An Investigation into the Water Management and Effluent Treatment in the Processing of

(i) pulp and paper (ii) Metals (iii) fermentation products and (iv) Pharmaceutical products.

By the

Pollution Research Group

Department of Chemical Engineering

University of Natal

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Report to the

WATER RESEARCH COMMISSION

for the project

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PART I

Investigations into water management and effluent treatment in the processing of pulp and paper.

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ABBREVIATIONS

RSA - Republic of South Africa
USA - United States of America
NSSC - Neutral Sulphite Semi-Chemical
SSL - Spent sulphite liquor
GAC - Granular activated carbon
CTC - Central Timber Co-Operation
ASB - Aerated stabilization basin
BOD - Bio-chemical oxygen demand
PCB - Polychlorinated bi-phenyl
AS - Activated sludge
DAF - Dissolved air flotation
CSIR - Council for Scientific and Industrial Research
DP - Degree of polymerisation
TOC - Total organic carbon
DO - Dissolved oxygen
TDS - Total dissolved solids
TSS - Total suspended solids
SS - Settleable solids
COD - Chemical oxygen demand
LC - Lethial concentration

BLEACHING STAGES :

A - Acid treatment or dechlorination
C - Chlorination
D - Chlorine dioxide
E - Alkaline extraction
H - Hypochlorite
HS - Hydrosulphite
O - Oxygen
P - Peroxide
PA - Peracetic acid
W - Water soak
/ - Successive chemical addition without a washing stage

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FIGURES

The pulp and paper industry is a large user of water and discharges effluent which gives high inorganic and organic pollution loads. It is a primary candidate for the implementation of water recycling and wastewater reclamation and reuse.

This industry in the Republic of South Africa (RSA) consists of seven integrated pulp mills which use Kraft, sulphite, soda, soda/oxygen and neutral sulphite semi-chemical (NSSC) pulping methods. In addition there are over ten non-integrated mills producing board, newsprint, liner, packaging and tissue products.

1.1 WATER USAGE

The majority of the RSA pulp and paper mills have low specific water usages when compared to international industry standards. These ranges from 5 to 107 kl/ton of product in the integrated sector and 3 to 35 kl/ton of product in the non-integrated sector.

Nearly all mills have introduced water recycle systems of various types, for example :-

(i) recycling of white water on papermachines,
(ii) external treatment of papermachine effluent,
(iii) treatment and recycling of certain pulp effluents, particularly Kraft and soda/oxygen type pulping.

Several mills use reclaimed secondary sewage water as a source of process water and others are investigating this source because of the potential economic benefits

1.2 EFFLUENT TREATMENT

The Kraft and soda/oxygen pulp mills treat their pulping effluents by evaporation/chemical recovery systems to permit reuse of the pulping chemicals and provide heat energy for the evaporation stage. Neutral sulphite semi-chemical (NSCC) pulp effluents are also evaporated at some mills. Integrated pulp/paper mills mainly discharge their effluents to the environment or via irrigation. The non-integrated paper mills mainly discharge to sewer.

The production loads vary from 0,8 to 11 kg SS/ton ; 4,3 to 32 kg COD/ton and 28 to 112 kg TDS/ton of product. In the integrated sector, one mill carries out biological treatment prior to discharge and as a result the COD load is relatively low at 1,1 kg SS/ton and 4,3 kg COD/ton of product. A mill in the non-integrated sector having an extensive external effluent treatment/recycle system achieves a discharge of 0,8 kg SS/ton but a high TDS load of 41 kg TDS/ton due to the TDS build-up in the recycle loop.

Most mills practice extensive recovery of suspended solids, which is mainly fibre, and reuse it back in product. This is done internally by the use of save-alls on papermachines and externally by treatment using clarification, centrifugation and filtration.

Several mills practice reasonably extensive effluent treatment and reuse of effluent. Additionally at least two mills used their treated effluent for irrigation purposes.

1.3 RECOMMENDATIONS

Our preliminary survey has indicated considerable potential for further water savings within the industry and improved effluent treatment. Integrated mills have two main pollution sources : those from bleaching and paper making. Non-integrated mills mainly have papermachine effluent.

