selector, i. e. a small tank with low oxygenation (anoxic conditions), preceding the aeration basin.

Treatment Efficiencies

Treatment efficiencies are variable, depending on effluent type, plant design and operating conditions. Typical values are within the ranges 80-95 % of BOD removal (normally 90 %) and 30-80 % of COD removal (normally 40-50 %), depending on the type of effluent. Effluents from bleaching with chlorine chemicals can typically achieve 30-50 % AOX removal.

High removals of acute toxicity to fish can be reached also in activated sludge plants. The same comments can be given here as for aerated lagoons above. Also in the activated sludge process a good function of the plant is required for efficient toxicity removals, which means BOD removals of 90 % or higher.

The removal of TSS in activated sludge plants is generally higher, and the resulting TSS discharges are lower, compared to aerated lagoons. Inlet TSS (outlet from the primary treatment) can be reduced typically by 50 %, giving discharges in the range of 3-7 kg/ADt of pulp for pulp mill effluents, and 1-3 kg/ton of paper for paper mill effluents.

Experiences of chlorate reduction in activated sludge plants are rare. A selector basin, if installed, will reduce chlorate efficiently.

Assuming optimal dosages of nitrogen and phosphorus, net removals of 0-20 % for nitrogen and 0-50 % for phosphorus can be reached.

Applications

The activated sludge process is preferably used, when high or very high treatment efficiencies are required. In the latter case, however, a two-stage process is an optional choice.

Activated sludge plants are extensively used in the pulp and paper industry. In Section 7.1 the approximate percentages of mills with biological treatment, for different mill categories and regions, are given. A rough estimate is that the activated sludge process is used in 60-75 % of all biological plants. This is also the most common process used in new plants being built today.

Development of the Activated Sludge Process

The following items summarize the present trends in the development of the activated sludge process:

- Decreasing loads, which aims at higher treatment efficiencies, lower nutrient demands, lower sludge production and lower operational costs.

- Biological phosphorus removal.

- Using inert carrier elements to improve sludge retention in the system.

- Minimizing power consumption, by increasing aeration basin depth, improving aerator efficiencies and controlling aeration.

One particular development is the so-called HCR process (High Capacity Reactor). The advantage of this process is said to be a potential for very high load values on the aeration basin, and consequently very small volumes of this basin. This shall be caused by one special feature, a jet device which gives very efficient contact and materia transport within the system water/air/sludge. Further, the sludge production is claimed to be low. A result of these advantages is said to be a reduction of installation and operational costs.

Two full-scale plants have recently been installed for semi-chemical and newsprint effluents in Norway. A few other installations are being planned.

Trickling Filters

Process Technology

The trickling filter is a type of fixed-film reactor, with the microorganism culture growing as a film on a carrier (or packing) material, arranged in a fixed bed. The carrier has a very large internal surface area, around 100 m^2/m^3 or higher. The effluent is pumped to the top of the bed and distributed over its cross-sectional area. The bed height is typically 4-6 m. The effluent flows downwards through the bed, while getting in contact with the microorganisms. The effluent is collected in a basin under the bed, part of it is recirculated to the incoming effluent, and the rest (the net flow) is discharged.

The necessary oxygen supply is generally accomplished by natural draught of air upwards through the bed.

Excess biological sludge is sloughed off from the bed surface and is discharged with the outgoing effluent. This sludge is collected in a sedimentation basin, placed after the trickling filter, or in a second-stage biological treatment.

Efficient primary treatment is essential, since even moderate amounts of fibres in the effluent will cause clogging of the filter bed.

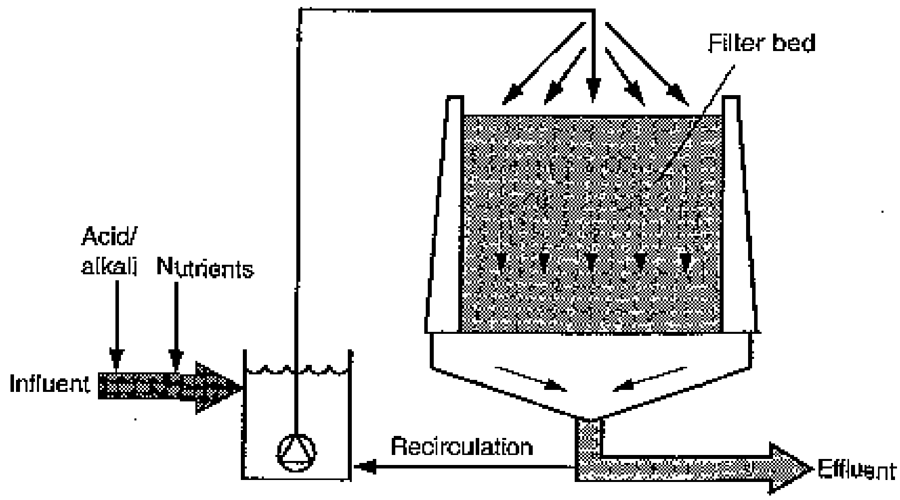
Nutrient dosage is generally required, with amounts similar to the activated sludge process, or lower.

The temperature may be a problem during cold winter operation, as the trickling filter to some extent works as a cooling tower.

Advantages of the trickling filter are the low susceptibility to various disturbances (except clogging!) and the rather high operational stability, the relatively low area demand and the relatively low operation costs. Disadvantages are the low treatment efficiencies, the risk of clogging and the risk of odour problems.

The principle of the trickling filter is shown in Figure 3.3.

Figure 3.3
Trickling filter.



Treatment efficiencies

The trickling filter gives lower efficiencies than the activated sludge process. Typical values are 30-60 % of BOD removal and 20-30 % of COD removal.

The toxicity removal is low.

TSS, nitrogen, and phosphorus will normally not be removed to any significant extent.

Applications

Trickling filters have their best application area as a pre-treatment stage in various types of multistage treatment. The advantage of using the trickling filter in this position would be that a substantial part of the treatment, for example 50 % BOD removal, can be reached in a plant with rather small operational problems and at relatively low costs.

At present trickling filters are not extensively used in the pulp and paper industry. Most applications are in paper mills.

The mentioned clogging problem has caused a declining interest in trickling filters, particularly for effluents high in suspended solids and/or organic matter.

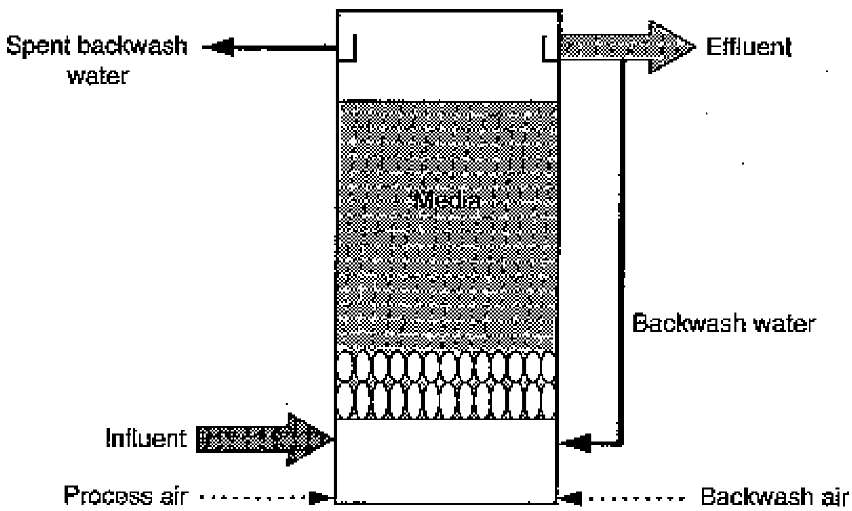
Submerged Biological Filters

The submerged biological filter is a type of fixed-film reactor, submerged in the effluent and aerated. This method is presently gaining a growing interest for pulp and paper mill effluent treatment. The filter media can be either more or less fixed beds or moving/fluidized beds of discrete carrier elements. Advantages of such systems are improved sludge retention and increased sludge concentration, compared to activated sludge, as well as reduced risk of clogging, compared to the trickling filter. The result should be improved operational stability and improved overall treatment efficiency, compared to the mentioned conventional systems.

The use of carrier elements in the activated sludge process is a special case within this area.

One application, in full-scale operation today, for instance at pulp mills in Japan, is the ActiContact method. This is a fixed bed of porous ceramic balls, working in up-flow mode. The bed can be expanded and mixed, for sludge release, by increasing the water and air flows. The principle is shown in Figure 3.4.

Figure 3.4
Submerged biological filter according to the ActiContact method.



Another type is the suspended carried biofilm process, where the biomass carrier are suspended and completely mixed with in an aerated basin. Recent applications in Sweden are for instance sulphite pulp mill and paper mill effluents.

Multistage Systems

There are two main reasons for using multistage biological treatment plants:

- to reach very high treatment efficiencies, for instance BOD removals of 95 % and above.

- to improve the operational stability.

Experience has shown that the highest treatment efficiencies may be hard to reach in one-stage plants. The use of at least two-stage systems will considerably improve the potential for this. Also the installation and operational costs may be reduced.

Examples of multistage plants, which have been applied for pulp and paper mill effluents, are the following:

- Trickling filter plus aerated lagoon:
  Newsprint mill, integrated with TMP

- Trickling filter plus activated sludge:
  Newsprint mill, integrated with TMP and sulphite pulp

- Two-stage Activated sludge (two complete activated sludge plants in series):
  · Sulphite mill
  · Paper board mill, integrated with CTMP
  · Newsprint mill integrated with recycled fibre pulping

Summary and Comments

Aerobic biological treatment has been applied for pulp and paper mill effluents for a long time. The method is well established, and good experiences exist for different applications. Most types of effluent can be treated.

The two main types of aerobic treatment is the aerated lagoon and the activated sludge plant. Today there is a trend towards the activated sludge process, due to its potential for higher treatment efficiencies and low susceptibility to cold climate (in northern areas).

Other aerobic methods, like the trickling filter, are less used today, but may have some niches. New developments, like the submerged biological filters and the HCR method, may find increased applications in the future.

The aerobic treatment gives high removals of biodegradable organic matter, measured as the BOD value, even over 95 % is possible. Also toxicity can be substantially reduced, giving virtually non-toxic effluents. However, total organic matter is removed to a lower degree, maximum 50 % for some types of effluents (for example bleached kraft pulping effluents), up to 80 % for other types. If higher COD removal rates are required in the effluent treatment, the biological treatment has to be combined with some type of physical-chemical treatment.

Aerobic biological treatment is characterized by high installation and operative costs. Possibilities to reduce these costs are mainly the following:

- Further development of the processes, aiming at cost optimization. However, one should not expect any substantial cost reductions this way, at least not on a short-term basis.

- Reducing of the discharges from the pulping processes.

- Use of anaerobic treatment for removing a substantial part of the organic matter (for reducing operating costs).

3.4.3 Anaerobic Methods

General

The anaerobic methods utilize microorganisms which work in the absence of oxygen. The main final products of the anaerobic degradation of organic matter are methane (CH_4), carbon dioxide (CO_2) and sludge. The methane and carbon dioxide form the biogas, with a methane content of approximately 60-70 %. This gas can be used as a fuel in power plants. The sludge production is considerably lower than in the aerobic biological treatment.

The advantages of anaerobic treatment, when compared with aerobic, are the following:

- lower electric power demand
- lower nutrient demand
- lower sludge production
- the biogas can be used as a fuel, and thus replace other fuels

These advantages mean lower operating costs for the anaerobic treatment, which then is the main advantage and the main driving force for its presently growing application in the industry. However, capital costs are of the same order of magnitude for the two methods.

Anaerobic treatment is not generally applicable to pulp and paper mill effluents. The main pre-requisite is a certain lowest concentration of organic matter, corresponding to approximately 1000 g of COD/m^3. However, most applications are for effluents with higher COD values.

Other disadvantages are a higher sensitivity to toxic compounds, which may obstruct anaerobic applications, for instance for debarking effluents and bleach plant effluents.

A special problem is the sulphur compounds (sulphate, sulphite, etc.), which are present in different types of pulping effluents. These compounds are easily reduced to sulphide, which is strongly toxic to the anaerobic micro-organisms. The effect may be a declining treatment efficiency and a reduced or inhibited methane production. There are various methods to reduce this problem, primarily minimising the sulphur content in the effluent as far as possible.

Anaerobic Lagoons, Low-Rate Systems

The treatment plant is a lagoon with a relatively large volume, giving detention times in the range of 5 - 20 days. The long detention times are required by the low concentrations of microorganisms and consequently low reaction rates. The content of the lagoon is mixed only by the gas, developed in the process, but the mixing can be improved by the installation of baffles. Covering of the lagoon surface by means of porous plastic sheets has been practised, for heat isolation and for minimizing odour emission.

Advantages of the anaerobic lagoon are mainly the simplicity of operation and the low installation and operative costs. In some cases it may be possible to convert an existing aerated lagoon, to a certain part, into an anaerobic lagoon, without reducing the treatment efficiency, and thus lower the operative cost. Disadvantages are the large area requirement, the fact that the process is difficult to control, and that the biogas cannot easily be collected.

The anaerobic lagoon has until now only been used to a limited extent. In India some plants are installed for kraft mill effluents. In the USA at least two plants are running for effluents from waste paper based paper mills. In these cases the anaerobic effluent is further treated by aerated lagoons.

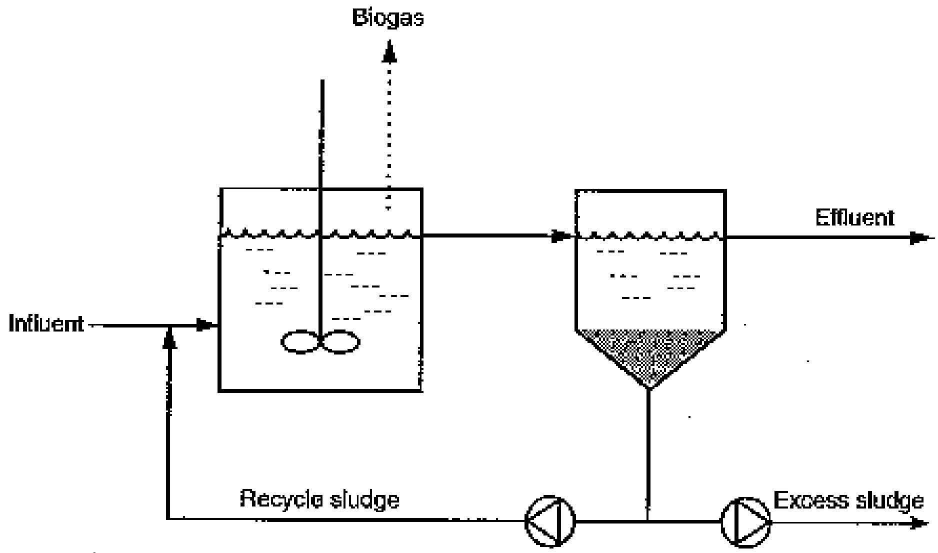
High-Rate Systems

Process technology

In the high-rate system the anaerobic sludge is efficiently retained, in order to keep a high concentration, and thus to increase the reaction rate. Consequently the plant volume can be considerably reduced, compared to the anaerobic lagoon. The two reactor types, most commonly used in the pulp and paper industry, are the contact reactor and the UASB reactor.

The contact reactor is designed basically like an activated sludge plant. A closed tank contains the mixture of effluent and anaerobic sludge, mixing being effected by the gas formation and by one or more mixers. The sludge is separated from the effluent in a subsequent settling stage. A main part of the sludge is recirculated back to the contact tank, in order to keep the high sludge concentration. The principle is shown in Figure 3.6.

Figure 3.6
Anaerobic contact reactor.



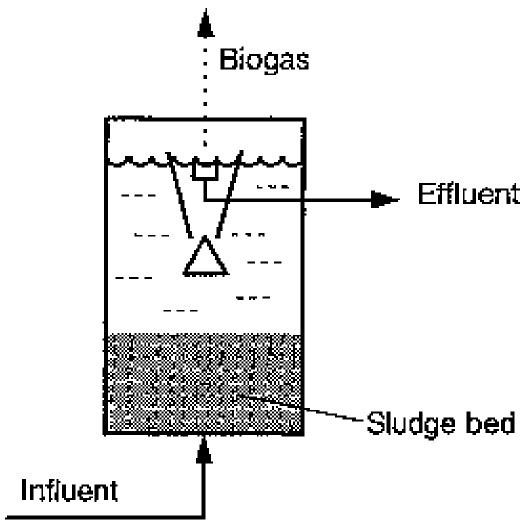
In the UASB reactor (Upflow Anaerobic Sludge Bed) the effluent is distributed over the reactor bottom and is then flowing upwards through a fluidized bed of anaerobic sludge. In the upper part of the reactor the treated effluent, the sludge and the biogas are separated by special arrangements. The successful use of the UASB process requires the development of a special type of "granular" sludge with excellent settling properties.

The principles of the UASB process are shown in Figure 3.7.

Other types of anaerobic reactors are only rarely used in the pulp and paper industry.

Also the high-rate anaerobic plants are normally followed by aerobic post-treatment, for improving the treatment result and for oxidizing (destroying) odorous compounds produced during the anaerobic process.

Figure 3.7
UASB (Upflow Anaerobic Sludge Bed) reactor.



Treatment Efficiencies

Treatment efficiencies for high-rate anaerobic processes are in the ranges of 70-99 % BOD removal and 50-85 % COD removal. The highest removals are generally obtained with sulphite pulp mill condensates.

Applications

More than 10 contact reactors are in operation in the pulp and paper industry, all of them for various types of pulping effluents. The largest number of applications are for sulphite mill condensates. Other applications are for sulphite mill alkaline bleach and condensate effluents, semi-chemical mill effluents, newsprint mill effluents and CTMP effluents.

More than 30 UASB plants are in operation in the pulp and paper industry, effluents from waste paper based paper mills being the most common application. At least 6 plants are for various pulp mill effluents: semichemical, TMP, CTMP and sulphite mill condensate effluents.

The applications are mainly in North America, Europe, Japan and Australia.

Summary and Comments

Anaerobic treatment has been applied for pulp and paper mill effluents only for about 15 years. With today's technology and development stage only certain types of effluent can be treated. One important pre-requisite for the successful application is a relatively high concentration of organic material.

The contact method and the UASB method can be regarded as well established method for certain types of effluent, e.g. mechanical pulping effluents, sulphite condensates, semi-chemical effluents and waste paper based paper mill effluents.

Anaerobic treatment is generally a pretreatment stage ahead of aerobic treatment, although the main treatment efficiency in most cases is achieved in the anaerobic stage. The aerobic stage will give a complementary treatment efficiency and will remove odorous compounds.

The main reason to use anaerobic biological treatment, instead of aerobic, is the possibility of lower operative costs. The main reason of this is the lower electrical power demand, but also the lower nutrient demand and lower sludge production. The utilization of the methane containing biogas as a fuel can further improve the operation economy.

3.5 Tertiary Treatment, Physical-Chemical Methods

3.5.1 General

Tertiary treatment refers to any treatment which is carried out as a post-treatment stage after biological treatment. The most commonly used method here is chemical flocculation. This is also classified as a physical-chemical treatment method, being the most common method within this group. However, chemical flocculation can also be used as a single treatment or as a pre-treatment ahead of biological treatment.

Other tertiary methods are sand filtration and micro-screening, however with a low level of application at present.

A large number of other physical-chemical methods have been tested and also applied for different pulp and paper mill effluents. Such methods are for instance various oxidation and adsorption methods which are not in use today. Other methods which presently are finding their applications are membrane filtration and evaporation.

3.5.2 Chemical Flocculation

Process Technology

Flocculation chemicals are of three types:

- Metallic salts
- Organic polyelectrolytes
- Mineral powder.

Their functions are briefly described below.

Generally the chemical is added to the effluent in a separate mixing tank. The next stage is a flocculation tank, where fine suspended solids, together with the chemical, are built up to bigger particles or aggregates, called "flocs". The final stage is a separation, where the flocs are removed from the effluent; this is accomplished in a sedimentation basin or a flotation plant.

Metallic salts are generally the most efficient type, as they can remove fine particles as well as dissolved substance. The most commonly used is aluminum sulphate or alum, but also ferric salts or lime (calcium hydroxide) can be used.

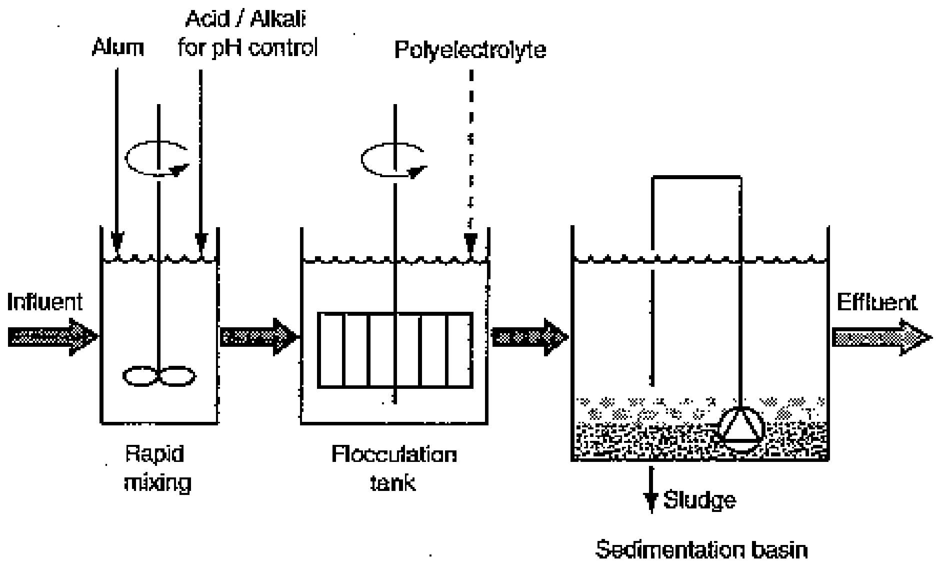
Flocculation with alum and ferric salts generally requires a pH control, as the optimal precipitation of the metallic hydroxides takes within certain pH intervals.