We recommended that consideration should be given to undertaking the following research an development projects :-

1.3.1 Treatment of Papermachine Effluent to Increase Water Reuse

Further closure of papermachines requires more exacting treatment of the effluent to remove the fine suspended solids not removed by conventional treatments. Typically up to 250 mg/l SS after treatment is common-place and on reuse this causes serious blockages to showers. The investigation of treatment methods such as centrifugation and microfiltration should be made for this duty.

Increased water reuse on a papermachine has the effect of increasing substantially the TDS and soluble organic contents of the recycle water. This causes corrosion problems and the required bleed stream may be difficult to dispose. Treatment methods for this bleed stream need investigation.

1.3.2 Treatment of Bleach Effluent

Research into the treatment of bleach effluent is recommended. Preliminary investigations on suitable treatment methods have been started by one company and these should be supported. Attention should be paid to by-product recovery in the treatment of bleach effluents, particularly the feasibility and economics of chloride treatment and recovery.

1.3.3 Treatment of Mill Effluent

Effluent from pulp and paper mills is reported to be suitable for land irrigation. The maximum treatment requirements, for different types of mills, prior to this disposal method should be investigated. Reported problems include the replacement in the soil of calcium and magnesium with sodium ; high temperature effluents ; reasonably high cost of irrigation. Public health considerations and the role of public agencies require careful examination in this type of investigation.

The above-mentioned projects are the most urgent research and development related projects identified by this preliminary survey. In addition, there are numerous in-house water and effluent management projects as outlined in Section 7 of this report which requires attention by each individual mill.

2.1 OBJECTIVES

Intensive research into water and effluent management has been instituted by the Water Research Commission. These include the fruit and vegetable, fish, meat, hide and textile industries.

This report covers a preliminary survey of the pulp and paper industry in RSA to determine their water usage, effluent production and scope for water reuse and by-product recovery. The project was carried out by means of a confidential questionnaire survey, factory visits and a detailed literature review. The objectives of the study are to :

(i) establish the current state of the art of water and effluent management in the pulp and paper industry of RSA.
(ii) assess the potential for water savings, pollution load reduction and the possible reuse of water.
(iii) compile a list of selected references to allow easy access of data presented in this report.
(iv) identify the research and development needs of the industry in water and effluent management.

2.2 BACKGROUND

Water reuse is becoming an increasing attractive solution to industry. New, stricter pollution control standards require large expenditures to clean industrial waste streams. In some cases, only a small additional cost would bring these same streams to reusable water quality. In addition, the cost of producing fresh water from local supplies is increasing rapidly in South Africa and alternative water supplies for industry are needed.

Since many industrial waste streams are spent wastewaters it is often possible to recover by-products of value from there washes. All these factors combine to make water reuse an increasingly attractive alternative.

The steps involved in water and effluent management at factory level are well documented and the strategy involves the stages of :

(i) compiling an inventory of waste production item by item and listing positive means to limit consumption to minimise levels required by each process stage,

(ii) defining qualities of water required at each process stage,

(iii) establishing treatment levels for recycle or cascading of wastewaters.

The reduction of waste volumes and strengths by good housekeeping, spill prevention or contaminant, conservation and reuse is the first step recommended in pollution control. Thereafter a programme to effect effluent treatment needs to be formulated and adopted for implementation.

At the industrial level the main reason for considering reuse of water are scarcity of resources, environmental constraints and economics. The practice of water reuse can be divided into sequential reuse and recirculation. Sequential reuse is the practice of using a given water for two or more processes before final treatment or discharge. Treatment may or may not occur between each process. Recirculation is the practice of recycling the water within a unit process or group of related processes.

The practice of treating wastewater to obtain compliance with discharge regulations may produce a water of or close to the quality needed for reuse in the plant. However, once this is recognised, the reuse of water by industry can be reviewed from a different perspective. The major concern is now shifted from the environment to one of proper water management, with an evaluation of the technical and economic factors involved in a reuse programme.

The obvious benefit to industry of an internal closed cycle water use system is that planning for the future is straight forward as the rules cannot change very much and the cost of pollution control and of reused water can be predicted in the future. Water users, at the same time, have the maximum protection of water quality as waste treatment is carried out within the factory.

The advantages of recycling water have been outlined by Stander and Funke (1). Recycling prevents water pollution while being an important water augmentation system. Several studies have indicated that the most effective way to eliminate pollution is at source. Water reuse is a pollution control technique that can provide valuable by-products and an inexpensive source of process water.