The principles of an alum flocculation plant is shown in Figure 3.8.

Organic polyelectrolytes have the function of enhancing the flocculation of smaller particles. They may be used together with alum for increasing the floc sizes, and thus enhancing the settling or flotation efficiency.

The mineral powder used for flocculation is of bentonite type. It is always used together with a polyelectrolyte. The function is mainly a flocculation of very fine suspended solids; the efficiency being better than with polyelectrolytes alone.

Figure 3.8
Alum flocculation plant.



All these chemicals form sludges, collected in the sedimentation basin or flotation plant. The largest sludge amounts are obtained with alum flocculation. Polyelectrolyte flocculation generally forms only a small amount of sludge, in addition to what is obtained without the polyelectrolyte.

Applications and Treatment Efficiencies:
a. Alum Flocculation

One interesting feature with alum (and other metallic salts) is that a significant COD removal can be reached, and this portion of COD is mainly the non-biodegradable COD, which is not removed in biological treatment. Therefore, if a very high COD removal is required, a combination of biological treatment and alum flocculation may be an efficient solution.

The following applications of alum flocculation are practised:

- "Direct flocculation", in combination with primary treatment, being the only treatment (no biology).
  The purpose is to improve the result, in excess of primary treatment alone.

- "Pre-flocculation", ahead of biological treatment.
  Most often this is made in combination with the primary treatment. The purpose may be to decrease the load of an over-loaded bio-treatment, or to remove toxic matter which may disturb the biology.

- "Post-flocculation", after biological treatment.
  The purpose may be to remove phosphorus compounds, to remove colour or to improve the treatment efficiency for BOD, COD or TSS.

Removal efficiencies very much depend on the effluent type and the specific conditions, for example the chemical doses. The following "typical" data shall be regarded as guidelines, which do not cover all applications and operating conditions. Direct and pre-flocculation may give 20-30 % BOD removals and 30-50 % COD removal in excess of what can be reached with primary treatment. AOX removals similar to the COD removals can be reached with effluents from bleaching with chlorine chemicals. Colour removals of the order of 70-90 % can be reached, for instance with bleach plant effluents.

Toxicity can be extensively reduced, as a result of the removal (precipitation) of resin compounds and fatty acids. Direct flocculation may in some cases give toxicity removals similar to what can be achieved with biological treatment. Pre-flocculation can be used as an important pretreatment stage, in cases with highly toxic effluents, which otherwise may be difficult to treat biologically. Post-flocculation may give complementary toxicity removals in cases where the biology is not fully efficient in this respect. Thus, biological plus chemical treatment (or a most efficient biological treatment alone) can be used when a more or less complete detoxification is aimed at. In such a case no significant toxicity effect in the receiving water is likely to be found.

Post-flocculation may give removals similar to the above data. COD and AOX removals are often higher, in some cases towards 75-80 %. Phosphorus removals of 80-90 % can be reached, either phosphorus was dosed to the bio-treatment or not. Nitrogen removal at chemical flocculation has been studied only to a very small extent; removals of 50 % have been indicated.

Chemical flocculation (generally with alum) of pulp and paper mill effluents is presently applied in large extent in Japan, where most pulp mills (all of them are integrated) use biological treatment followed by alum flocculation. This refers also to bleached kraft mills. The reason is generally that the COD limits, set by the authorities, can not be fulfilled with biological treatment alone.

In Sweden alum flocculation is used as post-flocculation at some mechanical pulp and CTMP mills, as well as at integrated paper and paper board mills based on such pulps. The purpose is here mainly to remove phosphorus, but also COD. Many paper mills use chemical flocculation to improve the efficiency in the primary clarification.

In most other countries chemical flocculation is today used to a limited extent.

One main argument against the use of chemical flocculation with alum and similar chemicals for bleached pulping effluents is the large amounts of organic matter in these effluents. This means large chemical consumptions, large sludge amounts and high operative costs. The present trends in changing the bleaching technology will result in less contaminated effluents, and consequently less chemical consumptions and operating costs for chemical flocculation of these effluents.

The main purposes of using alum flocculation today and in the future would most likely be to improve the total COD removal, when bio-treatment does not give a sufficient result, to remove toxicity and to remove TSS and phosphorus, when very low discharges are required. Also the potential for colour removal may receive attention in the future.

Applications and Treatment Efficiencies:
b. Bentonite Flocculation

Applications in effluent treatment are limited so far.

Applications in Sweden are for pre-flocculation of TMP and CTMP effluents ahead of biotreatment, and for post-flocculation at a TMP-based paper mill. The latter application has given significant removals of TSS, BOD, COD, phosphorus and nitrogen.

Applications for bentonite flocculation would be the same as for alum flocculation, provided that lower removal efficiencies can be accepted. The advantages would be lower chemical dose, sludge production and operative costs.

Applications and Treatment Efficiencies
c. Poly-Electrolyte Flocculation

Organic polyelectrolyte flocculation has two main application areas:

- To improve the removal of suspended solids in primary treatment. This is achieved by a certain flocculation effect on fibres and other suspended solids.

- To improve the flocculation during chemical flocculation with alum or bentonite.

Both these applications are important, but the polyelectrolyte shall be regarded as a "flocculation aid". Consequently this method should not be regarded as an independent treatment method. Therefore it is not relevant to give any data on treatment efficiencies.

The above comments refer to the conventional types of polyelectrolytes. A further development in this area are various combinations or "systems" of two or more organic chemicals, which are available on the market. These have not yet come into general use for pulp and paper mill effluents. However, for special applications such systems may find use in the future.

3.5.3 Tertiary Filtration

Filtration can be used as a final "polishing" stage, particularly after chemical flocculation plants, to remove fine suspended solids which are not removed in the sedimentation or flotation stage. In addition further removal of COD, BOD and phosphorus would be obtained, provided these are combined with suspended solids.

Applications would be either in cases when very low TSS limits are set, when an additional safety is required for the treatment plant, or when reuse of treated effluent is required.

Applications in the pulp and paper industry are not extensive so far.

3.5.4 Membrane Filtration

Process Technology

The principle of this method is the filtration through a semi-permeable membrane under a high pressure. By choosing the correct membrane, particulate material or dissolved molecules of a certain size or molecular weight can be retained or allowed to pass the membrane. The different processes microfiltration, ultrafiltration, nanofiltration and reverse osmosis retain particles/molecules of decreasing sizes.

The retained material is contained in a small volume, the retentate, while the volume of clean water, passing through the membrane, is called the permeate. The retentate needs further processing or disposal, incineration being the reasonable option in cases where organic matter has been retained.

Applications and Treatment Efficiencies

This separation technology is widely used in other industrial branches, for instance in mechanical industry, food industry and for desalting of sea water.

In the pulp and paper industry, R&D work on membrane filtration of effluents has been performed for more than 30 years, in North America, Europe and Japan, however with rather few practical applications as the result so far.

Present applications are mainly the following, all with ultrafiltration:

- Alkaline bleach effluents in kraft mills (at least two mills in Japan).
- Alkaline bleach effluents in sulphite mills (at least one mill in Sweden).
- Fibre building board effluent (one mill in Sweden).
- Coating effluent at a paper board mill (several mills in Europe).

Planned or promising applications, tested in pilot scale:

- Treatment of CTMP effluent.
- Internal treatment of papermill white water, for extensive reuse.

Membrane filtration is not, and will never be, a general effluent treatment method. The application field will rather be special treatment of small, separated flows, where other methods are not useful or not economical. The permeate water produced is often very clean, which means that reuse always should be considered. The treatment method for the retentate must be considered from case to case.

One interesting feature of membrane filtration is the continuous development of new membranes. This means that new potential applications can be expected in the future.

3.5.5 Evaporation

Evaporation, as a method for internal treatment of small separated effluent streams, will most likely find increasing uses in the future. Two basic types of evaporation process, both based on the falling film technology, may come in question:

- mechanical vapour recompression (MVR) evaporation.

- multiple effect evaporation.

Present applications are still very few, basically the following:

- effluent evaporation in two closed cycle CTMP mills in Canada (MVR type) and one in Brazil (multiple effect type).

- effluent evaporation in one TMP and one CTMP mill in Finland and Sweden (multiple effect type).

- white water evaporation in a paper mill in Saudi-Arabia (MVR type).

A closed-cycle concept for kraft pulp bleaching, being developed by Jaakko Pöyry, includes an evaporation stage for bleach effluent as an essential part of the process.

In all these applications an extensive reuse of the clean condensate is possible or required. The main part of the organic content of the effluent is obtained in the evaporation concentrate, which needs further processing. Incineration is here the method to be aimed at primarily.

3.5.6 Summary and Comments

Tertiary treatment with chemical flocculation ("post-flocculation"), using alum or bentonite/polyelectrolyte has a number of potential applications. This is a well-developed process, giving significant treatment improvement in excess of the results from biological treatment. The main drawbacks are the difficulties in handling and disposing the sludge, and the high operative costs, particularly when treating effluents from bleached chemical pulping.

Using chemical flocculation as the only treatment ("direct flocculation") will, in certain cases, give COD removals similar to what can be achieved by biological treatment (appr. 50 %), and in addition some toxicity removal. It shall be remembered that this COD removal refers primarily to non-biodegradable organic matter, while the bio-treatment removes mainly bio-degradable matter.

Of other types of physical-chemical treatment methods particularly membrane filtration and evaporation are of interest for the future. These will preferentially be used to treat small effluent streams for specific purposes, where other methods are not feasible or not sufficient. The potential of these methods to produce very clean water, suitable for reuse, should be recognized.

3.6 Irrigation

Irrigation and other methods for land application of effluents are not very widely applied in the pulp and paper industry. Such methods can be of beneficial use in regions with a fairly warm and dry climate, and where sufficient areas are available. Certain soil properties need to be fulfilled, for instance regarding soil type, drainage properties, soil depth and ground water level. The purpose can be either treatment/disposal of the effluent or only disposal, after conventional treatment.

One example of the latter type is a newsprint mill in Australia based on TMP and recycled fibre pulp. The mill's effluent treatment includes primary clarification, activated sludge, a holding pond and sand filtration. As an alternative to discharging the treated effluent to the nearby river, the mill investigated the utilisation of effluent for irrigation of a forest area. This is planned to be in operation by 1996.

3.7 Sludge Handling

3.7.1 General

The larger amounts of sludge, in today's effluent treatment plants, are generated in the primary treatment and in biological treatment with the activated sludge method. Aerated lagoons typically generate rather small amounts. Chemical flocculation, when applied, will also generated sludge, in some cases considerable amounts.

The sludge handling includes the following main stages:

- Reuse of fibre sludge from primary treatment. This is practised in many cases.

- Dewatering of fibre/biological/chemical sludge

- Final disposal of dewatered sludge.

Reuse of fibre sludge is practised in cases where this is suitable with regard to product requirements etc. Internal fibre recovery, however, often leads to low fibre discharges and poor sludge properties, in which cases reuse of the sludge is not feasible.

Biological and chemical sludges have very poor dewatering properties, and normally they have to be mixed with fibre sludge for acceptable dewatering conditions. So in the presence of biological/chemical sludges, at least a part of the fibre sludge should be dewatered, rather than reused. Also, a far-reaching internal fibre recovery will mean increased difficulties in dewatering biological/chemical sludges.

3.7.2 Dewatering

The dewatering aims at removing water from the sludge as far as possible, in order to facilitate the final disposal. Different types of mechanical equipment are available for this operation.

Biological and chemical sludges normally should be thickened prior to the dewatering. This means an increased dry solids (DS) content from about 1-2 % to 3-4 % or higher. The thickening is usually performed in a gravity thickener, which is basically a settling basin with low load.

Dewatering equipment includes the following types:

- Decanter centrifuges
- Belt presses (Twin wire presses)
- Screw presses

Most new installations during the last 10-15 years have been belt presses, which have a reliable function and produce fairly high DS values, 40-50 % with fibre sludges and 25-35 % with mixed fibre/biological/(chemical) sludges.

Decanter centrifuges are at present mostly used for sludges with very poor dewatering properties, like pure chemical sludges, if they need separate dewatering. They produce lower DS contents than the belt presses.

Screw presses can be used in two ways:

- to increase the DS content after belt press dewatering; approximately 10 % DS increase can be obtained.

- direct dewatering; a rather recent type of screw press is used; higher DS content can be obtained compared to belt-press dewatering.

An increasing application of screw presses has been observed for some years, due to an increasing interest in sludge incineration.

Prior to dewatering, the sludge normally must be conditioned with a polyelectrolyte, which adds to the operative costs. This refers particularly to sludge mixtures with biological and/or chemical sludge.

In summary, dewatering methods for all sludges of current interest are available, capable of dewatering to such DS contents which are suitable for final disposal.

3.7.3 Final Disposal

Landfill

Landfill means the disposal of sludge on a land area without any special further treatment. This is still the most commonly used method. The main problem is the large area requirement. Another problem is the leakage of water, containing organic matter, from the disposal area. Normally the leachate has to be collected and treated, either separately or in the mill's effluent treatment.

One potential problem, which has been recognized, is the leakage of chlorinated organic matter, in the case of sludge from bleached chemical pulp mills. Studies have indicated that such leakage, however, is of little significance. This may be due to the fact that the chlorinated organic compounds normally are of hydrofobic nature, thus with low solubility in water.

The present trend is to reduce landfilling, due to decreasing available areas.

Incineration

The area required for landfilling will be significantly reduced by incineration of the sludge. Landfilling of the ash is still required, but the area may be reduced some 80-90 %.

Sludge incineration is extensively used today in the pulp and paper industry. The organic content of the sludge would in many cases may represent a significant heat value. The following options are available:

- Incineration together with bark in bark boilers.

- Incineration with oil or gas in boilers of the type used for pulverized coal firing.

- Separate sludge incineration.

For separate incineration, particularly of rather low DS sludges, the fluidized bed boiler is presently predominant for new installations. This can be run with 100 % sludge, although the use of a support fuel is more common (like coal or oil). The requirement of the support fuel depends on the DS and the ash content of the sludge. Generally, at least 35-40 % DS is required for spontaneous combustion.

Separate sludge incineration with a moving-grate stoker equipment has also been successfully tried.

The question of emission of chlorinated dioxins, when incinerating sludge from bleached chemical pulp mills, has been raised. Studies in Finland have indicated that any dioxins, present in the sludge, will be destroyed in a bark boiler under proper incineration conditions (Vältilä et al., "Combustion of kraft mill biosludge", *Proceedings of the Tappi International Environment Conference*, Portland, Oregon, 1994). Their main conclusion was that when sludge incineration is carried out in a proper manner (good retention time, uniform and complete combustion, good dust removal) the flue gases are free from dioxins.

Land Application

Land application means the spreading of sludge on a land area, in order to take advantage of some useful property of the sludge. Application of sludge on low-quality soils may improve the plant growing properties of the soil. Application on farmland may have a fertilizing effect. In the latter case the potential problem of chlorinated organics and other hazardous components in the sludge such as heavy metals, should be recognized.

Land Application of Ash

Disposal of ash from biofuel incineration on forest land, with the important purpose of giving a fertilizing effect, is presently being studied on a research basis in Sweden. Such disposal, if proven successful, will most likely be applicable also for ash from sludge incineration.

Composting, etc.

Composting of pulp and paper mill sludges for the production of soil products is limited. There should be potential for more extensive use of composting, provided there is a market for the products within reasonable transport distances. The sludge is usually composted together with other materials, such as bark, municipal sludge, sawdust, sand, etc.

Another special use has been the preparation of top-soil material, from sludge and sand, for final covering of closed landfill areas.

Cement Manufacturing

Boiler ash can be used in cement and concrete manufacturing. A more attractive option should be the direct introduction of the sludge into the cement manufacturing process. The basic unit in this process is the cement rotary furnace, which is normally oil-fired. By introducing sludge into this furnace, the organic fraction of the sludge is burnt and simultaneously its heat value is utilised. The inorganic fraction, the ash, will be incorporated as a part of the cement.

Both these options are put into operation by paper mills in Austria, Denmark and the USA, through cooperation with near-by cement manufacturers.

Other Ways of Utilisation

Some further methods for the utilisation of pulp and paper mill sludges which have been used to a limited extent, but which may find application in special cases, are:

Brick manufacture: By adding sludge into the brick raw material two advantages will be obtained. First, the inorganic material of the sludge will add to the brick material. Second, the organic material, when being burnt, will add to the porosity of the brick.

Light weight aggregates (LWA): LWA refers to a group of materials which are used in various construction materials such as concrete blocks and decorative stone. Their function is to reduce the final density while maintaining acceptable strength properties. Sludge has been used for this purpose.

Pelletisation of sludge for other purposes has also been practised. These include the production of fuel pellets from sludge and non-recyclable paper, and the production of pellets from sludge for the special purpose of a carrier for pesticides in agriculture and gardening.

3.7.4 Summary and Comments

Sludge handling methods for dewatering as well as final disposal, are available for all those types of sludges, which are produced by the present effluent treatment methods. However, the future sludge handling may offer some increasing problems which must be considered. Here should be mentioned:

- The amounts of biological and, possibly, chemical sludges, will increase, absolute and in relation to the fibre sludge amounts, as a result of increasing application of the treatment methods. This will make the sludge dewatering more difficult, which will call for more efficient dewatering processes and equipment.

- The decreasing availability of land disposal areas will call for an increased use of sludge incineration, to a large extent as separate incineration. Equipment for this is available.

- Also the utilization of sludge or ash for soil quality improvement, fertilization of farm and forest land, for the production of soil material and other purposes will be considered.

4 COST ESTIMATING FOR EMISSION CONTROL

4.1 Emission Control Measures

To reduce the emissions from pulp and paper manufacturing there are a number of measures that may be used. Usually one distinguishes between internal and external measures, where internal measures include modifications to the actual processes and external measures include treatment methods "outside" the production lines often called "end-of-pipe" solutions.

During the last 20 years much of the development of pulp and paper processes and systems have been focused on environmental improvements and with the processes used in modern mills today the specific emissions (kg/ADt of pulp) are much lower than 10 or 20 years ago. (This has been roughly quantified on page 3 in Section 1.3.) Thus, as internal measures the following processes and techniques may be mentioned:

Internal Control of Emissions to Water

- Improved wood handling including dry debarking, debarking control, chipper improvements and chip screening in order to reduce bark content, fines content, impurities, and over-sized material in the wood chips.

- Pre-steaming, modified cooking for continuous as well as for batch cooking processes with the purpose to extend delignification in cooking (in closed water loop system) before the bleaching processes

- Improved washing before as well as after a possible oxygen stage. In order to avoid the carry-over of organic substances to the bleach plant, the installation of an open wash stage before the bleach plant has been attractive for a while in order to reduce formation of chlorinated substances. This process design can only be considered as a temporary improvement.

- Oxygen delignification. This stage is integrated in the closed brown-stock washing system and the lignin content of the unbleached pulp may be reduced by 40-60 % before bleaching. The emission of COD from the bleach plant is reduced accordingly.

- Peroxide and ozone bleaching. By switching to chlorine-free chemicals a closure of the bleach plant is facilitated, especially in terms of recycling of alkaline filtrates. Emissions of chlorinated compounds is reduced or eliminated. If no closure is applied COD emissions do not really decrease.

- Condensate stripping in order to reduce BOD and COD emissions. Volatile compounds like methanol are evaporated and incinerated and not released to receiving water.

- Improved fibre spill and liquor spill handling. Maybe, this is to be characterized as an external treatment, but the spills are normally taken back to the fibre system or the liquor cycle.

- In paper mills as well as in mechanical pulp mills the internal measures are related to recycling/recovery of internal water. Primarily, this requires internal treatment and the degree of treatment that is required is related to the degree of closure. Extensive recycling (low fresh water usage) requires more extensive treatments than limited recycling. The internal treatment may require various filters, micro-flotation, chemical treatment, biological treatment, evaporation, and so on. So far, various filter technologies and micro-flotation are usually the only measures that are needed.

Internal Control of Emissions to the Atmosphere

- Collection and incineration of malodorous gases. The concentrated gases are primarily collected from digester area (flash gases), from condensate stripping and from non-condensible gases from the evaporators. The sulphur dioxide formed from the incineration should preferably be washed out in a scrubber and recycled to the liquor cycle.

- Increased dry solids content of black liquor. Emissions of sulphur dioxide as well as of hydrogen sulphide (H_2S) are reduced.

- Modifications to reduce formation of NO_x in furnaces. These techniques either include changes to the mixing of fuel and air or a catalytic reductive process.

- Lime mud washing improvements to reduce TRS emissions from lime kiln.

External Control of Emissions to Water

The external control of water emissions may include the different methods for effluent treatment that are described in Chapter 3. In particular, in the analyses the following measures are included for the cost estimating:

- Primary treatment (clarification)

- Rebuild of aerated lagoons to systems with recycling of sludge, similar to activated sludge systems. Aerated lagoons have lower efficiencies than activated sludge and improvements to aerated lagoons have often been implemented in order to achieve results in the neighbourhood of those of activated sludge plants.

- Activated sludge systems. This is applicable for mills with no biological treatment when such a treatment becomes necessary.

- Anaerobic treatment. This may be a preferred biological treatment method when COD-concentration is high (above about 1000 g/m^3).

- Chemical precipitation. This is normally not required but may be an option in certain situations (cf. Chapter 3).