Benefits accruable to reclamation and reuse include the identifiable economic, ecological and social impact on receiving waters because of the reduced pollution load. In addition, costs are reduced for developing alternative sources of water supply, maximum development and use of existing water supplies results and high grade water is used for critical application areas.

Reclaimed (renovated) municipal wastewater as a supply source to industry is receiving increasing attention. It is apparent that may industries have a relatively large untrapped water resource available in reclaimed sewage effluent. Many applications, especially for cooling tower make-up are discussed in the literature. To date, principal applications are for irrigation, industrial cooling, process water applications and recreational lake maintenance.

In South Africa, secondary effluents have been reclaimed for industrial applications for some time. Hart and Henzen (2) report on their use in various industries. The pulp and paper industry in South Africa with reclamation systems at Mondi, Durban and SAPPI, Enstra were leaders in this type of reuse technology.

In-plant water reuse and recycle are usually specific to certain applications and industry. The pulp and paper industry has been very innovative in this area and this is covered in detail in

Chapter 6. An important factor in internal factory water reuse is that complete treatment is usually unnecessary and partial treatment will often suffice. The major factors for an effective water reuse programme are make-up water quality, individual process use pattern, type of manufacturing and the degree of pollution. Many examples of water savings by reuse/recycling have been published and often the savings are very significant. Additionally, those process industries using hot water may achieve economic benefits due to the reduced thermal energy requirements.

The pulp industry has made significant advances in chemical recovery with evaporation/chemical recovery being an integral part of Kraft and soda/oxygen mills. Many pulp and paper wastewater streams may also be suitable for by-product recovery ; for example : separation of lignosulphonates from sulphite pulping, fermentation to single cell protein and alcohol, recovery of vanillan and other compounds. Although a significant research and development effort has gone into both by-products recovery and effluent treatment options, the pulp and paper industry in the main produces large volumes of effluent with high organic and inorganic loads.

Cellulose fibre occurs abundantly in nature in vegetable matter and there are numerous commercially viable sources in many parts of the world. These vary from grasses, cereal straws, sisal, hemp, cotton to bagasse and, most importantly, wood.

Of importance to the paper maker is the quality of his cellulose or pulp. Cellulose fibres have different characteristics depending on source, age, growth rate and structure. To gain uniformity in the properties of pulp one has to either mix the pulps, or the woods used in pulp making to give a near average mixture all the time, or obtain wood for pulping from trees of the same age and species growth in similar climatic and other conditions.

Pulpwood is classified in two main categories - softwood (such as spruce) and hardwood (such as birch). Softwoods have longer and stronger fibres than hardwoods.

3.1 CELLULOSE FIBRES

Cellulose fibres from different wood sources differ in length, average diameter, wall thickness and other properties such as length to diameter ratio. These properties are important in papermaking as :

(i) they affect the strength of the fibres and hence the paper made from them, and

(ii) they affect the uniformity of the distribution of the cellulose fibres in the sheet of paper - known as the paper formation uniformity. Shorter fibres do not entangle or agglomerate into floss as easily as long fibres do, and thus short fibres produce a sheet of better formation. However, short fibres are less well bonded and hence have a lower tear resistance. Thick fibres will produce a sheet of higher bulk and stiffness; long and thin fibres are more flexible and have greater resistance to bending forces giving a superior fold strength in paper.

3.2 FIBRE TREATMENT

Raw cellulose fibre on their own are not sufficiently prepared to make sheets of paper. Some have to be bleached and have to be altered, physically or chemically, to improve their ability to bond together. The main fibre bonding factors are

(i) physical entanglement
(ii) surface tension
(iii) hydrogen bonding.

Physical treatment in machines such as beaters, conical refiners (jordans) and refineries provide for cut fibres, bruised fibres and peeled fibres producing spiral fines and increased water content of the fibres. Thus it is possible, using these techniques, to produce several grades of paper from one or a small number of fibre sources.

3.2.1 Groundwood Pulping

Grinding of wood logs with water spraying for cooling produces a groundwood pulp. The grindstone is designed to rip fibres out of the log and hence has rough profile. The friction heat generated on the surface of the log has the effect of heating up the wood inside i.e. the cellulose fibres, water and bonding materials in the wood such as lignins. Lignins start softening at 65°C and become plastic thereafter, thus allowing the fibres to separate more easily.