- Membrane filtration or evaporation is only required in a limited number of mills. These technologies will probably come into more use during the period up to the year 2005.

- Sludge dewatering and sludge handling. When larger amounts of sludge are being generated, which is the normal case in effluent treatment the sludge has to be taken care of in appropriate ways.

External Control of Emissions to the Atmosphere

- Electrostatic precipitators to reduce solid particulates (TSP) in flue gases. This kind of equipment is also applied to lime kilns.

- Multicyclones or bag-houses may occasionally be used as alternative to electro-filters. In particular for sulphite mills with magnesium base the multicyclones are in common use.

- Scrubbers. To reduce hydrochloric acid and sulphur dioxide from flue gases, alkaline solutions are used to absorb the acidic gases. NO_x also gives acidic reaction but the acidity is not high enough to absorb these gases in alkaline solutions.

4.2 Investment Costs for Control of Emissions to Water and to the Atmosphere

The investment cost estimates for the different environmental control measures that are considered in the present study are based on database information on investment costs. From the database information, relationships of investment costs *versus* production capacity (as t/a) have been determined as a functional relationship through a fitting procedure according to the least squares method. Through the fitting procedure the constant parameters A, B, C, ... in the functional relationship

$$Investment\ Cost = f(A, B, C, ..., x)$$

where x denotes the production capacity, have been fitted to the available discrete data points.

With such relationships for each of the considered environmental measures it becomes possible to calculate investment costs for different measures. Depending on the standard of a mill, different control measures need to be installed to improve the situation. For the mills, the investment requirements to upgrade from a particular category as described in Chapter 6 to Category I (the group with best environmental standards) has been estimated for each kind of production. Through the functional relationship the economy of scale is well represented in these estimates, i. e. for a smaller mill the specific investment costs (USD/t of product) normally become higher than for a bigger mill.

The investment costs required to raise all mills in a country up to Category I is the calculated for each country in the study. These costs are presented in Chapter 7. It must be realised that the presented cost data are theoretical and superficial, since many mills could never afford to make these investments. If they would be forced to make the improvements they may have to shut down the operation. Nevertheless, the addition of costs for environmental investments is done to indicate the world-wide level of expenditure for environmental measures that would be required to get all mills up to the same standards.

The investment costs used for the different control measures include the following items and are based on average situations

- main equipment (like reactors, vessels, evaporators, filters, screens, presses, furnaces, and so on) including basins
- pumps
- tanks
- piping
- electrification
- instrumentation
- transportation (typical)

It should be kept in mind that the investment costs may vary a lot from case to case related to local circumstances. In the estimates, the indirect costs (engineering and installation) have not been included since the need for such services cannot be specified in general terms. Building costs (civil constructions) have neither been included since those also depend greatly on local situation. However, for external treatment, the building costs for basins and clarifiers have been included. Thus, civil works may correspond to 0 - 20 % of total direct costs and the indirect costs may amount to 5 - 25 % of the total direct costs.

4.3 Operating and Annual Costs for Control of Emissions to Water and to the Atmosphere

Operating Costs

The operating costs (USD t^{-1} a^{-1}) for the different measures have been expressed by functional relationships in the same way as for the investment costs. These operating costs have then been calculated for the countries and regions that are defined for the present study.

The operating costs include

- use of chemicals
- use of utilities like electric power, steam (heat) and water
- use of fuels (like oil and gas)
- maintenance

The cost for manpower to operate the environmental control equipment has not been included because of the difficulties to define and to determine that need. Furthermore the cost for manpower varies substantially from one of the regions to another.

Annual Costs

To estimate the annual cost for the environmental measures the following costs have been added:

- operating costs
- depreciation factor corresponding to a depreciation of 10 % per annum
- interest rate of 15 %

The annual costs for the environmental measures are also presented in Chapter 7. Once again is should be emphasized that these costs are theoretical and could normally not be carried by many small mills.

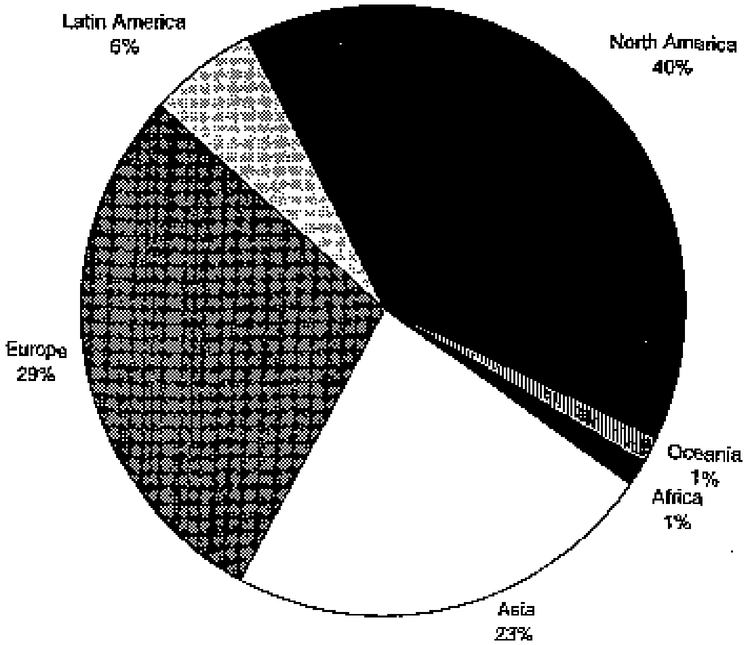
5 PULP AND PAPER CAPACITY

5.1 Pulp Capacity by Regions

5.1.1 Pulp Capacity in all the Regions

The total capacity of pulp production in the countries included in this study is shown in Figure 5.1. This represents about 98 % of the worlds total pulp manufacturing capacity. The total capacity in the countries included in the study and in Figure 5.1 is about 291 million ADt of pulp and that includes 193 million ADt of virgin pulp and 98 million ADt of recycled fibre pulp. About 25 % of the recycled pulp is deinked. There are about 9 400 pulp mills in the world, but about 8 000 of these are situated in China and are very small (with production levels below 1000 ADt/a). This production can not really be considered as industrial processing but rather like manual production. On a worldwide basis, the average mill size is 30 000 (23 000 without RCF) ADt/a, but if excluding China's many small mills the average capacity reaches 166 000 ADt/a (122 000 ADt/a without RCF).

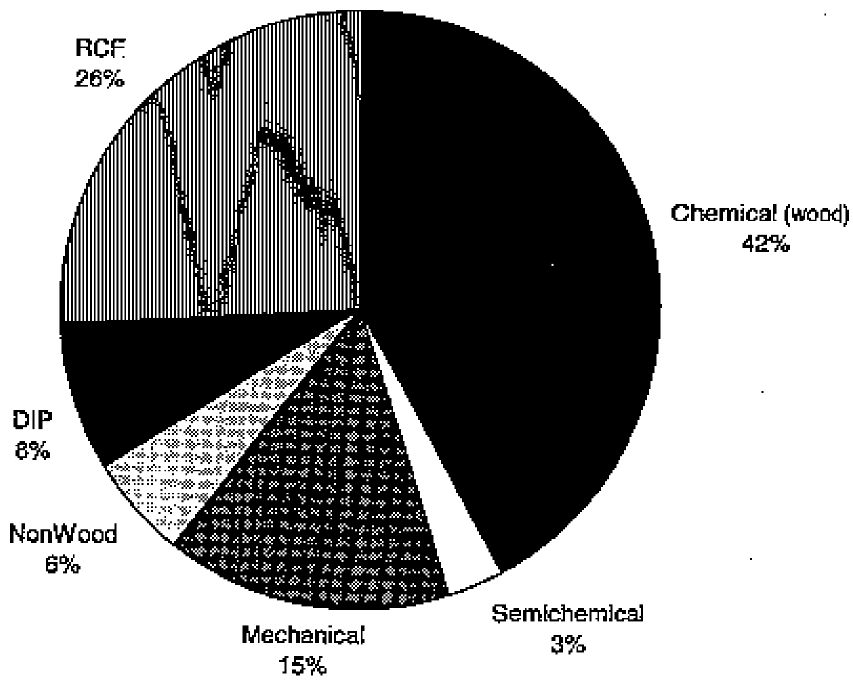
Figure 5.1
The total pulp capacity including recycled fibres (total of 291 million ADt/a) in the countries included in the study divided into main continents.



The total pulp capacity divided into different grades has been summarised in Figure 5.2.

A very big portion of the virgin fibre pulps is produced from wood by chemical pulping processes. In this process group are the kraft, sulphite and soda processes included. In the semichemical group, processes like NSSC, soda processes and various high-yield pulping methods are included. Groundwood pulp, TMP and RMP as well as CTMP are included in the mechanical pulp group.

Figure 5.2
The total pulp capacity in the countries included in the study divided into grades, total of 291 million ADt/a.



Non-wood pulping is quite different from wood pulping so in this group has all the different processes in which non-wood are used been included. The main process is based on soda pulping but also kraft, sulphite and mechanical processes are used. The raw materials that are being used in non-wood pulping are for example bagasse, straw, reed and many other annual plants.

The number of pulp mills in the countries included in the study has been summarised in Table 5.1.

Table 5.1
Number of pulp mills in the countries included in the study divided into main continents.

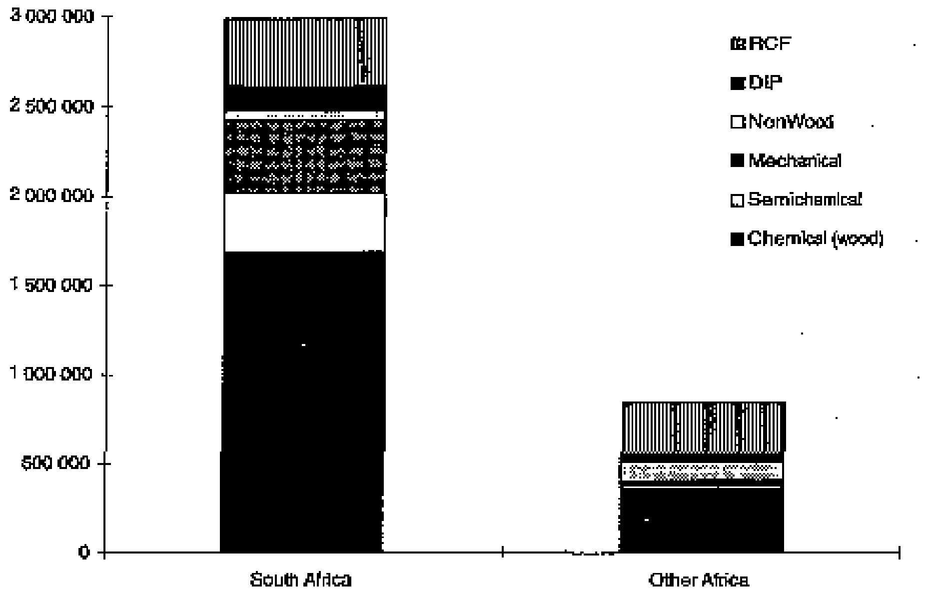
Continent	Number of mills
Africa	23
Asia	8296[a]
Europe	448
Latin America	179
North America	407
Oceania	19

[a] The number of mills in China is estimated to 8000. The number of mills in China with capacities above 1000 ADt/a is about 250.

5.1.2 Pulping Capacity in Africa

The pulping capacities for the different regions in Africa in the study are shown in Figure 5.3.

Figure 5.3
Pulping capacity by grades for the different regions in Africa, as ADt/a.

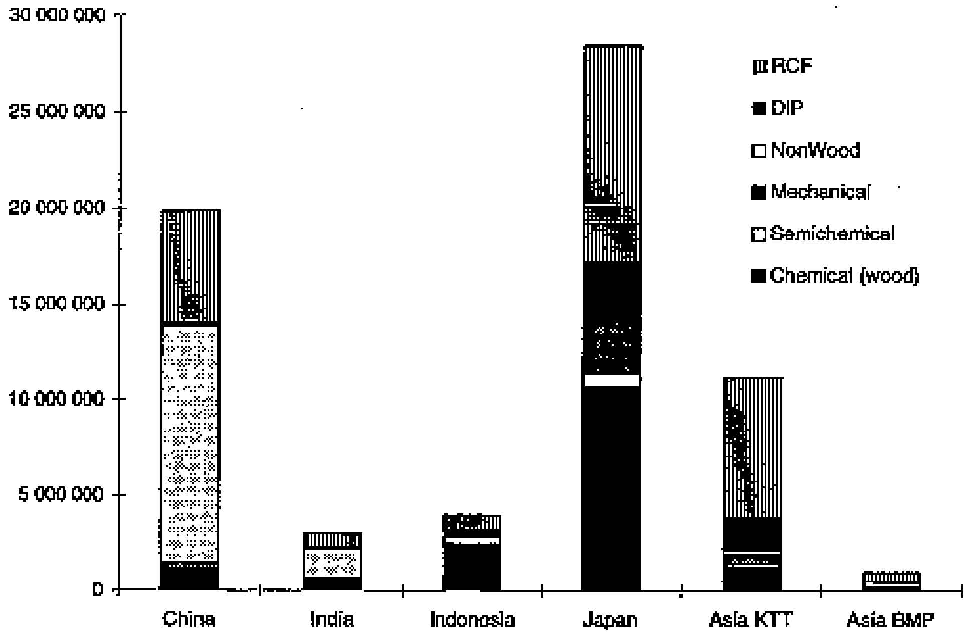


The main part of the pulp production in Africa is carried out in South Africa. South Africa produces more than twice as much pulp as the rest of the African countries produce together. Most of the pulp production in South Africa is based on wood which is also the case for Kenya, Morocco and Swaziland. In Egypt the main raw material source is of non-wood nature.

5.1.3
Pulping Capacity in Asia

The pulping capacities in the different Asian regions of this study are shown in Figure 5.4.

Figure 5.4
Pulping capacity by grades for the different regions in Asia, as ADt/a.



China is the worlds biggest producer of non-wood pulp. As mentioned earlier in Section 5.1, most of the pulp is produced in small production units. The statistics over China's pulp production is very uncertain and the amount of production as well as the number of mills are estimates.

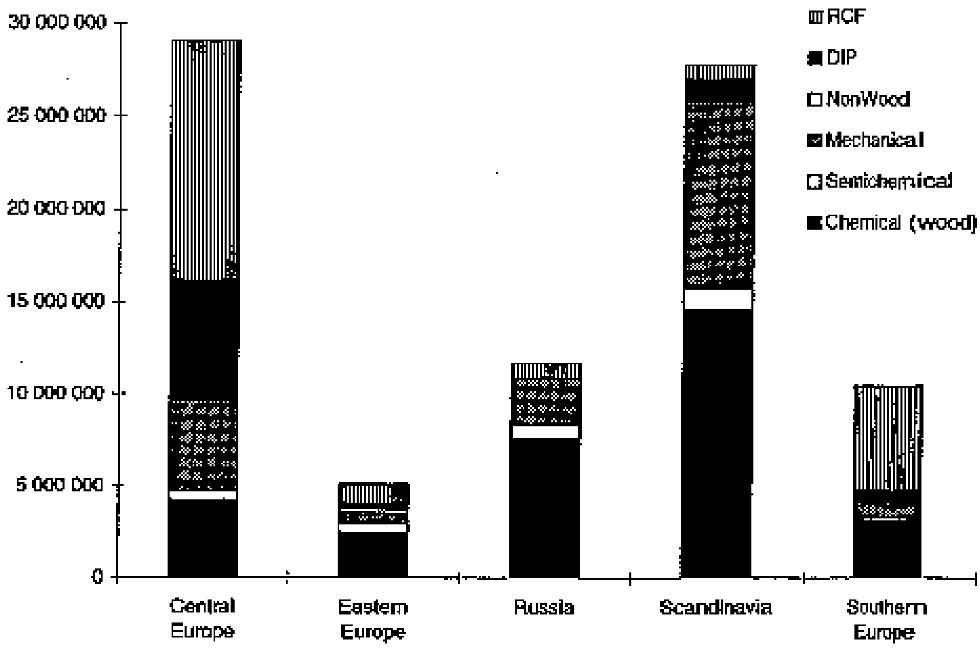
Japan is the country in Asia that has the biggest production of pulp. It is also the biggest user of recycled fibres. On the whole the proportion of recycled fibres is high in Asia and to manage the use of such a high amount of recycled fibres, waste paper is imported (mainly from the USA) by many Asian mills.

Indonesia is also a large pulp producing country with a grade profile comparable to the Western world. The pulping capacity has increased substantially in Indonesia over the last 5 years and the growth in this country seems to continue at a high rate.

5.1.4 Pulping Capacity in Europe

The pulping capacity in the different European regions of this study are shown in Figure 5.5.

Figure 5.5
Pulping capacity by grades for the different regions in Europe, as ADt/a.



In Europe, non-wood pulping is insignificant.

In Central Europe more than half of the pulp processed comes from recycled fibres and a large amount of the pulp from virgin fibers is processed with mechanical processes. Thus, a comparatively small amount of pulp is produced through chemical processes, and among the latter processes the sulphite process has kept a surprisingly high proportion of the chemical pulping capacity.

Scandinavia is the biggest producer of virgin pulp in Europe with a high proportion of softwood. Kraft pulping as well as thermo-mechanical pulping dominate in Scandinavia and the Scandinavian pulps represent an important supply of virgin fibres to the Central European markets where recycling is so important.

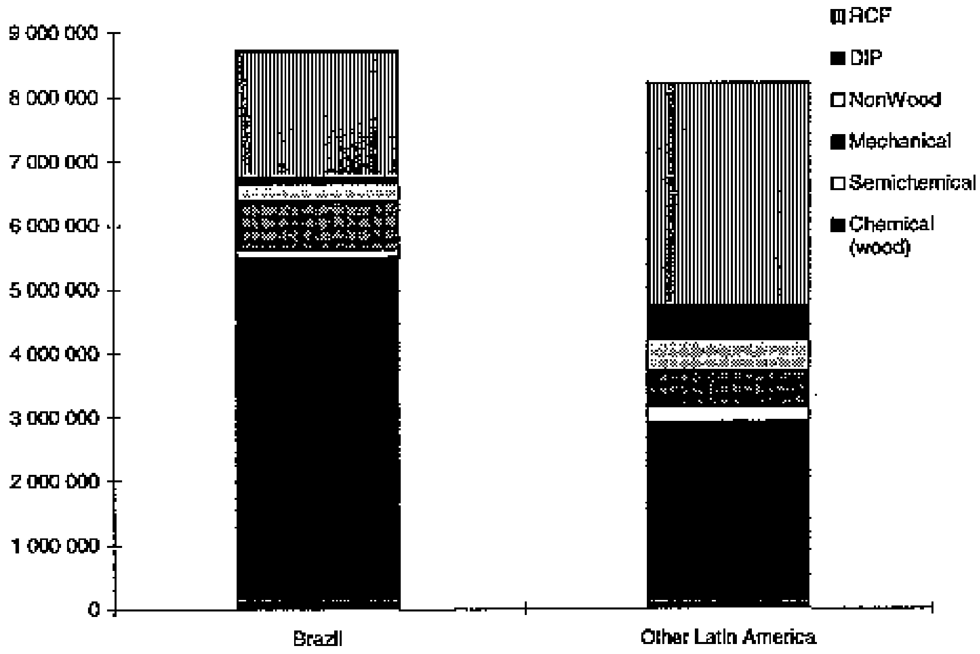
Pulping in Southern Europe is mainly carried out in Spain and Portugal with a high proportion of Eucalyptus kraft for the virgin fibre production.

In Russia and in particular in Eastern Europe the production comparatively low with large needs for modernisation.

5.1.5
Pulping Capacity in Latin America

The pulping capacities in the different Latin American regions in this study are shown in Figure 5.6.

Figure 5.6
Pulping capacity by grades for the different regions in Latin America, as ADt/a.



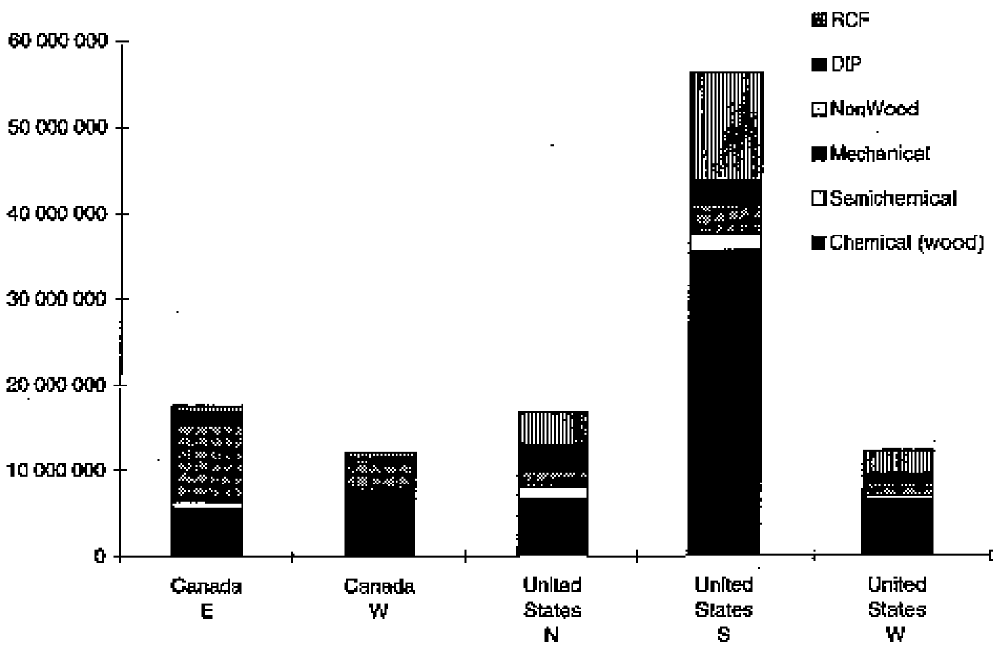
The dominating raw material for the pulp production in Latin America is Eucalyptus, which also implies that the kraft process is the most important one. Mechanical processes that are less suited for hardwood species are not used at significant degree. Fibre recycling is very important. Non-wood pulping is of some importance.

Brazil is by far the most important pulp producing country in Latin America with almost 7 million ADt of virgin fibre production. Then, Argentina, Chile and Mexico represent the major share of all the other producing countries in Latin America.

5.1.6
Pulping Capacity in North America

The pulping capacities in the different North American regions of this study are shown in Figure 5.7.

Figure 5.7
Pulp capacity by grades for the different regions in North America, as ADt/a.



The North American territory is by far the most important pulp and paper producing region in the world. Non-wood pulping is almost non-existent in this region. In Canada, recycled fibre is of small significance, while this raw material plays a more important role in the USA.

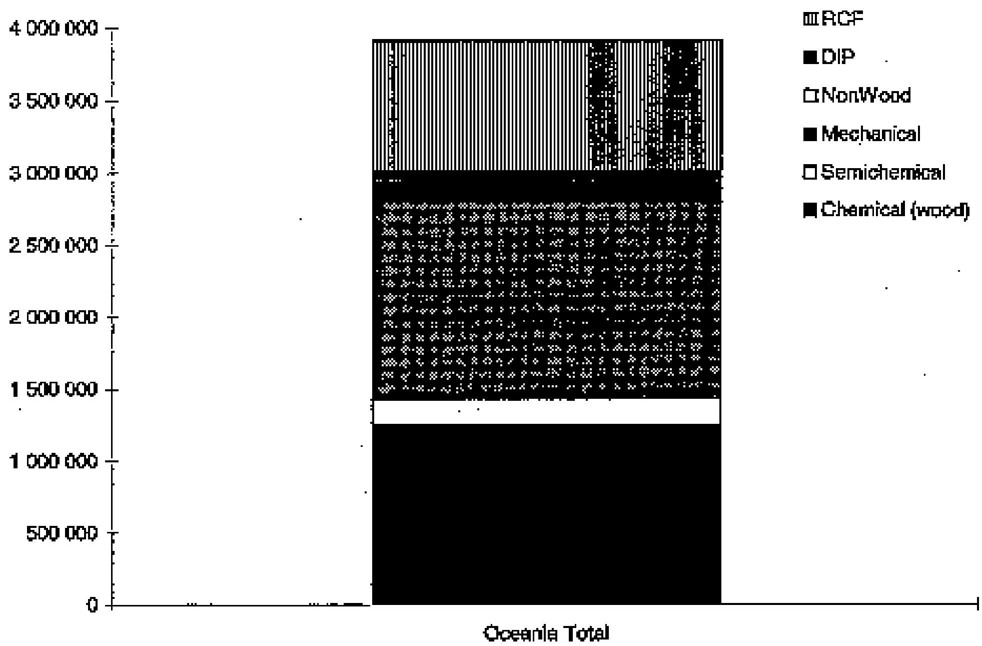
In Canada, softwood pulping dominates and the production is focused on mechanical grades for newsprint and printing grades and on kraft pulping.

In the USA, chemical pulps are also the major fibre source for papermaking. The Southern states produce more pulps than the Northern and the Western together.

5.1.7
Pulping Capacity in Oceania

The pulping capacities in the different regions in Oceania are shown in Figure 5.8.

Figure 5.8
Pulping capacity by grades for the different regions in Oceania, as ADt/a.



Oceania is represented by Australia and New Zealand. Also in this region non-wood pulping is insignificant.

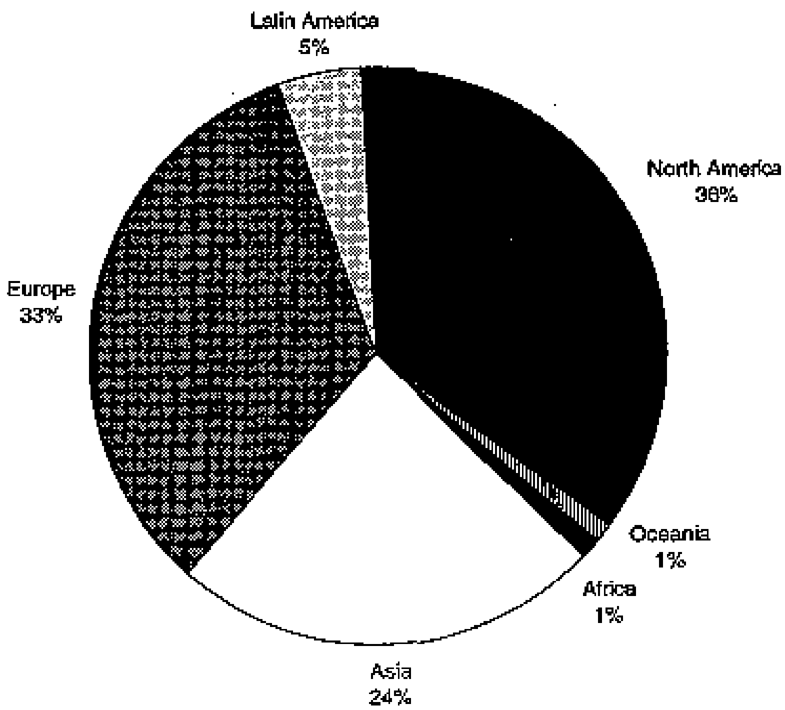
The fibre supply for papermaking is roughly divided into three equal parts represented by kraft pulps, mechanical pulps and recycled fibre. Some parts of the recycled fibre are deinked. Smaller amounts of semichemical pulps are produced.

5.2
Papermaking Capacity by Regions

5.2.1
Papermaking Capacity in all the Regions

The total capacity of paper production in the countries included in the study are shown in Figure 5.9. This capacity represents about 97 % of the world's total paper capacity. The total capacity in the countries included in the study amounts to about 292 million metric tonnes per year. There are about 13 000 paper mills in the world, but about 10 000 of these are situated in China and are very small (with capacities less than 1000 t/a). In the mills with capacities above 1000 t/a, there are about 8 000 papermachines. The average capacity of the mills larger than 1000 t/a is about 80 000 t/a. Most of the mills (about 66 %) are non-integrated while the rest are integrated with a pulp mill.

Figure 5.9
The total paper capacity in the countries included in the study divided into main continents as ADt/a. The total capacity is about 292 million t/a.



In Figure 5.10 the capacity for paper manufacturing is divided into different grades. Table 5.2 shows the number of paper mills and their machines for the different regions of this study.

Figure 5.10
The total paper capacity in the countries included in the study divided into grades, ADt/a. The total capacity is about 292 million t/a.

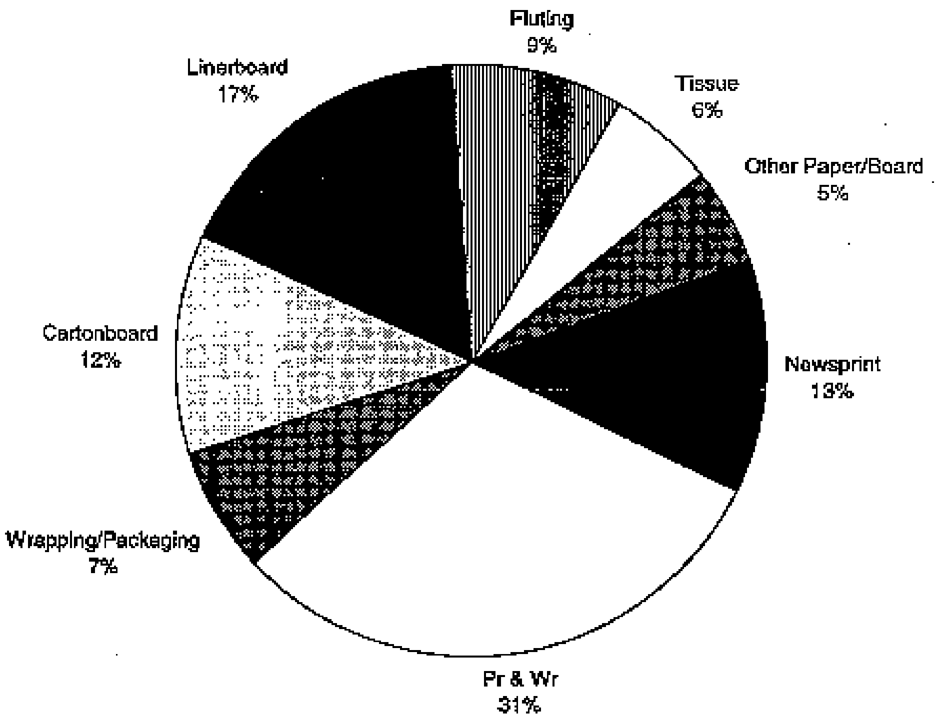


Table 5.2
Number of papermills and papermachines in the countries included in the study divided into continents.

Continent	Number of papermills	Number of papermachines
Africa	56	123
Asia	10 772[a]	3 071[b]
Europe	1 328	2 645
Latin America	424	822
North America	675	1 443
Oceania	26	49

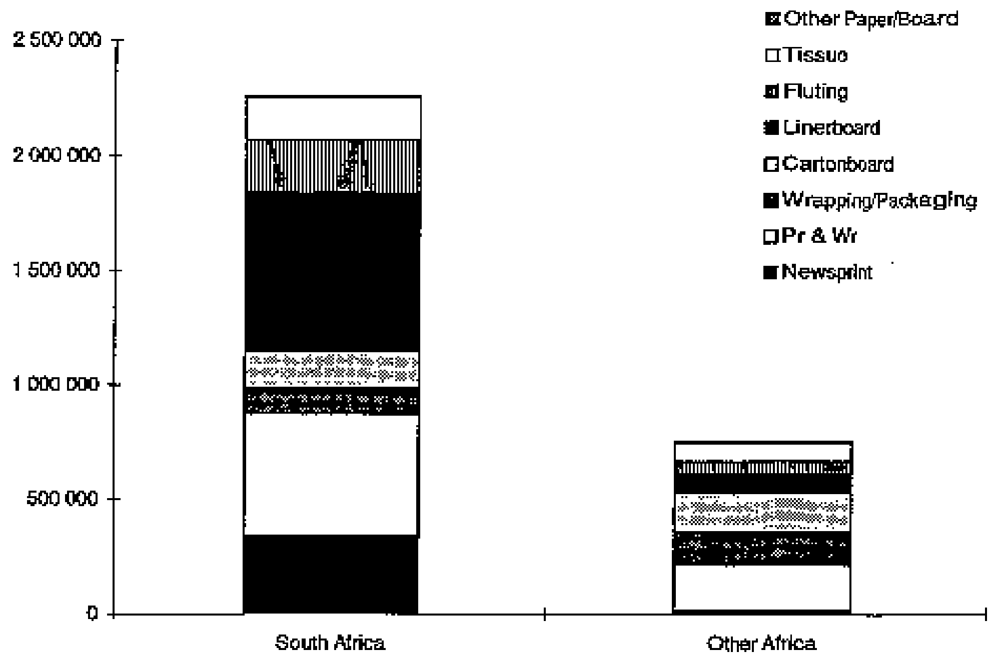
[a] The number of papermills in China is estimated to 10 000. The number of mills in China with capacities above 1000 t/a mills is about 320.

[b] The number of papermachines in China that is shown here represents only the bigger machines and is about 1400.

5.2.2
Papermaking Capacity in Africa

The papermaking capacity in the different African regions of the present study are shown in Figure 5.11.

Figure 5.11
Papermaking capacity by grades for the different regions in Africa, as t/a.

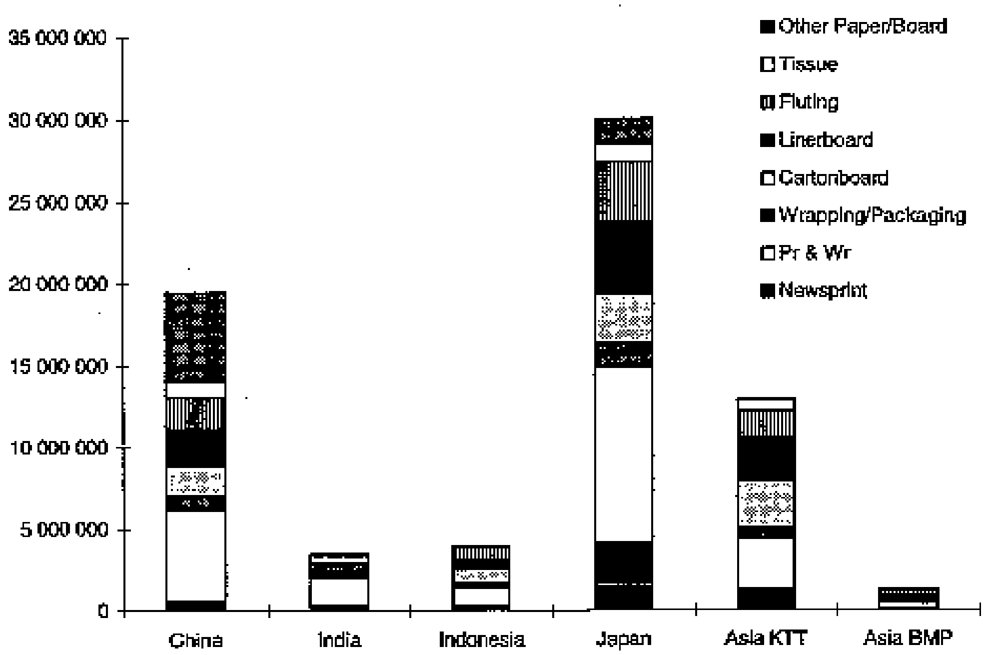


As for pulp, the South African production is dominating in Africa.

5.2.3
Papermaking Capacity in Asia

The papermaking capacity in the different Asian regions of this study are shown in Figure 5.12.

Figure 5.12
Papermaking capacity by grades for the different regions in Asia, as t/a.



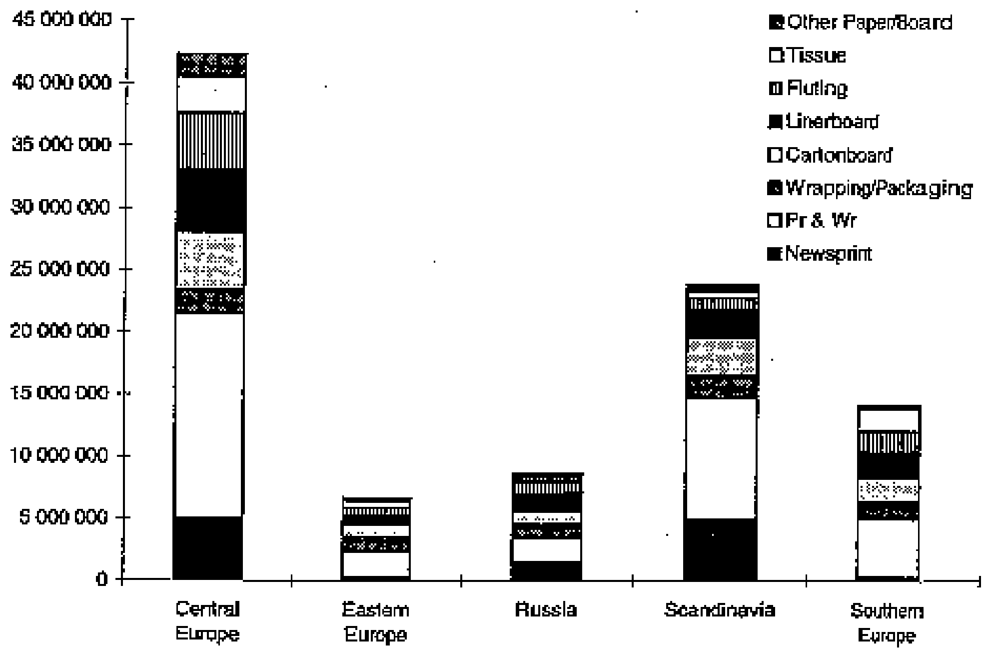
Japan is the largest paper producing country. Production in China is substantial but mainly carried out in very manual ways. It seems likely that papermaking capacity will grow more rapidly in China and probably also in Indonesia in the next 10 years.

Korea, Taiwan and Thailand represent significant capacities as well.

5.2.4
Papermaking Capacity in Europe

The papermaking capacity in the different European regions in the present study are shown in Figure 5.13.

Figure 5.13
Papermaking capacity by grades for the different regions in Europe, as t/a.



Central Europe represent the largest paper production in Europe while the Scandinavian countries are more in balance with their pulping capacities. This means that the Central European producers are less integrated and purchase substantial amounts of market pulps.

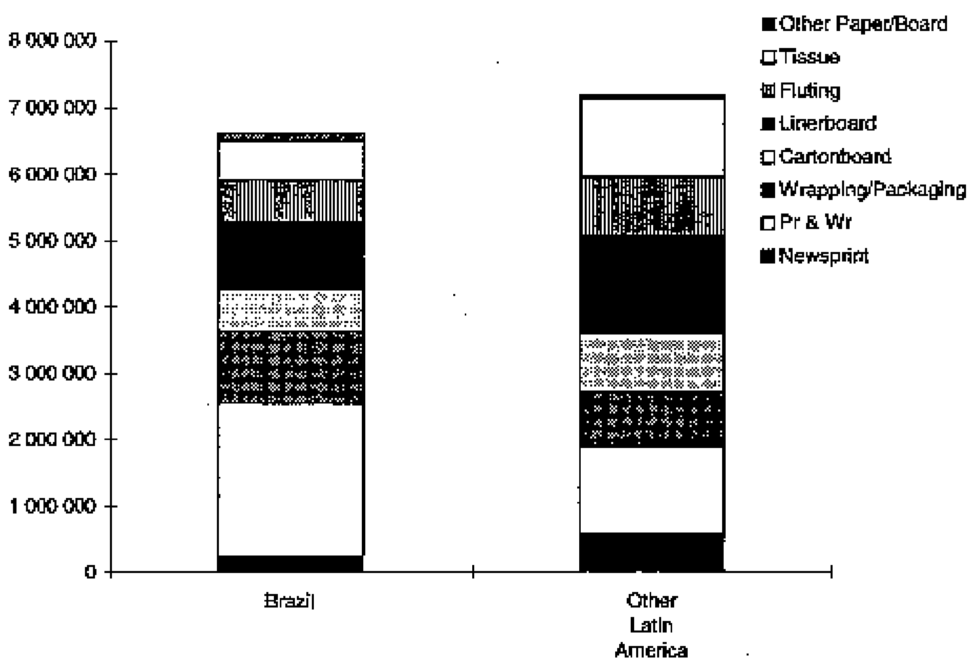
Paper production in Eastern Europe and in Russia is comparatively small, but may be expected to increase at higher rates than for other European regions.

In Southern Europe, Italian producers play a much bigger role than they do on the pulping side.

5.2.5
Papermaking Capacity in Latin America

The papermaking capacity in the different Latin American regions are shown in Figure 5.14.

Figure 5.14
Papermaking capacity by grades for the different regions in Latin America, as t/a.



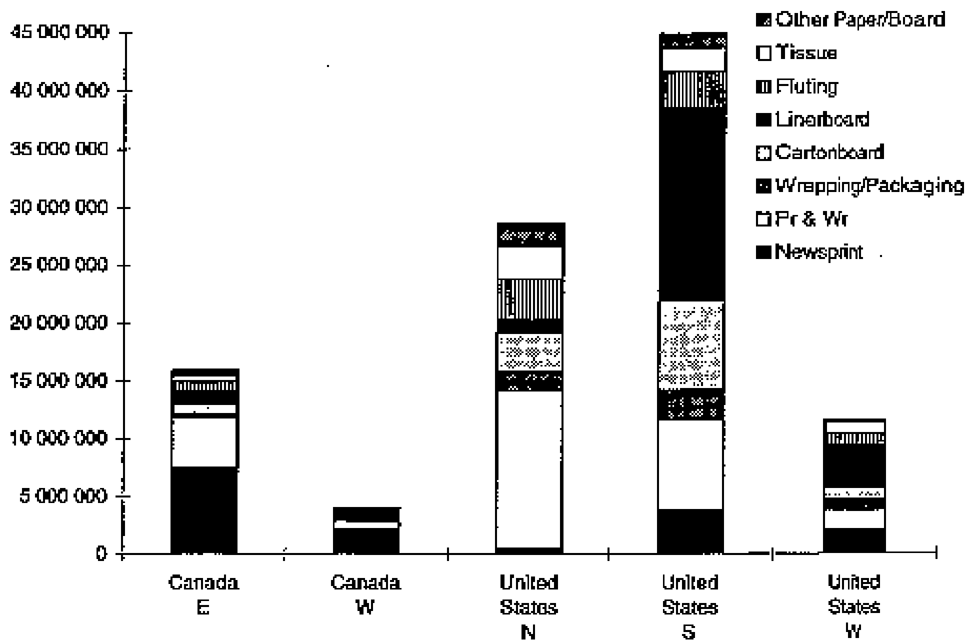
As for pulping, Brazil is the dominating country in Latin America for papermaking as well.

Newsprint production is surprisingly small, which is due to the lack of suitable raw material.

5.2.6 Papermaking Capacity in North America

The papermaking capacity in the different North American regions are shown in Figure 5.15.

Figure 5.15
Papermaking capacity by grades for the different regions in North America, as t/a.