Groundwood contains a high percentage of cut pieces of cellulose fibre and fine debris material. The fibres are also bruised and fibrillated.

Commercial grinders today are commonly 1,2 m face width rotating at 250 rpm.

3.2.2 Refiner Mechanical Pulping

A modern development of grinding is the use of refiners which process coarse sawdust of woodchips (12,5 mm square and 4 mm thick). The refiner consists of patterned metal surfaces which bruise and separate the fibres into a slush pulp.

A further modification is thermo - mechanical pulping in which the raw material is preheated with stream prior to mechanical pulping. This helps to soften the lignin and produce a higher proportion of whole fibres.

Chemical treatments are also being applied either partially or wholly to dissolve the lignin prior to mechanical pulping.

3.2.3 Chemical and Semi-Chemical Pulping

The aim of chemical pulping is to attack the lignin and other binding materials in the wood that hold the fibres to one another.

Examples are :-

ACIDS : Sulphite
Neutral sulphite semi-chemical (NSSC)

ALKALI : Soda
Kraft (or sulphate)

In Kraft, chemicals are added to the caustic to limit fibre attack and hence this can be carried out further.

3.2.4 Pulp Yields

Yields vary from 95% for mechanical pulps, 75% for semi-chemical, 55% for unbleached, 45% for bleached to 25% for dissolving pulp (used in rayon manufacture). Yields vary also with the wood species.

3.3 CHARACTERISTICS

3.3.1 Mechanical Pulp

Has good opacity and printability but lower colour than bleached pulp. With its high yield it is cheaper than chemical pulp but weaker.

3.3.2 Unbleached Chemical Pulp

Has good burst, tensile and tear strengths.

3.3.3 Semi-Chemical Pulp

Does not fibrillate as easily as unbleached chemical pulp and also does not bond as well. Hence it is inferior as regards burst, tensile and generally also tear strength. However it is stiffer and has good crush resistance.

3.3.4 Fully Bleached Pulp

Has good whiteness and appearance.

3.3.5 Waste Paper

Significant quantities of waste paper are used by the industry - up to 50%. It is suitable for only lower grades of paper as cellulose fibres are degraded on reuse. Deinking and sorting are important areas.

3.4 PAPERMAKING

Paper is made by dispersing cellulose fibres in water and laying them on a sheet-forming medium. When the water is withdrawn it leaves behind a sheet of nearly dry, intermeshed or bonded fibres, making a sheet of paper.

The main stages of papermaking are :

stock preparation and approach flow
machine headbox
sheet forming
pressing
drying
calendering and glazing
reeling.

3.4.1 Stock Preparation

Paper producing plants or sections receive pulp in several different forms : such as air dry (90% consistency); pulp in sheets, bricks, bales or noodles ; and high consistency pulp at 3,5 to 5,5%.

The minimum treatment needed is that which is necessary to provide a continuous stream of corrected consistency stock, generally with some degree of refining to the fibres and some addition of chemicals. Outside the supplementary actions such as bleaching of deinked paper, removal of pitch and other contraries, the following steps may be encountered :-

.pulping or slushing of air dry pulp
.slushed pulp storage
.slushed pulp consistency control
.centrifugal cleaning of normal consistency or thickstock pulp
.deflaking particularly of slushed or repulped paper
.stock screening
.centrifugal cleaning of low consistency stock
.deflaking particularly of slushed or repulped paper
.stock screening
.centrifugal cleaning of low consistency stock
.holding or storage chests
.dilution and thickening of pulp
.pulp refining (or heating)
.blending of two or more pulps and additives

- .stock metering
- .consistency control
- .screen or other rejects refining
- .handling of repulped waste paper or broke from the machine
- .storage and treatment of water.

Cellulose fibres are generally 0,5 to 3 mm long and relatively slender and to form a good surface some refining is needed. In addition fibres in suspension in water tend to acclomerate and hence this flocculation tendency has to be controlled or broken down to allow a reasonably uniform sheet to be formed.

3.4.2 Pulp Consistency

At 1% consistency pulp suspensions behave and are pumped very much like water and respond similarly to agitation. When they reach 3%, the pulp begins to thicken and the friction co-efficient rises sharply. At 6% they are very sluggish, at 20% it appears almost solid and at 35% it can be pressed into relatively stable bricks, bales or sheets.