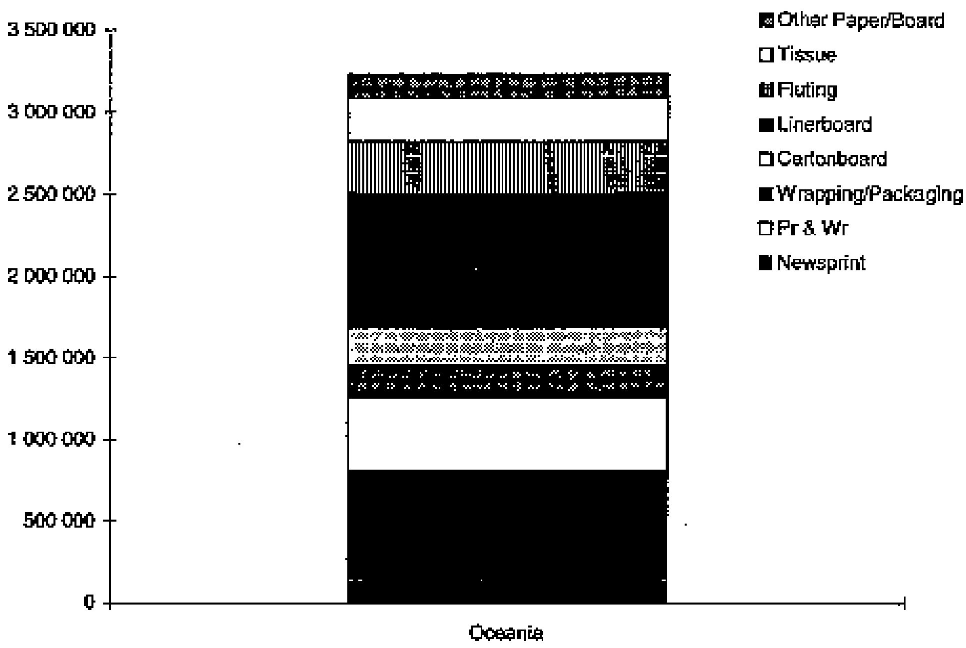
Newsprint production is large in Canada due to the availability of suitable softwood species for this production. The large production of kraft pulps in Canada implies quite a large production of bleached pulps for wood-free printing and writing grades.

In the USA, the Southern states dominate the papermaking as well as the pulp manufacturing. Very large quantities of packaging grades (like linerboard and corrugating medium) are manufactured in this region.

5.2.7
Papermaking Capacity in Oceania

The papermaking capacity in the different regions in Oceania are shown in Figure 5.16.

Figure 5.16
Papermaking capacity by grades for the different regions in Oceania, as t/a.



The paper production in Australia and New Zealand is somewhat less (about 15 %) than the pulping capacity. The proportion of printing and writing grades is comparatively low.

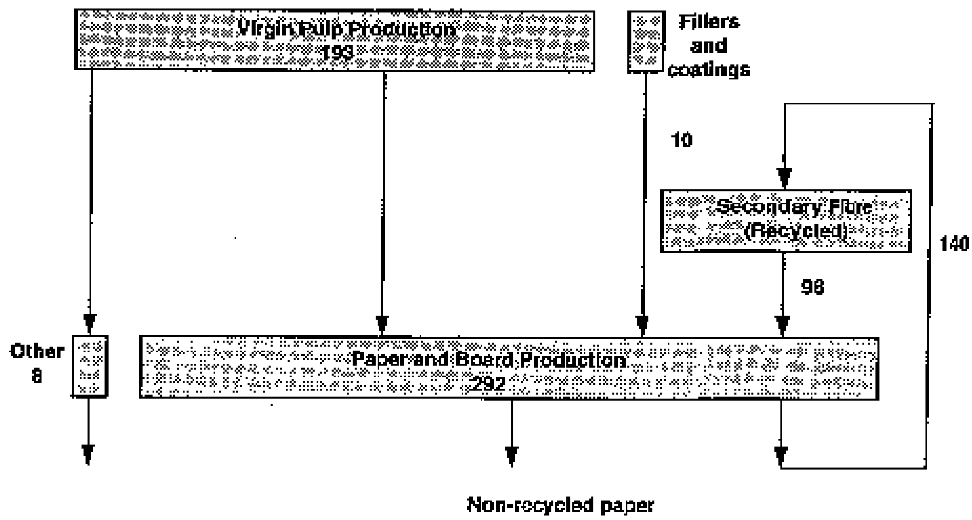
5.3 Fibre Balance

Figure 5.17 is included to illustrate the fibre balance in the world. Roughly, recycled fibre represent one third of the fibre raw material while virgin fibre represent about two thirds (or 63 % of the papermaking fibres). Some virgin pulps are used for other purposes than for papermaking (like diapers for instance). Fillers and coatings represent a small amount (3-4 %) of the raw materials for paper manufacturing.

Figure 5.17 shows capacity data for the industry except for the recycled fibre portion (98 million t/a), which is based on actual data (DIP+RCF in Appendix I). The reason for using actual numbers for recycled fibre is simply that there is no well defined upper capacity limit for the use of recycled fibre.

Almost 45 % of the paper that is being produced is recycled as waste paper, but the losses in recycling are about 30 % which reduces the papermaking proportion of recycled fibres to about 33 % (= 98/292). Actual share of recycled fibre is more like 98/270 = 36 % (based on 270 million t/a of paper, cf. page 1).

Figure 5.17
Schematic representation of the fibre balance based on capacity data (t/a) for the pulp and paper industry.



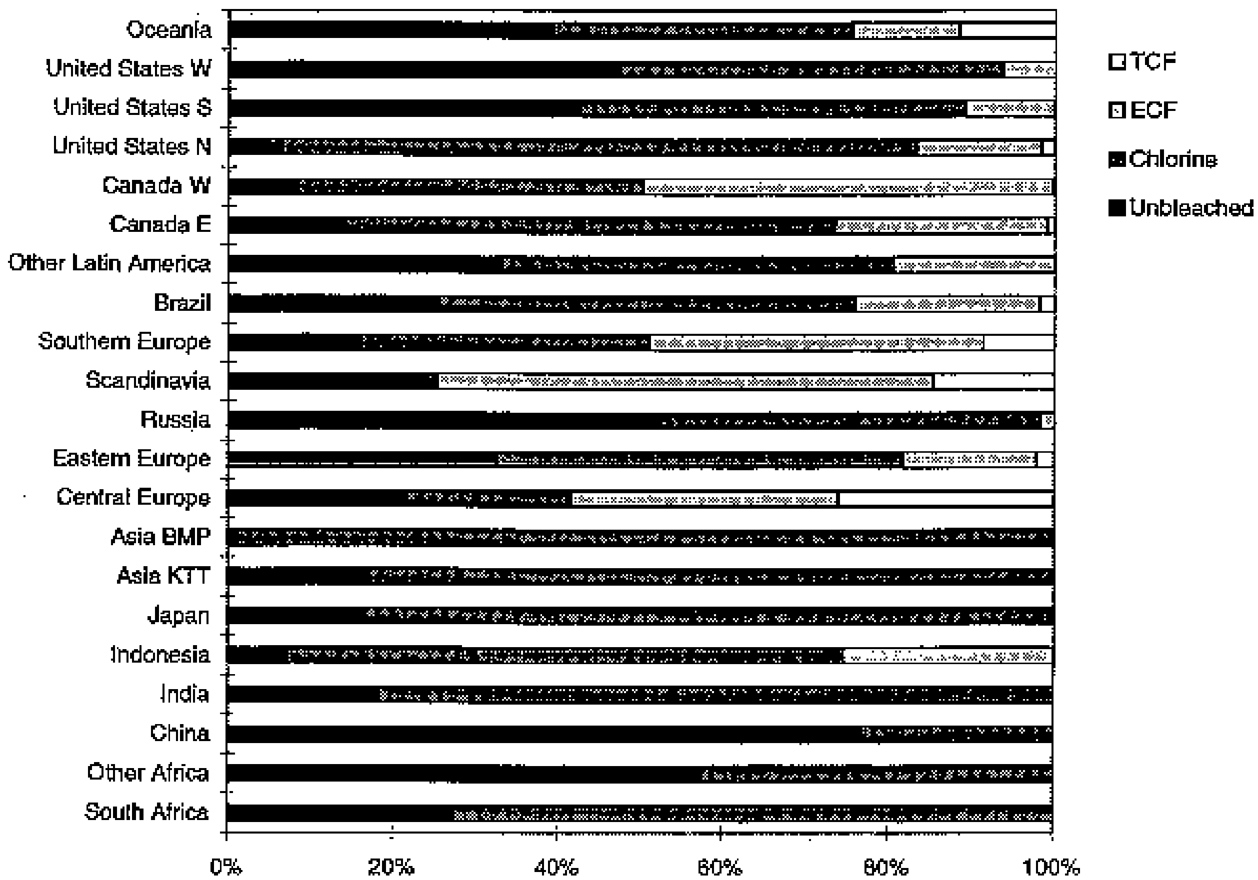
5.4 Bleached Pulps

5.4.1 Chemical Pulps

In bleaching chemical pulps, the remaining lignin is chemically removed in order to produce bright pulps. More than two thirds of the worlds total pulp capacity of chemical wood pulp are bleached pulps. Most of these pulps are bleached with chlorine as major chemical, but about 30 % of these pulps are today bleached without chlorine (ECF pulps) and a small amount (about 4 %) are bleached without any chlorine compounds at all (TCF pulps). The proportions of the different kinds of bleaching processes differs from region to region and has been summarised in Figure 5.18.

It appears likely that most quite a few of the mills in Europe and North America that are using chlorine will switch to ECF bleaching before the year 2000. It is probably less likely that this change will take place in other regions of the world.

Figure 5.18
The proportion of unbleached, chlorine bleached, ECF and TCF bleached chemical pulps by region.[a]



[a] The figures representing unbleached and chlorine bleached pulp are based on capacity data, while the figures representing ECF and TCF pulps are based on production data. This does not affect the proportionality between the different grades in any significant degree.

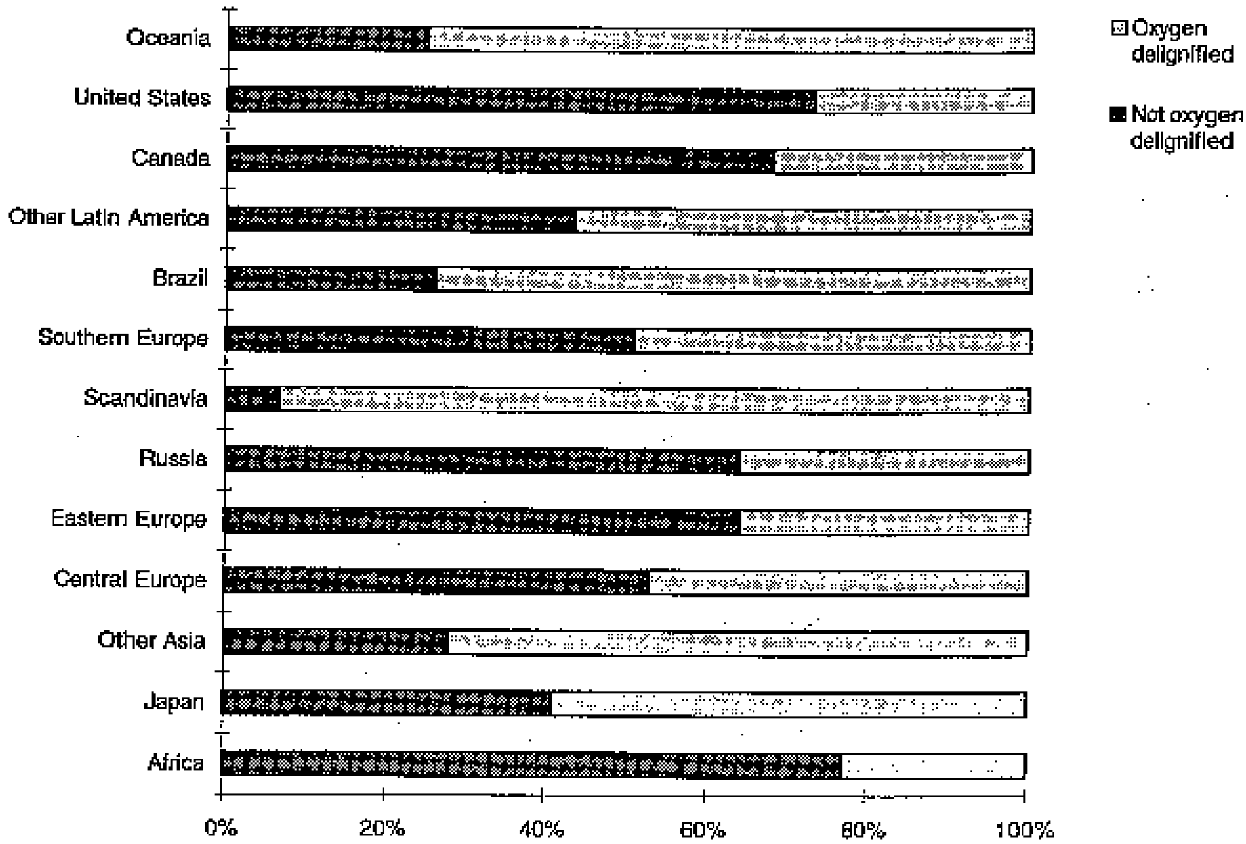
Scandinavia and Central and Southern Europe are the regions with the largest proportion of ECF. Today, Scandinavia has almost no production of chlorine bleached pulps. These regions also have the largest proportions of TCF pulp.

North America is moving towards more ECF bleaching. The development of TCF bleaching does not appear to have a large influence on the pulp bleaching in North America during the 20th Century.

Asia (except Indonesia) and Africa is only producing chlorine based bleached pulps.

The use of oxygen delignification as a mean to reach higher brightness levels, to decrease the demand of bleaching chemicals, and to reduce water emissions differ also from region to region, cf. Figure 5.19.

Figure 5.19
The proportion of oxygen delignified bleached kraft pulp by region.



Scandinavia is the region which has the highest proportion of oxygen delignification. Only Finland produces some amounts of bleached kraft pulp without oxygen delignification.

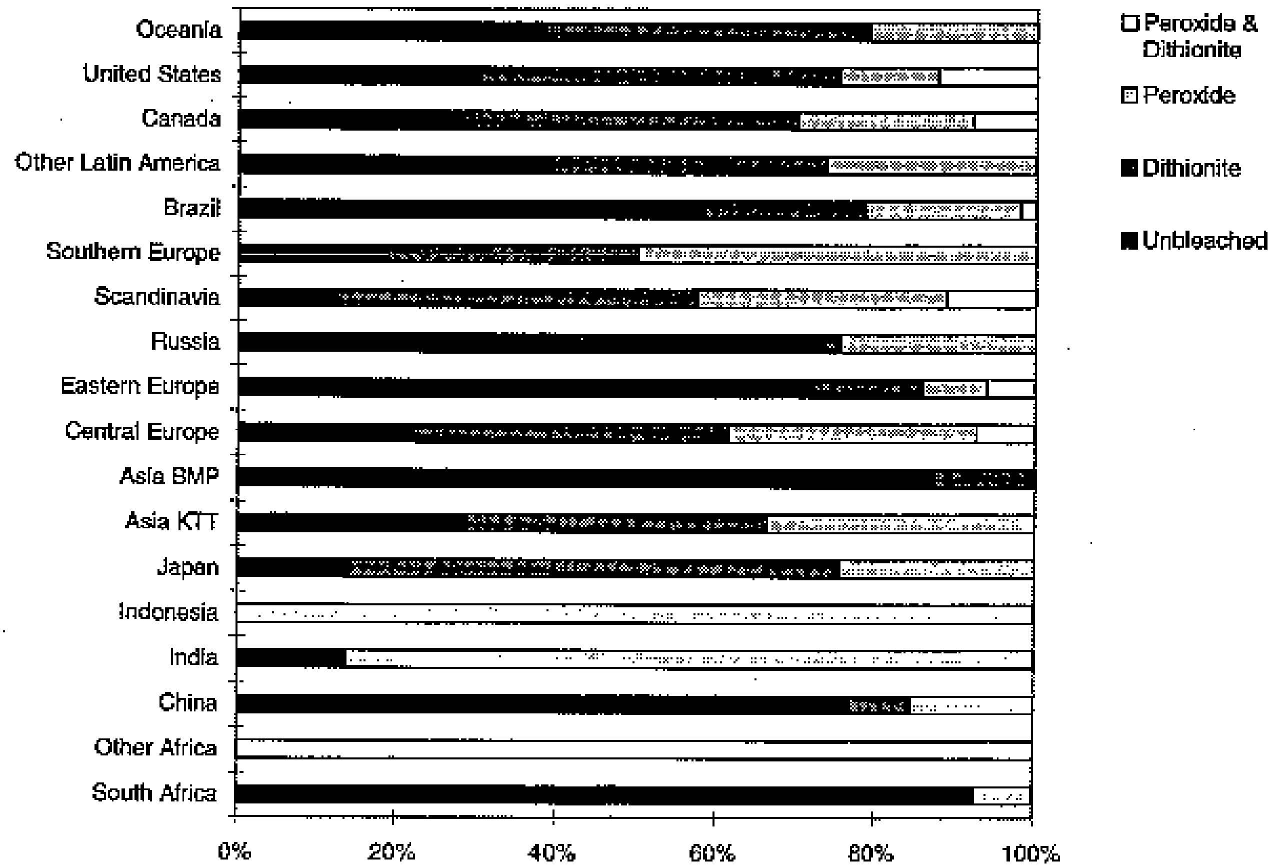
Asia and Latin America has also a high proportion of oxygen delignified bleached kraft pulp, whereas North America and Africa has a comparatively a low proportion.

5.4.2 Mechanical Pulps and Recycle Fibre

Mechanical pulps are bleached to increase the brightness levels without removal of lignin compounds. This means that emissions from the bleaching of mechanical pulps are smaller than for chemical pulps. Furthermore, in the bleaching of mechanical pulps as well as for recycled fibre, there are no chlorine containing chemicals being used since these chemicals have a lignin degrading and lignin removal impact.

The proportions of different chemicals used in the bleaching of mechanical pulps together with the proportion of unbleached mechanical pulp in different regions is shown in Figure 5.20.

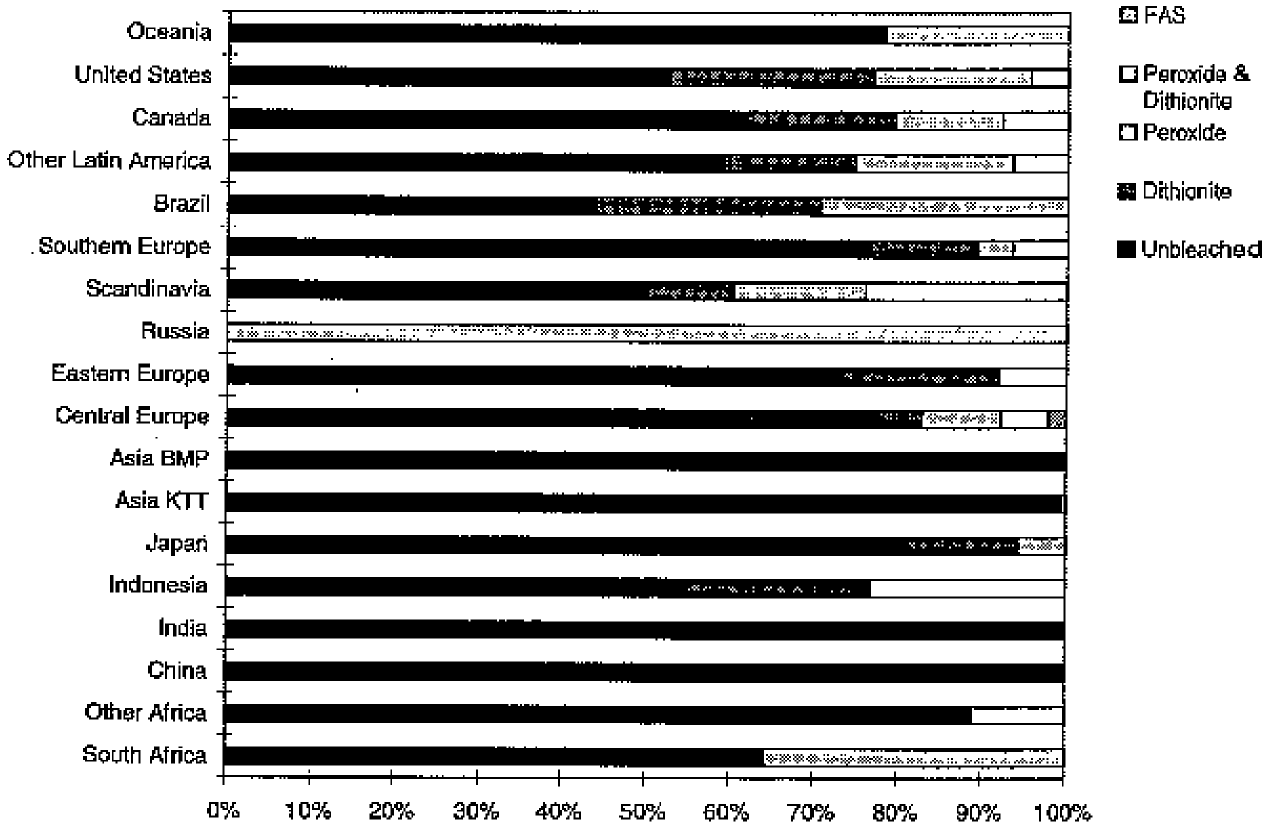
Figure 5.20
The proportion of unbleached, dithionite and peroxide bleached mechanical pulp by regions.



Africa and Indonesia has one mechanical pulp mill each. The mill in Indonesia uses non-wood (bagasse) as raw material

The proportions of different chemicals used in the bleaching of deinked pulp together with the proportion of unbleached deinked pulp in different regions are shown in Figure 5.21.

Figure 5.21
The proportion of unbleached, dithionite, peroxide and FAS bleached deinked pulp by regions.



Russia has only one mill with deinking.

It should be noted that for mechanical pulps and for recycled fibre the bleaching sometimes is carried out with very simple equipment and the bleaching is normally carried out in accordance with market demand or orders. Furthermore, the bleaching may be quite limited with the purpose to improve the quality a bit, but not to highest levels. Thus, Figure 5.20 and 5.21 must be interpreted with these facts in mind.

6 ACTUAL EMISSION LEVELS

6.1 General

There are many different kinds of emissions to water and air that is being studied and monitored for the pulp and paper industry. However, in the present study only the following parameters are being considered for emissions to water:

- TSS, total amount of suspended solids, the amount of solid particles dispersed in the effluent, can in larger amounts be harmful to the water environment and is therefore an important parameter. The TSS parameter includes inorganic as well as organic particles. Chlorinated substances of hydrophobic nature from the bleaching processes also adsorb on solid particles and render them more harmful. For this reason also, it is thus important to have a low TSS-profile.

- COD, which gives a good measure of the organic content in the effluent from the mill. It is preferred compared to BOD since it represents essentially the total amount of the organic substances. Since BOD is measured at many mills in the world, it is therefore included as a reference.

- AOX, which measures the amount of chlorinated (or rather halogenated) substances in the effluent and is considered as an important emission parameter for pulp mills with bleaching processes using chlorine in any form, since chlorinated substances may be harmful to the water environment.

For emissions to the atmosphere the following parameters are considered:

- TSP, particulate materials emitted to the air, from pulp and paper industries are normally more of a sanitary problem than a very harmful emission. Solid particulates in flue gases are mainly precipitating in the surroundings of a mill and may then be of a nuisance to people in the vicinity.

- Sulphur (as SO_2 and TRS). The reduced sulphur compounds (TRS) include hydrogen sulphide (H_2S), merkaptan, dimethylsulphide and dimethyldisulphide. The reduced sulphur compounds are often collectively called malodorous gases because of their foul smell.

- Nitrogen oxides (NO_x as NO_2) being a more recent parameter. The NO_x emissions have come into the picture because of the acidic nature as well as the fertilizing properties causing eutrophication.

6.2 Emissions from Pulp Production by Processes

6.2.1 Emissions from Chemical Pulp Mills

For this study, the emissions from chemical pulping is being rated in three levels corresponding to "Good", "Average" and "Poor". The "Good" rating is met by approximately 10-15 % of all mills, and the "Poor" rating is also roughly represented by 30-40 % of the mills in the world. Thus, the "Average" rating is represented by 45-60 % of the mills. The emission data for the rating for emissions to water are summarised in Table 6.1.

Table 6.1
Rating of emission levels to water for chemical pulp mills.

Emisssion parameter	Rating	Emission levels, kg/ADt	
		Bleached	Unbleached
TSS	Good (1)	< 5	< 4
	Average (2)	5 - 10	4 - 8
	Poor (3)	> 10	> 8
COD	Good (1)	< 25	< 10
	Average (2)	30 - 60	10 - 20
	Poor (3)	> 60	> 20
BOD	Good (1)	< 4	< 2
	Average (2)	4 - 10	2 - 5
	Poor (3)	> 10	> 5
AOX	Good (1)	< 0.8	-
	Average(2)	0,8 - 3	-
	Poor (3)	> 3	-

The ratings for emissions to the atmosphere are summarised in Table 6.2. These atmospheric emissions include those from the pulping processes and from bark boilers (combustion of internal fuels) but not any emissions from any other type of energy production from external fuels, such as burning of fuel oil or coal.

Table 6.2
Rating of emission levels to the atmosphere for chemical pulp mills.

Emission parameter	Rating	Emission levels, kg/ADt
TSP[a]	Good (1)	< 3
	Average (2)	3 - 10
	Poor (3)	> 10
Sulphur (SO_2 and TRS)	Good (1)	< 2
	Average (2)	2 - 5
	Poor (3)	> 5
NO_x	Good (1)	< 1
	Average (2)	1 - 3
	Poor (3)	> 3

[a] 1 kg/ADt corresponds to about
- 150 mg/Nm^3 dry gas for the recovery boiler,
- 2 000 mg/Nm^3 dry gas for the lime kiln,
- 960 mg/Nm^3 dry gas for the bark boiler.

6.2.2
Emissions from Semichemical Mills

The emissions from semichemical pulp mills are also rated from "Good" to "Poor". The ratings for emissions to water can be seen in Table 6.3 and the rating for emissions to the atmosphere is summarised in Table 6.4.

Since semichemical pulps normally are used for production of packaging material like corrugating medium, they are not bleached, at least not with chlorine containing chemicals. Thus, there are no AOX emissions and the AOX rating is omitted in Table 6.3.

Table 6.3
Rating of emission levels to water for semichemical mills.

Emisssion parameter	Rating	Emission levels, kg/ADt
TSS	Good (1)	< 4
	Average (2)	4 - 10
	Poor (3)	> 10
COD	Good (1)	< 25
	Average (2)	25 - 60
	Poor (3)	> 60
BOD	Good (1)	< 5
	Average (2)	5 - 15
	Poor (3)	> 15

Table 6.4
Rating of emission levels to air for semichemical pulp mills.

Emission parameter	Rating	Emission level, kg/ADt
TSP	Good (1)	< 3
	Average (2)	3 - 10
	Poor (3)	> 10
Sulphur (SO_2 and TRS)	Good (1)	< 2
	Average (2)	2 - 5
	Poor (3)	> 5
NO_x	Good (1)	< 1
	Average (2)	1 - 3
	Poor (3)	> 3

6.2.3 Emission Levels for Mechanical Pulp Mills

The emissions from mechanical pulp mills have also been rated from "Good" to "Poor", which is summarized in Table 6.5 for water emissions and in Table 6.6 for atmospheric emissions. As for the semichemical pulp mills, the AOX emissions are of no relevance since chlorine containing chemicals are not used in the bleaching of mechanical pulps.

Table 6.5
Rating of emission levels to water for mechanical pulp mills.

Emisssion parameter	Rating	Emission level, kg/ADt
TSS	Good (1)	< 3
	Average (2)	3 - 10
	Poor (3)	> 10
COD	Good (1)	< 15
	Average (2)	15 - 40
	Poor (3)	> 40
BOD	Good (1)	< 4
	Average(2)	4 - 10
	Poor (3)	> 10

Table 6.6
Rating for emission levels to the atmosphere for mechanical pulp mills.

Emission parameter	Rating	Emission levels, kg/ADt
TSP	Good (1)	< 1
	Average (2)	1 - 4
	Poor (3)	> 4
Sulphur (SO_2 and TRS)	Good (1)	< 1
	Average (2)	1 - 3
	Poor (3)	> 3
NO_x	Good (1)	< 1
	Average (2)	1 - 3
	Poor (3)	> 3

6.3 Emissions from Paper Production

The emissions considered for non-integrated paper production are the same as those considered for pulp production with the exception that emissions to the atmosphere are not taken into consideration and AOX emissions are of no relevance. Only non-integrated paper mills are considered in this connection since the integrated ones are reviewed together with their pulp mills. The systems in a paper mill that give rise to emissions to the atmosphere are essentially only the on-site energy generating plants. The energy production may be very diversified and may also include purchased energy. In the present study only process related emissions including emissions from burning of "internal" fuels like bark, sludge, paper residues, and so on, are considered. Thus, the atmospheric emissions from non-integrated paper mills are not considered.

The ratings for water emissions from non-integrated paper mills are summarised in Table 6.7.

Table 6.7
Rating of emission levels to water for paper mills.

Emisssion parameter	Rating	Emission levels, kg/ADt
TSS	Good (1)	< 1
	Average (2)	1 - 3
	Poor (3)	> 3
COD	Good (1)	< 1
	Average (2)	1 - 6
	Poor (3)	> 6
BOD	Good (1)	< 0.5
	Average (2)	0.5 - 3
	Poor (3)	> 3

6.4
System of Mill Classification

From the ratings in Section 6.2 and 6.3 the mills in the different regions of this study have been grouped into four categories (I - IV) depending on their emission levels. The grouping has simply been done by adding the ratings with respect to the various parameters (TSS, COD, AOX, TSP, S, NO_2) and by representing each group by a certain interval for this sum of added ratings. Since it is generally more expensive to reduce water emissions than air emissions and since only the air emissions related to processes are considered, the rating numbers for the water emissions are multiplied by 2 to give them a larger weight. The intervals of the added and weighted ratings for the different pulp mill categories can be seen in Table 6.8.

Table 6.8
System for classification of pulp mills.

Mill category	Environmental status of mill	Sum of ratings[a], chemical pulp mills	Sum of ratings[a], other pulp mills
I	Good	9 - 11	7 - 9
II	Good to average	12 - 17	10 - 13
III	Average to poor	18 - 23	14 - 17
IV	Poor	24 - 27	18 - 21

[a] Sum of rating ("1", "2" or "3", double weight for water emissions) with respect to (a) TSS, (b) COD or BOD, (c) AOX, when applicable, (d) TSP, (e) Sulphur (SO_2 or TRS, measured as S), and (f) NO_X.

The mills in category "I" have to have Good (1) emission levels for almost all the considered emission parameters. In category IV almost all emission levels are Poor (3).

For non-integrated paper mills where air emissions are not considered or of no relevance and where AOX emissions are not an issue, the different paper mill categories are determined by emissions of suspended solids and by COD/BOD only as shown in Table 6.9.

Table 6.9
System for classification of non-integrated paper mills.

Mill category	Environmental status of mill	Sum of ratings[a]
I	Good	4 - 5
II	Good to average	6 - 7
III	Average to poor	8 - 9
IV	Poor	10 - 12

[a] Sum of rating ("1", "2" or "3", double weight) with respect to (a) TSS, and (b) COD or BOD.

6.5
Classification of Mills in Different Regions

In Tables 6.10 - 6.15 the classifications of various kinds of mills according to the above categories are summarised for the different regions included in this study.

Table 6.10
Classification of mills in different regions in *Africa*.

Region	Production	Categories
South Africa	Chemical (wood)	II - III
	Semichemical	II - III
	Mechanical	II - III
	Non-wood	II - IV
	DIP/RCF	III
	Paper	I - III
Other Africa (Swaziland, Kenya, Egypt, Morocco)	Chemical (wood)	III - IV
	Semichemical	III - IV
	Mechanical	III
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	III - IV

Table 6.11
Classification of mills in different regions in Asia.

Region	Production	Categories
China	Chemical (wood)	I - IV
	Semichemical	n.a.
	Mechanical	III - IV
	Non-wood	III - IV
	DIP/RCF	III - IV
	Paper	III - IV
India	Chemical (wood)	III - IV
	Semichemical	III - IV
	Mechanical	III - IV
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	III-IV
Indonesia	Chemical (wood)	I - IV
	Semichemical	II - IV
	Mechanical	n.a.
	Non-wood	II -IV
	DIP/RCF	III - IV
	Paper	II-IV
Japan	Chemical (wood)	I - II
	Semichemical	I - II
	Mechanical	I - II
	Non-wood	I - III
	DIP/RCF	I - II
	Paper	I - II
Asia KTT (Korea, Taiwan, Turkey)	Chemical (wood)	II - IV
	Semichemical	II - IV
	Mechanical	II - IV
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	II - IV
Asia BMP (Bangladesh, Malaysia, Pakistan)	Chemical (wood)	II - IV
	Semichemical	III - IV
	Mechanical	III - IV
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	II - IV

Table 6.12
Classification of mills in different regions in Europe.

Region	Production	Categories
Central Europe (France, Germany, UK, Ireland, Belgium, the Netherlands, Austria, Switzerland, Denmark)	Chemical (wood)	I - III
	Semichemical	I - III
	Mechanical	I - III
	Non-wood	I - III
	DIP/RCF	I - III
	Paper	I - II
Eastern Europe (Baltic countries, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Bulgaria, Romania, Belarus)	Chemical (wood)	I - IV
	Semichemical	II - IV
	Mechanical	II - IV
	Non-wood	III - IV
	DIP/RCF	II - IV
	Paper	
Russia	Chemical (wood)	II - IV
	Semichemical	III - IV
	Mechanical	II - IV
	Non-wood	II - IV
	DIP/RCF	II - IV
	Paper	
Scandinavia (Finland, Sweden, Norway)	Chemical (wood)	I - II
	Semichemical	I - III
	Mechanical	I - III
	Non-wood	I - II
	DIP/RCF	I - II
	Paper	I - II
Southern Europe (Portugal, Spain, Italy, Greece)	Chemical (wood)	I - III
	Semichemical	II - III
	Mechanical	I - III
	Non-wood	II - IV
	DIP/RCF	II - III
	Paper	

Table 6.13
Classification of mills in different regions in Latin America.

Region	Production	Categories
Brazil	Chemical (wood)	I - III
	Semichemical	II - III
	Mechanical	II - III
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	II - IV
Other Latin America (Argentina, Chile, Colombia, Venezuela, Mexico)	Chemical (wood)	II - IV
	Semichemical	II - IV
	Mechanical	II - IV
	Non-wood	IV
	DIP/RCF	III - IV
	Paper	II - IV

Table 6.14
Classification of mills in different regions in North America.

Region	Production	Categories
Canada East (New Brunswick, New Foundland, Nova Scotia, Ontario, Quebec)	Chemical (wood)	I - II
	Semichemical	I - III
	Mechanical	I - II
	Non-wood	II - IV
	DIP/RCF	I -III
	Paper	I -III
Canada West (Alberta, British Columbia, Manitoba, Saskatchchewan)	Chemical (wood)	I - II
	Semichemical	I - II
	Mechanical	I - II
	Non-wood	II - IV
	DIP/RCF	I -III
	Paper	I -III
United States North (CT, DE, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, ND, NE, NH, NJ, NY, OH, PA, RI, SD, VT, WI, WV)	Chemical (wood)	I - II
	Semichemical	I - III
	Mechanical	I - II
	Non-wood	II - IV
	DIP/RCF	I -III
	Paper	I -III
United States South (AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA)	Chemical (wood)	I - II
	Semichemical	I - III
	Mechanical	I - III
	Non-wood	II - IV
	DIP/RCF	I -III
	Paper	I -III
United States West (AK, AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY)	Chemical (wood)	I - III
	Semichemical	I - III
	Mechanical	I - II
	Non-wood	n.a.
	DIP/RCF	I -III
	Paper	I -III

Table 6.15
Classification of mills in Oceania.

Region	Production	Categories
Oceania (Australia, New Zealand)	Chemical (wood)	I - III
	Semichemical	II - III
	Mechanical	I - III
	Non-wood	III
	DIP/RCF	II - III
	Paper	I - III

6.6 Actual Emission for Different Regions

First, Tables 6.16-6.21 give summaries of specific emissions as ranges for different main territories of the world. The data in these tables have been calculated in the following way. First, for each region (as defined by Tables 6.10-6.15 in this study) the average emissions for the mills in the particular region has been calculated. Then, for each main territory the interval (span) is represented by the averages for the regions. Thus, these specific numbers represent typical ranges for average mills within the main territories, but are not to be interpreted as maximum or minimum values for the mills in these regions.

Consider for example Table 6.16. In Latin America and in North America there are mills with AOX emissions below 0.3 kg/t, but there are also a number of mills with AOX levels above 3-4 kg/t, which implies that the average number for these territories becomes higher than 2 kg/t. These average numbers indicate that quite heavy investments would be required to reduce the average emission levels in these territories, while certain mills have done such investments already. In a smaller regions like Scandinavia, with a number of mills with low AOX emissions, the average number also becomes low (0.5 kg of AOX/t) indicating that most mills in this region have spent a lot of efforts on AOX reductions.

Table 6.16
Typical ranges of specific emissions from chemical pulp mills operating with wood as raw material.

Main	Specific emissions to water			Specific emissions to air		
territory	TSS, kg/t	COD, kg/t	AOX, kg/t	TSP, kg/t	SO_2, kg/t	NO_x, kg/t
Africa	8 - 13	45 - 90	1.1-3.0	8 - 15	4 - 7	2.5-3.5
Asia	5 - 24	70 -150	2.1-6.6	2 - 23	3 - 10	2.3-5.0
Europe	4 - 13	38 - 90	0.5-4.4	1 - 24	1 - 7	1.7-5.0
Latin America	5 - 12	50 - 76	1.1-4.1	9 - 21	3 - 4	2.9-3.4
North America	3 - 6	40 - 50	2.1-4.3	4 - 9	2	2.0-3.0
Oceania	4 - 6	40 - 50	2.1	9	2	2.5

Table 6.17
Typical ranges of specific emissions from semi-chemical pulp mills.

Main territory	Specific emissions to water		Specific emissions to air		
	TSS, kg/t	COD, kg/t	TSP, kg/t	SO_2, kg/t	NO_x, kg/t
Africa	5 - 12	34 - 120	9 - 17	4 - 14	2.1-3.9
Asia	4 - 20	49 - 140	3 - 21	4 - 20	1.8-4.8
Europe	3 - 9	32 - 64	1 - 20	1 - 11	1.5-4.7
Latin America	5 - 6	60 - 69	12 - 13	11 - 13	2.9-3.1
North America	2 - 5	20 - 45	5	3 - 5	1.9-2.1
Oceania	5	46	5	3	1.8

Table 6.18
Typical ranges of specific emissions from mechanical pulp mills.

Main territory	Specific emissions to water	
	TSS, kg/t	COD, kg/t
Africa	10 - 38	25 - 90
Asia	10 - 70	20 - 110
Europe	2 - 30	10 - 43
Latin America	12 - 37	30 - 52
North America	4 - 7	12 - 17
Oceania	7	18

Table 6.19
Typical ranges of specific emissions from non-wood pulp mills.

Main territory	Specific emissions to water			Specific emissions to air		
	TSS, kg/t	COD, kg/t	AOX, kg/t	TSP, kg/t	SO_2, kg/t	NO_x, kg/t
Africa	20-300	150-400	8	14 - 19	5 - 12	3.5-4.1
Asia	40-300	100-400	8	3 - 50	1 - 20	3.0-33
Europe	30-300	100-400	4 - 8	3 - 23	1 - 5	2.0-5.0
Latin America	50-300	100-400	8	15 - 20	17	3.1-3.5
North America	10-100	50-250	8	4 - 11	1 - 2	3.2
Oceania	100	100	8	10	1	3.1

Table 6.20
Typical ranges of specific emissions from deinked pulp mills.

Main territory	Specific emissions to water	
	TSS, kg/t	COD, kg/t
Africa	10 - 53	25 - 88
Asia	10 - 90	20 - 110
Europe	2 - 30	10 - 42
Latin America	13 - 42	30 - 57
North America	5 - 7	12 - 17
Oceania	12	23

Table 6.21
Typical ranges of specific emissions from paper mills.

Main territory	Specific emissions to water	
	TSS, kg/t	COD, kg/t
Africa	2 - 20	3 - 38
Asia	3 - 23	6 - 30
Europe	2 - 12	1 - 21
Latin America	6 - 18	4 - 25
North America	1 - 2	1 - 6
Oceania	2	3

Data of the kind shown in Tables 6.16-6.21 have been used to calculate overall emissions. Thus, in Tables 6.22- 6.27 are the actual emissions summarised for the different regions included in this study.

Table 6.22
Total actual emissions from pulp and paper mills in different regions in Africa.

Region	Emission parameter		Amount (t/a)
South Africa	Water:	TSS	26 800
		COD	116 000
		AOX	2 300
	Air:	TSP	25 700
		SO_2	7 500
		NO_x	5 100
Other Africa (Swaziland, Kenya, Egypt, Morocco)	Water:	TSS	82 900
		COD	119 000
		AOX	2 100
	Air:	TSP	7 000
		SO_2	3 800
		NO_x	1 700

Table 6.23
Total actual emissions from pulp and papermills in different regions in Asia.

Region	Emission parameter		Amount (t/a)
China	Water:	TSS	1 759 600
		COD	1 728 900
		AOX	28 300
	Air:	TSP	424 800
		SO_2	115 400
		NO_x	91 300
India	Water:	TSS	1 032 700
		COD	963 000
		AOX	18 100
	Air:	TSP	42 900
		SO_2	9 900
		NO_x	7 300
Indonesia	Water:	TSS	310 000
		COD	450 300
		AOX	16 700
	Air:	TSP	27 600
		SO_2	10 100
		NO_x	7 600
Japan	Water:	TSS	208 100
		COD	860 200
		AOX	35 800
	Air:		
		TSP	17 900
		SO_2	34 700
		NO_x	25 900
Asia KTT (Korea, Taiwan, Turkey)	Water:	TSS	285 800
		COD	489 900
		AOX	6 600
	Air:	TSP	22 300
		SO_2	8 700
		NO_x	5 300
Asia BMP (Bangladesh, Malaysia, Pakistan)	Water:	TSS	153 200
		COD	164 400
		AOX	3 400
	Air:	TSP	9 400
		SO_2	4 200
		NO_x	1 900

Table 6.24
Total actual emissions from pulp and paper mills in different regions in Europe.