Pulp screens work at 1 to 4% consistency. Centrifugal cleaners can remove high specific gravity dirt at 3 to 4,5% consistency but normally operate at 0,5 to 1% consistency to remove more difficult contraries. Simple wire mesh drum thickeners can thicken 1% stock to 4% with relative ease and up to 8%. Vacuum aided drum filters thicken to 12 to 20% consistency.

3.4.3 Chemical Additives

These are used to make the paper suitable for its end use and to overcome some of the process difficulties.

3.4.4 Pitch Control

Pitch is the resin from pine trees and is troublesome in papermaking causing paper flaws and deposits on machinery. Avoidance of mechanical, temperature and pH shocks improve the situation. Alternatives are the use of resin solvents or anti-coagulants.

3.4.5 Defoaming or De-aerating

Air entrainment has to be avoided hence defoamers are added to the pulp or the pulp has to be de-aerated.

3.4.6 Sizing

Sizing is used to increase water repellency. For recosprint only a small amount of alum is needed. Other papers use a combination of resin and alum to bind the fibres and wax to reinforce the resin. Sizing may be carried out in acid, neutral or alkaline conditions.

3.4.7 Retention Aids

In the wet sheet forming process, large quantities of water are drained from the pulp slurry that contains water, modified cellulose fibres, fines, fillers and additives. To aid retention of the finer and dissolved material, chemical flocculation aids are used.

3.4.8 Wet and Dry Strength Aids

Wet strength additives are urea formaldehyde, melamine resins and other resins. They are normally added to the pulp shock prior to the forming of the sheet.

Dry strength additives are starch, cationic starch, carboxymethyl cellulose, polyvinyl alcohol and alginates and are added at the size presses.

3.4.9 Miscellaneous

Various other chemicals are used for :

- tint and brightness regulation
- machine cleaning

corrosion inhibition
slime control

3.4.10 Mineral Fillers and Coatings

Mineral fillers are used mainly to fill voids and improve opacity. Coating pigments are added as a paste to provide a final finish to the paper. The amounts added vary with the type of paper and pulp and are often in the range 5 to 40% of the dry paper. Examples of filler are kaolin, talc, calcium carbonate and titanium dioxide.

3.4.11 Stock Cleaning and Centrifugal Cleaning

Screens and centrifugal cleaners are used to remove contraries and oversize material and are used at various stages of preparation.

Various types of screen are used depending on the process requirements and include inclined stationary, vibrating perforated plates, cylindrical gravity and pressure screens. Showers are often used to aid the screening process.

Centrifugal cleaners are hydrocyclone type devices using tangential flow to a conical shaped vessel. High specific gravity material is rejected by the action of centrifugal force. Some rejection of short, thick fibre bundles also occurs.

3.4.12 Refining

Refining is needed to impart suitable paper forming qualities to the pulp. These include neutralising the negative charge of each fibre and encouraging physical entanglement.

Beaters for cutting, bruising and fibrillating the fibres used to be used but have been almost completely superseded by conical and disc refiners.

3.4.13 Broke Handling

Off-cuts of paper from the dry end of the paper or wet breaks on the papermachine amount to 10 to 25% of the output of the papermachine. These "brokes" have to be repulped and blended back to the blending chest.

3.4.14 Thick Stock Machine Chest

The pulp blend from the blending chest is next needed in the papermachine approach flow circuit. Close consistency control at about 3% is needed. This thick stock is carefully metered to the head box of the forming section of the papermachine.

3.4.15 Headbox

The machine headbox is supplied at a fixed consistency in the range 0,2 to 1,3%. At these low consistencies a good, even disposition of fibres in water can generally be obtained. Because of the time delay between the blending chest and the former, a control refiner or machine refiner, is needed between the machine chest and the headbox to allow easy adjustment of necessary changes to the pulp.

3.4.16 Cylinder Former or Fourdrinier

The paper sheet may be formed on a cylindrical mould former or a continuous wire fourdrinier. The latter consists of a woven metal or plastic cloth or fabric running around as an endless belt and is fed on its top surface with the stock suspension from the head box. Top wire and twinwire fourdriniers are now common and these mainly assist in drainage.

3.4.17 Paper Wet Pressing and Drying

The papermachine consists of three main processes: forming, pressing and drying. Drainage on the forming wire increases the consistency from about 0,5 to 1% to 20%. Pressing increases this to 35 to 45% and then the paper is dried to 95%. Thus about 98% of the water in the stock is removed in the forming part.