Region	Emission Parameter		Amount (t/a)
Central Europe (France, Germany, UK, Ireland, Belgium, the Netherlands, Austria, Switzerland, Denmark)	Water:	TSS	203 800
		COD	696 600
		AOX	5 800
	Air:	TSP	21 300
		SO_2	14 600
		NO_x	8 400
Eastern Europe (Baltic countries, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Bulgaria, Romania, Belarus)	Water:	TSS	188 700
		COD	435 500
		AOX	11 800
	Air:	TSP	55 200
		SO_2	21 100
		NO_x	12 500
Russia	Water:	TSS	222 000
		COD	896 500
		AOX	25 600
	Air:	TSP	198 600
		SO_2	57 600
		NO_x	41 800
Scandinavia (Finland, Sweden, Norway)	Water:	TSS	99 600
		COD	732 100
		AOX	7 800
	Air:	TSP	14 500
		SO_2	15 600
		NO_x	27 100
Southern Europe (Portugal, Spain, Italy, Greece)	Water:	TSS	255 200
		COD	563 300
		AOX	5 400
	Air:	TSP	17 700
		SO_2	8 900
		NO_x	10 300

Table 6.25
Total actual emissions from pulp and paper mills in different regions in Latin America.

Region	Emission parameters		Amount (t/a)
Brazil	**Water:**	TSS	243 300
		COD	520 100
		AOX	7 000
	Air:	TSP	59 100
		SO_2	19 100
		NO_x	17 200
Other Latin America (Argentina, Chile, Colombia, Venezuela, Mexico)	**Water:**	TSS	463 700
		COD	695 500
		AOX	11 400
	Air:	TSP	72 200
		SO_2	15 200
		NO_x	12 200

Table 6.26
Total actual emissions from pulp and paper mills in different regions in North America.

Region	Emission parameters		Amount (t/a)
Canada East (New Brunswick, New Foundland, Nova Scotia, Ontario, Quebec)	**Water:**	TSS	104 500
		COD	435 900
		AOX	24 200
	Air:	TSP	48 600
		SO_2	14 000
		NO_x	12 700
Canada West (Alberta, British Columbia, Manitoba, Saskatchchewan)	**Water:**	TSS	77 300
		COD	382 300
		AOX	28 400
	Air:	TSP	69 700
		SO_2	14 800
		NO_x	23 200
United States North (CT, DE, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, ND, NE, NH, NJ, NY, OH, PA, RI, SD, VT, WI, WV)	**Water:**	TSS	141 000
		COD	597 700
		AOX	31 600
	Air:	TSP	40 000
		SO_2	18 600
		NO_x	18 900
United States South (AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA)	**Water:**	TSS	267 100
		COD	1696 500
		AOX	94 600
	Air:	TSP	225 000
		SO_2	74 100
		NO_x	94 000
United States West (AK, AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY)	**Water:**	TSS	48 400
		COD	399 500
		AOX	17 500
	Air:	TSP	48 000
		SO_2	13 400
		NO_x	14 000

Table 6.27
Total actual emissions from pulp and paper mills in Oceania.

Region	Emission parameter		Amount (t/a)
Oceania (Australia, New Zealand)	**Water:**	TSS	40 300
		COD	125 400
		AOX	2 800
	Air:	TSP	14 700
		SO_2	2 700
		NO_x	3 500

7 COSTS FOR EMISSION CONTROL

7.1 Mill Technologies Related to Regions and Mill Categories

7.1.1 General

The environmental standards and emission control for pulp and paper industries varies a lot over the world. To a large extent the variations are related to the size and age of the mills. Smaller and mostly older mills with specifically high emissions may still cause a limited impact simply because the total amount of emissions (specific emissions times production) is limited. This fact does not justify high specific emissions, especially not when considering stable compounds like many chlorinated organic compounds or atmospheric emissions that are conveyed over large distances and contribute to general environmental problems like sulphur dioxide and nitrogen oxides.

For bigger mills the environmental impact become more evident if the specific emissions are high. The technologies that are being used in order to reduce emissions from pulp and paper industries have been summarized in Chapter 4 and the emission levels for different kinds of mills have been reviewed in Chapter 6. In Chapter 6 the mills in different regions have also been categorized into different categories (I, II, III, or IV) with respect to emission levels.

The following describes the kind of technologies that may be considered as representative for each of these categories for the different kinds of production and the different regions that are considered in the present study.

7.1.2 Chemical Pulping of Wood

Emission control includes a number of internal measures and also external treatment methods as listed in Chapter 4. Emissions to water as well as to the atmosphere have to be considered. The environmental control in production of bleached pulps becomes much more extensive than for unbleached pulps.

The following emission control is being used in different parts of the world:

Africa *Internal control of water emissions*: In South Africa, oxygen delignification in all mills, ECF production by about 50 % of the mills, condensate stripping at larger mills. In other African mills conventional technology.
External control of water emissions: In South Africa, mechanical treatment at all mills, biological treatment at about 70 % of the mills. In other African mills, mechanical treatment at about 70 % of the mills, biological treatment at

only few mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at all mills in South Africa.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 20 % of other boilers or lime kilns. No scrubbers for sulphur dioxide control.

Asia

Internal control of water emissions: Oxygen delignification in about 50 % of the mills, ECF production by about 10 % of the mills, condensate stripping at larger mills. In other mills conventional technology.
External control of water emissions: Mechanical treatment at about 80 % of the mills, biological treatment at about 40 % of the mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at about 70 % of the mills.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 30 % of other boilers or lime kilns. Few scrubbers for sulphur dioxide control.

Europe

Internal control of water emissions: Oxygen delignification in about 90 % of the mills, ECF production at about 50 % of the mills, TCF production at about 10 % of the mills. Condensate stripping at all mills.
External control of water emissions: Mechanical treatment at all mills, biological treatment at about 70 % of the mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at about 80 % of the mills. Collection and incineration of weak TRS gases at about 10 % of the mills.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 60 % of other boilers or lime kilns. Scrubbers for sulphur dioxide control at about 70 % of the mills.

Latin America

Internal control of water emissions: Oxygen delignification in about 70 % of the mills, ECF production at about 10 % of the mills, TCF production at about 10 % of the mills. Condensate stripping at 80 % of the mills.
External control of water emissions: Mechanical treatment at about 90 % of the mills, biological treatment at about 70 % of the mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at about 70 % of the mills. No collection of weak TRS gases.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 30 % of other boilers or lime kilns. Few scrubbers for sulphur dioxide control.

North America

Internal control of water emissions: Oxygen delignification in about 50 % of the mills, ECF production at about 10 % of the mills. Condensate stripping at most mills.

External control of water emissions: Mechanical treatment at all mills, biological treatment at about 90 % of the mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at all mills. Collection and incineration of weak TRS gases at about 10 % of the mills.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 30 % of other boilers or lime kilns. Scrubbers for sulphur dioxide control at about 20 % of the mills.

Oceania

Internal control of water emissions: Oxygen delignification in about 50 % of the mills, ECF production by about 10 % of the mills, condensate stripping at larger mills. In other mills conventional technology.
External control of water emissions: Mechanical treatment at all mills, biological treatment at about 80 % of the mills.
Internal control of air emissions: Collection and incineration of highly concentrated TRS at all mills. Collection and incineration of weak TRS gases at about 15 % of the mills.
External control of air emissions: Electrostatic precipitators (ESP) at all recovery boilers and at about 30 % of other boilers or lime kilns. Scrubbers for sulphur dioxide control not installed.

7.1.3 Semichemical Pulping

The spent liquors from semichemical pulping are difficult to recover because of their low content of organic as well as of inorganic substances. Recovery becomes too expensive. The only attractive way to recover these liquors is when cross-recovery systems in combination with kraft mills can be practised.

The chemicals that are being used are usually not as expensive as for kraft pulping partly because of their lower amount and partly because of their composition. Sodium carbonate is mostly used as alkali source and sulphur dioxide is dissolved in sodium carbonate solutions for NSSC pulping. This means that separate recovery systems for semi-chemical mills are not feasible for economic reasons. Such extra operating as well as investment costs would make it impossible for semi-chemical pulping to compete with recycling of fibre, which is the main kind of competing raw material for this kind of products.

Thus, if cross recovery is not an option, the spent liquors have to be treated externally through mechanical treatment and biological treatment. The waste waters mainly contain suspended solids (TSS), organic compounds (mainly degraded lignin and carbohydrate residues from the wood) and some inorganic compounds. As an option, some mills use evaporation and incineration of the waste liquors.

The air emissions from the processes are of limited concern and mainly originate from the digester plant including blow tanks. Relief gases and blow gases (containing wood extractives and some sulphur) should preferably be condensed to recover the heat of vaporization as well as the turpentine. Sulphur may be recovered through scrubbing, which is not often practised.

The following emission control is being used in different parts of the world:

Africa Mechanical treatment in mills in South Africa and biological treatment in some of the South African mills. one South African mill uses membrane filtration.

In other parts of Africa no effluent treatment is in use.

Asia Mainly no emission control at all. Mechanical treatment in use at some mills

Europe Mechanical treatment in use at most of the mills. Cross recovery is being practised at some of the mills. Biological treatment only at a small number of these mills. Mills in Eastern Europe and Russia having larger emission levels (categories III and IV).

Latin America Limited emission control. Some mechanical treatment plants, no biological treatment at separate semi-chemical plants.

North America Cross-recovery being used at several sites. Mechanical treatment in use at essentially all units. Some mills with biological treatment plants as well.

Oceania Mechanical treatment in use at essentially all units.

7.1.4 Mechanical Pulping

The emissions from mechanical pulp mills mainly include suspended solids (TSS) and dissolved material (COD/BOD). TSS in effluents may be reduced through clarifiers and also through chemical (tertiary) treatment. Dissolved material is reduced by external biological treatment systems. Tertiary treatment (chemical precipitation) is practised at some mills.

Bark is being burnt at about 40 % of the mills. Flue gas cleaning (ESP) is then practised in more than 70 % of these cases. Very limited control of NO_x is being practised.

The following emission control is being used for effluents in different parts of the world:

Africa Mechanical treatment in all mills in South Africa, and in about 40 % of the other mills. Biological treatment in all mills in South Africa, but not elsewhere.

Asia Mechanical treatment at about 50 % of the mills, biological treatment at about 30 % of the mills.

Europe Mechanical treatment at essentially all mills. Biological treatment at about 70 % of the mills.

Latin America Mechanical treatment at about 50 % of the mills, biological treatment at about 10 % of the mills.

North America Mechanical treatment at essentially all mills. Biological treatment at about 80 % of the mills.

Oceania Mechanical treatment at essentially all mills. Biological treatment at about 80 % of the mills.

7.1.5 Non-Wood Pulping

Non-wood pulping normally result in more discharges than any other pulping method. This is due to the difficulties in recovering the chemicals and these difficulties are to a large extent caused by the high silicate content of the non-wood material making evaporation almost impossible. Emissions mainly have to be controlled by external methods.

Some mills making pulps from non-wood long-fibre sources, like cotton linters, used for high quality paper production normally have environmental problems of similar nature as for non-integrated paper mills. This is because the processing of these fibres is not very extensive.

The following emission control is being used in different parts of the world:

Africa Mechanical and some biological treatment in South Africa. Otherwise limited mechanical treatment, but no biological treatment.

Asia No biological treatment and very limited mechanical treatment.

Europe Mainly mechanical treatment. In some mills extensive biological treatment.

Latin America Mechanical treatment at about 25 % of the mills. No biological treatment.

North America Mechanical treatment at all mills. Biological treatment at about 50 % of the mills.

Oceania Mainly mechanical treatment.

7.1.6
Recycled Fibre Usage and Deinking

Environmental control in connection with recycled fibre processing and deinking includes internal measures like reject handling, white water clarification (through dissolved air flotation, DAF), sludge treatment (dewatering and incineration) and external treatment through clarification and biological treatment systems. Deposition of solid material sludge, waste and/or ash is of increasing importance.

The following emission control is being used in different parts of the world:

Africa Deinking mills mostly with flotation treatment of white waters. Sludge normally burnt or taken to landfill. External treatment with clarifiers in about 70 % of the mills. Biological treatment in about 50 % of the mills. For mills without deinking, biological treatment is not in use and mechanical treatment at about 40 % of the mills.

Asia Deinking mills mostly with flotation treatment of white waters. Sludge normally burnt or taken to landfill. External treatment with clarifiers in about 50 % of the mills. Biological treatment in about 20 % of the mills. For mills without deinking, biological treatment is not in use and mechanical treatment at about 50 % of the mills.

Europe Deinking mills with flotation treatment of white waters. Sludge normally burnt or taken to landfill. External treatment with clarifiers is standard. Biological treatment in majority of the mills. For mills without deinking, biological treatment is in use at about 40 % of the mills and mechanical treatment at most of the mills.

Latin America Deinking mills mostly with flotation treatment of white waters. Sludge normally taken to landfill. External treatment with clarifiers in about 40 % of the mills. Biological treatment not common. For mills without deinking, biological treatment is not in use and mechanical treatment at about 30 % of the mills.

North America Deinking mills with flotation treatment of white waters. Sludge dewatered and burnt but mostly taken to landfill. External treatment with clarifiers is standard. Biological treatment in majority of the mills. For mills without deinking,

biological treatment is in use at about 40 % of the mills and mechanical treatment at most of the mills.

Oceania Deinking mills with flotation treatment of white waters. Sludge normally burnt but mostly taken to landfill. External treatment with clarifiers is practised at more than 70 % of the mills. Biological treatment in about 50 % of the mills. For mills without deinking, biological treatment is in use at about 20 % of the mills and mechanical treatment at most of the mills.

7.1.7 Non-Integrated Paper Manufacturing

The emissions from paper mills mainly include suspended solids (TSS) and smaller amounts of dissolved material (COD/BOD). TSS is reduced by internal recovery of fibres as well as of inorganic material like coating substances. TSS in effluents may be reduced through clarifiers in some cases in combination with chemical (tertiary) treatment. Dissolved material can be reduced internally to some extent in connection with closure of white water systems, but external biological treatment systems are more common and more efficient.

The following emission control is being used in different parts of the world:

Africa Internal fibre recovery as well as external mechanical treatment at more than half of the mills in South Africa. Very limited internal as well as external treatment in other parts of Africa.

Asia Internal fibre recovery as well as external mechanical treatment at less than 30 % of the mills and mainly in Japan. Biological treatment at about 25 % of the mills in Japan, but hardly elsewhere.

Europe Internal fibre recovery practised widely. External mechanical treatment essentially standard. Biological treatment being practised at about 30 % of the mills.

Latin America Internal fibre recovery as well as external mechanical treatment only at major mills. Very limited biological treatment.

North America Internal fibre recovery practised widely. External mechanical treatment essentially standard. Biological treatment being practised at about 30 % of the mills.

Oceania Internal fibre recovery normally practised. External mechanical treatment essentially standard. Biological treatment being practised at some of the mills.

7.2 Technological Requirements for Reduced Emissions in Different Regions

In this study, the costs to improve the environmental control in all mills in the study regions up to Category I is estimated. This category represents "Good" environmental standards with respect to most of the six emission parameters suspended solids (TSS), COD/BOD, chlorinated compounds (AOX), solid particulates (TSP), sulphur dioxide, and nitrogen oxides. For a Category I mill "good" standards have to be met with respect to all parameters but one effluent parameter or two air emission parameters.

A Category I mill may be specified by the kind of production and the equipment to meet required levels ("Good" or possibly "Average") of the different emission parameters as specified in Sections 6.2 and 6.3. The following specifications with respect to emission control may be given for the different kinds of production:

Chemical pulp mills

For chemical pulp mills one has to distinguish between those with production of bleached pulps and those with unbleached pulps. For those with unbleached pulps the reductions of COD to the "Good" levels should include closed screening, proper washing, liquor spill handling, condensate stripping. For the air emission control, electrostatic precipitators (or other TSP reducing devices) are required on recovery boilers and on bark boilers. The lime kilns may require this as well. Alkaline scrubbers for control of sulphur dioxide are normally required on the recovery boilers.

For bleached pulp production a reduction of bleach plant effluents is required. To meet the "Good" emission levels, as defined in Chapter 6, some extended delignification in cooking is normally required in combination with oxygen delignification. (Sulphite pulping differs from kraft pulping in these respects.) For the bleaching chlorine cannot be used, but 100 % chlorine dioxide has to be applied. In addition to this, reinforced alkali extraction (with peroxide or oxygen) should preferably be applied. Ozone is normally not considered as necessary to meet the required emission levels.

External treatment including primary treatment (clarification) and biological treatment is considered necessary. For the biological treatment, activated sludge systems, or other systems with equal efficiency, should be chosen as they are considered superior to aerated lagoons. A sludge handling plant is required.

Semichemical pulp mills

From an environmental point of view, the semichemical pulp mills have a disadvantage since the liquors are difficult to recover. For mills without recovery system (including cross recovery) extensive external treatment is required.

External treatment including primary treatment and biological treatment becomes necessary. For the biological treatment, activated sludge systems, or other systems with equal efficiency, should be chosen. A sludge handling plant is required. Anaerobic treatments may be feasible because of the high concentration of COD (> 1000 g/m^3). Presence of sulphide, that may also be formed through reduction of other sulphur compounds, may disturb the anaerobic processes and make aerobic treatment necessary.

If bark and wood waste (internal fuels) are being burnt in bark boilers, electrostatic precipitators or other flue gas cleaning equipment are required.

Mechanical pulp mills

Fairly closed process systems are required as internal measures in order to reduce water volumes and increase concentrations of COD and BOD. External treatment including primary treatment and biological treatment is considered necessary. For the biological treatment, activated sludge systems, other methods with equal efficiency, should be chosen. A sludge handling plant is required.

Anaerobic treatments may be feasible if the COD concentration is high enough (> 1000 g/m^3). Presence of sulphide, that may also be formed through reduction of other sulphur compounds, may disturb the anaerobic processes and make aerobic treatment necessary.

Chemical precipitation (flocculation) may also be used for reduction of COD.

If bark and wood waste (internal fuels) are being burnt in bark boilers, electrostatic precipitators or other flue gas cleaning equipment are required.

Recycle fibre mills and deinking mills

Internal closure is required to reduce effluent volumes. This may be facilitated through extensive screening and cleaning of pulps and through dissolved air flotation systems for recycled white waters.

External treatment including clarifier basins (sedimentation or flotation) and biological treatment is considered necessary. For the biological treatment, activated sludge systems, or other methods with equal efficiency, should be chosen. A sludge handling plant is required.

Non-wood pulping

As described earlier, the environmental problems connected with non-wood pulping are often complicated to solve. The following systems should be considered.

For mills with bleaching (common in India) the technology indicated above under "Chemical pulp mills" must be applied.

Liquors may sometimes be evaporated and burnt. Scalings make the evaporation difficult.

Extensive external treatment including primary treatment and biological treatment is necessary. For the biological treatment, activated sludge systems, or other systems with similar efficiency, should be chosen. A sludge handling plant is required. Anaerobic treatment is often feasible because of the high concentration of COD (> 1000 g/m^3). Presence of sulphide in the effluent, that may also be formed through reduction of other sulphur compounds, may disturb the anaerobic process and make aerobic treatment necessary.

Paper mills

Internal closure and recirculation of white waters are required to reduce effluent volumes. This may be facilitated through fibre recovery systems like disc filters and dissolved air flotation systems. Clarifiers for recovery of coating material may also be useful. Flocculation with chemicals may be required.

External treatment with primary treatment (sedimentation or flotation) is considered as required. Often, but not always, biological treatment is also necessary. A sludge handling plant is required.

7.3
Costs (Capital and Annual) for Reduced Emissions (by Regions)

The total costs required to transfer all mills in the regions in this study to Category I mills has been estimated. These costs refer to additional costs for the industry compared to the present situation and include investment costs as well as operational or annual costs. The costs for those mills that already have made investments in different respects in environmental control are not included in the compilations.

Because of the large variation of mill sizes in the world, it is almost impossible to estimate the costs for the environmental control in a general, accurate and correct way. A small mill could never implement the environmental control as required to become a "Category I" mill. In countries with many small mills, the only way to establish "Category I" mills would be to replace many small mills by one or a few much larger mills based on modern technology. In such cases, the true costs for environmental control may be disputable. Thus, these inconsistencies should be borne in mind when considering the environmental control costs in the tables below.

In Tables 7.1 - 7.6 the overall environmental costs to transfer all various kinds of mills to "Category I" mills are summarised for the different regions included in this study.

Table 7.1
Additional environmental costs for mills in different regions in Africa.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
South Africa	Investment costs Annual costs	285 103
Other Africa (Swaziland, Kenya, Egypt, Morocco)	Investment costs Annual costs	180 62

Table 7.2
Additional environmental costs for mills in different regions in Asia.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
China	Investment costs Annual costs	1 895[a] 621[a]
India	Investment costs Annual costs	1316 412
Indonesia	Investment costs Annual costs	456 180
Japan	Investment costs Annual costs	1 800 684
Asia KTT (Korea, Taiwan, Turkey)	Investment costs Annual costs	696 257
Asia BMP (Bangladesh, Malaysia, Pakistan)	Investment costs Annual costs	271 87

[a] In China only the mills with a production above 1000 t/a have been taken into consideration when evaluating the costs.

When evaluating the additional environmental costs in China, only the mills with a production above 1000 t/a have been taken into consideration. This means that there are only about 250 pulp mills and 300 paper mills included in the costs and there are approximately eight thousand pulp mills and ten thousand paper mills in China. The unconsidered mills are mostly very small and produce non-wood pulp or paper. It would not be economically reasonable to apply the environmental measures on these mills that have been taken into consideration for the other mills included in this study.

Table 7.3
Additional environmental costs for mills in different regions in Europe.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
Central Europe (France, Germany, UK, Ireland, Belgium, the Netherlands, Austria, Switzerland, Denmark)	Investment costs Annual costs	1 370 510
Eastern Europe (Baltic countries, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Bulgaria, Romania, Belarus)	Investment costs Annual costs	674 284
Russia	Investment costs Annual costs	1 218 479
Scandinavia (Finland, Sweden, Norway)	Investment costs Annual costs	590 222
Southern Europe (Portugal, Spain, Italy, Greece)	Investment costs Annual costs	637 269

Table 7.4
Additional environmental costs for mills in different regions in Latin America.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
Brazil	Investment costs Annual costs	769 348
Other Latin America (Argentina, Chile, Colombia, Venezuela, Mexico)	Investment costs Annual costs	754 297

Table 7.5
Additional environmental costs for mills in different regions in North America.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
Canada East (New Brunswick, New Foundland, Nova Scotia, Ontario, Quebec)	Investment costs Annual costs	959 449
Canada West (Alberta, British Columbia, Manitoba, Saskatchewan)	Investment costs Annual costs	907 470
United States North (CT, DE, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, ND, NE, NH, NJ, NY, OH, PA, RI, SD, VT, WI, WV)	Investment costs Annual costs	1 350 606
United States South (AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA)	Investment costs Annual costs	3 055 1 577
United States West (AK, AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY)	Investment costs Annual costs	681 332

Table 7.6
Additional environmental costs for mills in Oceania.

Region	Costs for environmental control	Estimated additional costs, 1 000 000 USD
Oceania (Australia, New Zealand)	Investment costs Annual costs	159 73

APPENDIX I

PULP AND PAPER CAPACITY BY PROCESSES AND BY REGIONS

Country	Number of mills	Chemical (wood) t/a	Semichemical t/a	Mechanical t/a	NonWood t/a	DIP t/a	RCF t/a	Total Pulproduction t/a
South Africa	12	1 690 000	325 000	410 000	50 000	140 000	375 000	2 990 000
Egypt	5		14 000		90 000	10 000	206 500	320 500
Kenya	3	60 000		30 000	8 000	20 000	30 000	148 000
Morocco	2	125 000				15 000	33 250	173 250
Swaziland	1	180 000					25 000	205 000
Other Africa Total	11	365 000	14 000	30 000	98 000	45 000	294 750	846 750
Africa Total	**23**	**2 055 000**	**339 000**	**440 000**	**148 000**	**185 000**	**669 750**	**3 836 750**
China	8 000	1 099 000		369 000	12 400 000	150 000	5 848 500	19 866 500
India	100	419 000	90 000	150 000	1 535 000	59 000	726 250	2 979 250
Indonesia	25	2 360 000	88 000		351 000	365 000	793 750	3 957 750
Japan	96	10 675 000	725 000	2 706 000	21 000	3 053 000	11 318 750	28 498 750
Korea, Republic of	13	467 000		275 000		1 170 000	3 241 500	5 153 500
Taiwan	21	462 000	65 000	35 000	126 000	505 000	3 649 750	4 842 750
Turkey	12	305 000	65 000	225 000	82 000	35 000	483 250	1 195 250
Asia KTT Total	46	1 254 000	130 000	535 000	208 000	1 710 000	7 374 500	11 211 500
Bangladesh	7	15 000	15 000	40 000	54 000		47 000	171 000
Malaysia	4	125 000				28 000	365 000	518 000
Pakistan	18	45 000	10 000		143 000	5 000	74 750	277 750
Asia BMP Total	29	185 000	25 000	40 000	197 000	33 000	486 750	966 750
Asia Total	**8 296**	**16 992 000**	**1 068 000**	**3 800 000**	**14 712 000**	**5 370 000**	**26 548 500**	**67 480 500**
Austria	15	1 140 000	45 000	478 000	3 000	520 000	755 000	2 941 000
Belgium	5	220 000		375 000		100 000	216 000	911 000
Denmark	3		75 000		1 000	45 000	295 750	416 750
France	40	1 995 000	150 000	1 219 000	23 000	775 000	3 106 250	7 268 250

Pulp capacity

Country	Number of mills	Chemical (wood)	Semichemical	Mechanical	NonWood	DIP	RCF	Total Pulproduction
		t/a	t/a	t/a	t/a	t/a	t/a	t/a
Germany	59	745 000	85 000	2 005 000	49 000	2 970 000	4 447 500	10 301 500
Netherlands	7			205 000		450 000	1 535 500	2 190 500
Switzerland	7	145 000		185 000		300 000	423 000	1 053 000
United Kingdom	27		120 000	475 000	26 000	1 245 000	2 111 750	3 977 750
Central Europe Total	163	4 245 000	475 000	4 942 000	102 000	6 405 000	12 890 750	29 059 750
Belarus	4			17 000	5 000		2 000	24 000
Bulgaria	9	210 000	35 000	40 000		20 000	71 000	376 000
Czech Republic	7	605 000		83 000	2 000	30 000	212 500	932 500
Hungary	3		75 000	30 000	30 000		186 000	321 000
Latvia	1			2 000			2 000	4 000
Lithuania	2			17 000			20 000	37 000
Poland	13	430 000	230 000	193 000	20 000	35 000	448 250	1 356 250
Romania	14	785 000	85 000	115 000	121 000	75 000	33 500	1 214 500
Slovakia	5	290 000	80 000	5 000		50 000	102 500	527 500
Slovenia	5	160 000		70 000		100 000	15 000	345 000
Eastern Europe Total	63	2 480 000	505 000	572 000	178 000	310 000	1 092 750	5 137 750
Russia	49	7 645 000	735 000	2 470 000	17 000	15 000	831 250	11 713 250
Finland	44	6 175 000	610 000	4 905 000		420 000	39 000	12 149 000
Norway	18	800 000	85 000	1 820 000		35 000	182 250	2 922 250
Sweden	48	7 650 000	430 000	3 403 000	1 000	715 000	514 250	12 713 250
Scandinavia Total	110	14 625 000	1 125 000	10 128 000	1 000	1 170 000	735 500	27 784 500
Greece	4			70 000	30 000	30 000	208 500	338 500
Italy	22	45 000	30 000	559 000	53 000	200 000	3 075 000	3 962 000
Portugal	9	1 660 000				35 000	208 250	1 903 250
Spain	28	1 485 000	120 000	210 000	30 000	200 000	2 227 000	4 272 000
Southern Europe Total	63	3 190 000	150 000	839 000	113 000	465 000	5 718 750	10 475 750
Europe Total	**448**	**32 185 000**	**2 990 000**	**18 951 000**	**411 000**	**8 365 000**	**21 269 000**	**84 171 000**

Pulp capacity

Country	Number of mills	Chemical (wood) t/a	Semichemical t/a	Mechanical t/a	NonWood t/a	DIP t/a	RCF t/a	Total Pulproduction t/a
Brazil	115	5 520 000	113 000	776 000	245 000	105 000	1 958 750	**8 717 750**
Argentina	17	535 000	121 000	110 000	67 000	25 000	444 750	**1 302 750**
Chile	12	1 775 000		220 000		65 000	82 750	**2 162 750**
Colombia	10	145 000	39 000	50 000	187 000	95 000	243 250	**759 250**
Mexico	14	445 000		150 000	150 000	215 000	2 415 250	**3 375 250**
Venezuela	6	30 000	60 000	40 000	85 000	120 000	276 000	**611 000**
Other Latin America Total	59	2 930 000	220 000	570 000	489 000	540 000	3 462 000	**8 211 000**
Latin America Total	**174**	**8 450 000**	**333 000**	**1 346 000**	**734 000**	**645 000**	**5 420 750**	**16 928 750**
Canada E	90	5630000	730000	8820000	4000	1730000		**16 914 000**
Canada W	37	7710000	40000	3660000	7000	210000		**11 627 000**
Canada Total	**127**	13 340 000	770 000	12 480 000	11 000	1 940 000	1 202 000	**28 743 000**
United States N	**127**	6597000	1345000	1900000	74000	3130000		**13 046 000**
United States S	117	35630000	1920000	3350000	275000	2575000		**43 750 000**
United States W	36	6675000	275000	1410000		1205000		**9 565 000**
USA Total	280	48 902 000	3 540 000	6 660 000	349 000	6 910 000	18 963 500	**85 324 500**
North America Total	**407**	**62 242 000**	**4 310 000**	**19 140 000**	**360 000**	**8 850 000**	**20 165 500**	**115 067 500**
Australia	13	550 000	180 000	540 000	15 000	205 000	843 750	**2 333 750**
New Zealand	6	700 000		825 000			53 000	**1 578 000**
Oceania Total	19	**1 250 000**	**180 000**	**1 365 000**	**15 000**	**205 000**	**896 750**	**3 911 750**
GRAND TOTAL	**9 367**	**122 174 000**	**9 210 000**	**45 042 000**	**16 380 000**	**23 620 000**	**74 970 250**	**291 396 250**

Pulp capacity

Country	Number of mills	Number of PMs	Newsprint t/a	Woodfree uncoated t/a	Woodfree coated t/a	Mechanical uncoated t/a	Mechanical coated t/a	Wrapping/ Packaging t/a
South Africa	22	46	340 000	325 000	80 000	130 000		114 000
Egypt	18	42		114 100		3 000		53 200
Kenya	6	11	15 000	58 000				41 500
Morocco	9	19		27 500				25 200
Swaziland	1	5						23 000
Other Africa Total	34	77	15 000	199 600		3 000		142 900
Africa Total	**56**	**123**	**355 000**	**524 600**	**80 000**	**133 000**		**256 900**
China	10 000	>>1393	660 000	4 716 000	189 000	524 000	21 000	1 000 000
India	229	350	330 500	1 633 000	99 500	5 000		931 700
Indonesia	61	130	310 000	887 500	223 000	15 800		284 600
Japan	213	715	4 130 000	4 502 300	3 113 000	1 338 000	1 777 000	1 490 100
Korea, Republic of	70	148	947 000	926 300	769 000	421 000		391 300
Taiwan	91	184	110 000	517 200	318 000	5 000		174 000
Turkey	51	67	202 500	112 300	25 000	25 000		137 000
Asia KTT Total	212	399	1 259 500	1 555 800	1 112 000	451 000		702 300
Bangladesh	9	14	40 000	62 000		5 000		10 500
Malaysia	18	34	4 500	178 500	40 000			22 200
Pakistan	30	36		63 400	2 000			53 000
Asia BMP Total	57	84	44 500	303 900	42 000	5 000		85 700
Asia Total	**10 772**	**3 071**	**6 734 500**	**13 578 500**	**4 778 500**	**2 338 800**	**1 798 000**	**4 494 400**
Austria	28	55	505 000	435 000	745 000	375 000	200 000	233 000
Belgium	16	31	115 000	92 000	290 000	180 000	405 000	40 000
Denmark	4	8		116 500	20 000			
France	144	234	950 000	1 545 800	857 000	110 000	879 000	590 700
Germany	222	407	1 803 000	1 984 800	1 996 000	947 500	1 827 000	758 700

Country	Cartonboard t/a	Linerboard t/a	Fluting t/a	Tissue t/a	Other Paper/Board t/a	Total production of Paper t/a
South Africa	159 000	693 000	230 000	180 600	9 000	**2 260 600**
Egypt	102 100	43 200	10 600	36 000	12 500	**374 700**
Kenya	24 000	10 300	1 200	8 600		**158 600**
Morocco	41 000	26 600	31 800	8 000		**159 900**
Swaziland		5 000	15 000	24 000		**67 000**
Other Africa Total	167 100	85 100	58 400	76 600	12 500	**760 200**
Africa Total	**326 100**	**778 100**	**288 400**	**257 200**	**21 500**	**3 020 800**
China	1 700 000	2 323 000	1 943 000	965 000	5 445 000	**19 486 000**
India	384 200	9 000	14 400	22 500	63 100	**3 492 900**
Indonesia	815 000	645 700	730 800	85 300	36 900	**4 014 600**
Japan	2 978 600	4 455 700	3 651 600	1 015 500	1 582 100	**30 033 900**
Korea, Republic of	1 429 500	1 042 500	303 500	327 600	55 500	**6 613 200**
Taiwan	1 081 500	1 417 000	927 000	248 100	25 600	**4 823 400**
Turkey	245 000	314 700	362 700	51 000	6 800	**1 482 000**
Asia KTT Total	2 756 000	2 774 200	1 593 200	626 700	87 900	**12 918 600**
Bangladesh	23 000	4 000	3 500		6 500	**154 500**
Malaysia	10 000	193 000	192 000	84 000		**724 200**
Pakistan	105 000	62 000	68 100	14 000	2 500	**370 000**
Asia BMP Total	138 000	259 000	263 600	98 000	9 000	**1 248 700**
Asia Total	**8 771 800**	**10 466 600**	**8 196 600**	**2 813 000**	**7 224 000**	**71 194 700**
Austria	398 000	448 000	228 000	117 300	55 500	**3 737 800**
Belgium	71 000	30 000	125 000	148 000	4 500	**1 500 500**
Denmark	30 000	105 000	105 000		20 000	**396 500**
France	529 100	1 619 000	1 137 000	832 000	312 600	**9 162 200**
Germany	2 032 700	1 575 500	1 527 000	1 013 900	908 700	**16 374 800**

Paper capacity

Country	Number of mills	Number of PMs	Newsprint t/a	Woodfree uncoated t/a	Woodfree coated t/a	Mechanical uncoated t/a	Mechanical coated t/a	Wrapping/ Packaging t/a
Ireland	1	1						
Netherlands	28	60	365 000	467 600	515 000	50 000		79 000
Switzerland	26	44	280 000	178 400	188 000	62 000	90 000	55 000
United Kingdom	95	192	1 045 000	1 127 500	498 000	37 000	230 000	211 000
Central Europe Total	564	1 032	5 063 000	5 945 600	5 109 000	1 761 500	3 631 000	1 967 400
Belarus	9	39		81 500		6 000		111 300
Bulgaria	11	22		41 000	5 000	30 000		96 000
Czech Republic	28	74	100 000	159 000	34 000	60 000		231 900
Estonia	2	3		10 000				42 000
Hungary	9	23		93 200		32 000		103 300
Latvia	5	13		17 000	7 000	4 200	1 300	10 000
Lithuania	4	18		59 500				21 000
Poland	44	114	141 000	469 500		158 800		380 100
Romania	18	69	100 000	117 300	22 000	84 200		234 900
Slovakia	8	18		210 800	22 000	10 000	9 000	47 900
Slovenia	9	26	50 000	98 500	105 000			13 000
Eastern Europe Total	147	419	391 000	1 357 300	195 000	385 200	10 300	1 291 400
Russia	90	293	1 567 000	1 055 300	26 000	725 400		1 200 800
Finland	47	102	1 565 000	1 411 500	1 010 000	1 760 000	2 535 000	635 000
Norway	17	40	1 101 000	48 000		607 000		112 700
Sweden	52	117	2 355 000	918 500	570 000	540 000	295 000	1 118 000
Scandinavia Total	116	259	5 021 000	2 378 000	1 580 000	2 907 000	2 830 000	1 865 700
Greece	19	38	15 000	61 000	16 000	25 000	20 000	41 000
Italy	225	359	105 000	638 400	1 048 000	357 500	1 034 000	836 800
Portugal	41	55		524 600	30 000			130 700
San Marino	1	1						
Spain	125	189	180 000	459 000	383 000	71 400		434 900
Southern Europe Total	411	642	300 000	1 683 000	1 477 000	453 900	1 054 000	1 443 400
Europe Total	**1 328**	**2 645**	**12 342 000**	**12 419 200**	**8 387 000**	**6 233 000**	**7 525 300**	**7 768 700**

Paper capacity

Country	Cartonboard t/a	Linerboard t/a	Fluting t/a	Tissue t/a	Other Paper/Board t/a	Total production of Paper t/a
Ireland		17 000	18 000			35 000
Netherlands	708 000	305 000	320 000	168 000	57 700	3 035 300
Switzerland	182 000	173 000	170 000	131 000	49 000	1 556 400
United Kingdom	607 800	822 000	886 000	668 000	449 200	6 581 500
Central Europe Total	4 556 600	5 094 500	4 516 000	2 878 200	1 857 200	42 380 000
Belarus	27 500	100 000	52 600	1 000	25 000	404 900
Bulgaria	82 000	130 000	75 000	18 000	13 000	500 000
Czech Republic	87 400	109 000	58 000	19 800	42 900	902 000
Estonia						52 000
Hungary	63 000	35 000	95 000	31 100	2 700	455 300
Latvia	6 000				5 000	50 500
Lithuania	15 000			5 000	23 500	124 000
Poland	235 900	238 000	168 500	129 100	76 000	1 996 900
Romania	173 600	118 000	96 000	42 100	28 200	1 014 300
Slovakia	46 000	39 000	140 000	118 000	63 000	703 700
Slovenia	107 500	16 000	3 000	90 500	15 200	498 700
Eastern Europe Total	853 900	785 000	888 100	452 600	292 500	6 702 300
Russia	965 700	1 493 000	863 500	147 300	652 700	8 696 700
Finland	1 454 000	350 000	465 000	171 000	462 000	11 818 500
Norway	72 000	268 000	87 000	33 000	48 000	2 376 700
Sweden	1 509 000	1 670 000	345 000	299 000	131 000	9 750 500
Scandinavia Total	3 035 000	2 288 000	897 000	503 000	641 000	23 945 700
Greece	94 500	34 500	38 500	164 500	6 000	516 000
Italy	1 217 300	850 500	966 800	1 184 700	199 200	6 438 200
Portugal	68 000	303 000	55 000	61 500	19 200	1 210 000
San Marino			25 000			25 000
Spain	521 600	855 000	656 500	316 500	64 500	3 942 400
Southern Europe Total	1 899 400	2 043 000	1 741 800	1 747 200	288 900	14 131 600
Europe Total	**11 310 600**	**11 703 500**	**8 706 400**	**5 728 300**	**3 732 300**	**95 856 300**

Paper capacity

Country	Number of mills	Number of PMs	Newsprint t/a	Woodfree uncoated t/a	Woodfree coated t/a	Mechanical uncoated t/a	Mechanical coated t/a	Wrapping/ Packaging t/a
Brazil	218	455	241 000	1 835 900	160 000	161 500	140 000	1 099 000
Argentina	93	129	140 000	199 500	29 000	49 200	30 000	161 300
Chile	14	28	257 000	38 000	13 500	46 000	7 500	58 200
Colombia	18	39	30 000	206 700	27 600	45 000		81 000
Mexico	65	131	150 000	425 100	61 000			445 900
Venezuela	16	40		131 000				95 700
Other Latin America Total	206	367	577 000	999 300	131 100	140 200	37 500	842 100
Latin America Total	**424**	**822**	**818 000**	**2 835 200**	**291 100**	**301 700**	**177 500**	**1 941 100**
Canada E	102	206	7 471 000	1 211 000	138 000	2 310 000	670 000	246 000
Canada W	18	35	2 175 000	285 000	70 000	339 000		305 000
Canada Total	120	241	9 646 000	1 496 000	208 000	2 649 000	670 000	551 000
United States N	336	725	420 000	4 893 800	4 406 300	1 334 000	3 072 000	1 669 900
United States S	152	335	3 800 000	6 232 000	455 000	200 000	955 000	2 598 500
United States W	67	142	2 101 000	1 233 000	245 000	230 000		885 000
United States Total	555	1 202	6 321 000	12 358 800	5 106 300	1 764 000	4 027 000	5 153 400
North America Total	**675**	**1 443**	**15 967 000**	**13 854 800**	**5 314 300**	**4 413 000**	**4 697 000**	**5 704 400**
Australia	20	37	405 000	230 000	40 000	135 000	15 000	124 000
New Zealand	6	12	405 000	18 000		15 000		72 000
Oceania Total	**26**	**49**	**810 000**	**248 000**	**40 000**	**150 000**	**15 000**	**196 000**
Grand Total	13 281	8 153	37 026 500	43 460 300	18 890 900	13 569 500	14 212 800	20 361 500

Paper capacity

Country	Cartonboard t/a	Linerboard t/a	Fluting t/a	Tissue t/a	Other Paper/Board t/a	Total production of Paper t/a
Brazil	622 500	1 029 300	620 400	575 800	132 600	6 616 000
Argentina	173 800	229 200	180 500	115 500	12 900	1 320 900
Chile	54 000	60 000	40 000	106 500	3 600	684 300
Colombia	41 900	93 000	80 500	109 900	8 500	723 100
Mexico	439 500	901 000	484 700	613 500	31 500	3 552 200
Venezuela	152 500	192 000	107 000	225 300	3 200	906 700
Other Latin America Total	861 700	1 475 200	892 700	1 170 700	59 700	7 187 200
Latin America Total	**1 484 200**	**2 504 500**	**1 513 100**	**1 746 500**	**192 300**	**13 805 200**
Canada E	911 000	1 190 000	770 000	590 500	403 000	15 910 500
Canada W	49 000	535 000	60 000	90 000	66 000	3 974 000
Canada Total	960 000	1 725 000	830 000	680 500	469 000	19 884 500
United States N	3 357 000	1 086 000	3 554 500	2 821 400	1 949 400	28 564 300
United States S	7 664 500	16 628 000	3 087 000	2 018 000	1 215 500	44 853 500
United States W	1 007 000	3 675 500	1 038 500	984 000	215 600	11 614 600
United States Total	12 028 500	21 389 500	7 680 000	5 823 400	3 380 500	85 032 400
North America Total	**12 988 500**	**23 114 500**	**8 510 000**	**6 503 900**	**3 849 500**	**104 916 900**
Australia	175 000	613 000	283 000	216 000	115 400	2 351 400
New Zealand	55 000	210 000	37 000	45 000	31 000	888 000
Oceania Total	**230 000**	**823 000**	**320 000**	**261 000**	**146 400**	**3 239 400**
Grand Total	**35 111 200**	**49 390 200**	**27 534 500**	**17 309 900**	**16 166 000**	**292 033 300**

Paper capacity