3.4.18 Water for the Stock Preparation Plant

Machine Backwater

Water used for diluting thick stock for the approach flow system and sheet former is supplied by water that drains off in the former. The excess water is collected in a backwater or whitewater chest and contains some fibre and more fines and fine filler material. From here it may be used for various purposes in the stock preparation area, but continual reuse causes build-up of dissolved salts and other materials.

Save-alls

Suspended solids are easier to remove from the backwater than are dissolved salts. Save-alls (thickeners, settlers and flotation cells) recover fibre and fillers and these may be reused. The clarified water is often routed preferentially to the papermachine showers.

3.5 PULPING TECHNOLOGY

Pulping is used to remove components such as lignin from the cellulose fibres. Various pulping processes exist and they use combinations of chemicals containing sulphur, oxygen and alkali. The main pulping systems are given in Figure 3.1

The interaction of the sulphur compounds with lignin in conjunction with the rate of hydrolysis governed by pH largely controls the source of the pulping action.

pH

1 — 4,5 — 7 — 14

Acid Pulping | Neutral Pulping | Alkaline Pulping

Chemical Species in Water Solution

SO_2 HSO_3^- SO_3^{--} S^{--}

HSO_3^- ⟶ SH^-

H^+ ⟵ ⟶ OH^-

Soluble Basis

Na^+ ⟶

NH_4^+ (Not used for Alkaline and Neutral Systems)

Bases of Limited Solubility

Mg^{++} ⟶

Ca^{++} ⟶

Processes

Acid	Neutral	Alkaline
		Kraft (Sulfate) (Na^+, S^{--}, SH^-, OH^-)
Acid Sulfite	Neutral Sulfite Semi-Chemical [NSSC]	Soda (Na^+, OH)
High Yield Sulfite		Kraft Semi-Chemical
Magnefite		
	Chemigroundwood	Cold Soda

FIGURE 3.1 : Aqueous pulping systems for important commercial processes

3.5.1 Alkaline Pulping

Two main processes exist: soda and sulphate (Kraft) pulping. Today soda pulping is almost non-existent because of the faster cooking action of the sulphate process.

The process outline is given in Figure 3.2.

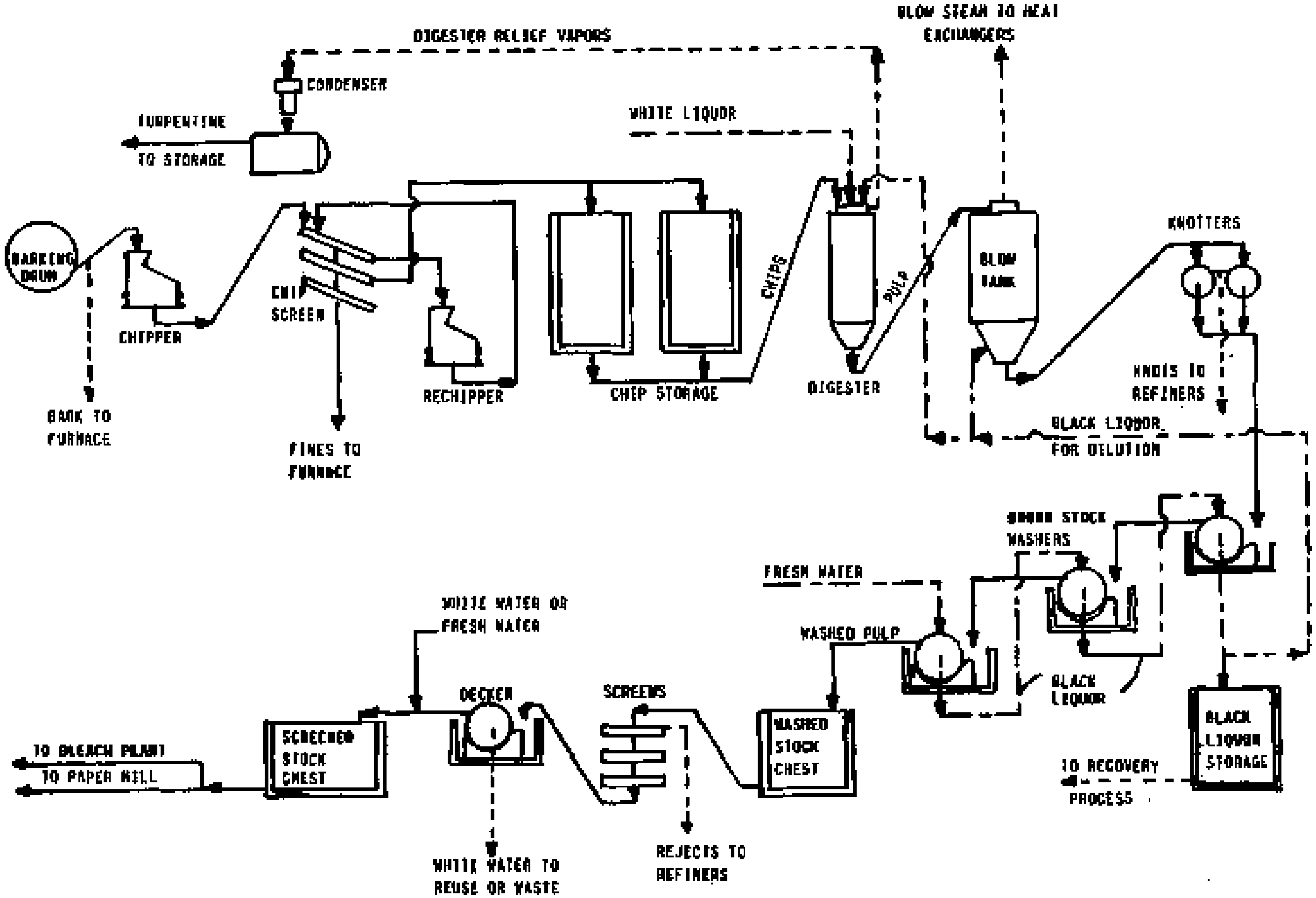

FIGURE 3.2 : Pulp mill flow sheet of stock preparation

3.5.1.1 Cooking Process

The main stages are :-

1. Wood logs are barked in debarkers and chipped in multiknife chippers.

2. These chips are carried by conveyor from the storage silos to the digesters, where the maximum amount of chips are fed into the top of the digester. Cooking liquor is added at this time. The ratio of chips and liquor, along with concentration, moisture content, and other variables, is carefully controlled.

3. The wood chips are cooked for the prescribed time under the proper temperature and pressure. Usual cooking time is about 2 to 4 hours at a pressure of about 700 kPa. While the wood is cooking, turpentine and other volatile constituents distill and these are condensed for sale as by-products.

4. At the end of the cook the pulp and liquor are "blown" into the blow tank. The pressurized steam in the digester effect this, and it blows the digester clean, ready for another cook. The steam from the blow is utilized to heat water for mill use.

5. The blow tank contains the pulp and the black liquor consisting of the spent cooking chemicals, as well as lignin and other solids extracted from the wood. The pulp and black liquor are diluted with dilute black liquor and pumped through the de-knotters to the brown-stock washers, where the liquor, containing the soluble residue from the cook, is washed out of the pulp.

6. The washed pulp is then screened and sent to the bleach plant or paper mill. A portion of the black liquor is used as a diluent for the cooling liquor and blow-tank stock. The remainder is sent to the recovery unit for reclamation of the cooking chemicals.

3.5.1.2 Recovery System

The flowsheet of the system is given in Figure 3.3.
The stages are :-

1. The black liquor from the brown-stock washers, containing about 16% solids, is evaporated in multiple-effect evaporators to about 50%. During evaporation, soaps are separated as a by-product.

2. The liquor is further evaporated to 65% solids in a direct contact evaporator.

3. The thick liquor is burnt in the recovery furnace. Lignin and other extracts maintain combustion and the cooking chemicals form a smelt at the bottom of the furnace. Sodium sulphate in the liquor is reduced to sodium sulphite. Heat from the furnace is used to produce super-heated steam for turbogeneration and for process steam.

4. The smelt is dissolved to give green liquor containing mainly sodium sulphide, sodium sulphate and sodium carbonate.

5. Green liquor is causticised to convert the carbonate to the hydroxide with the calcium hydroxide precipitating as calcium carbonate.

6. The calcium carbonate is kilned to produce calcium oxide and this is slaked to reproduce calcium hydroxide.

7. The white liquor containing the sodium hydroxide and sulphite is returned to the digesters.

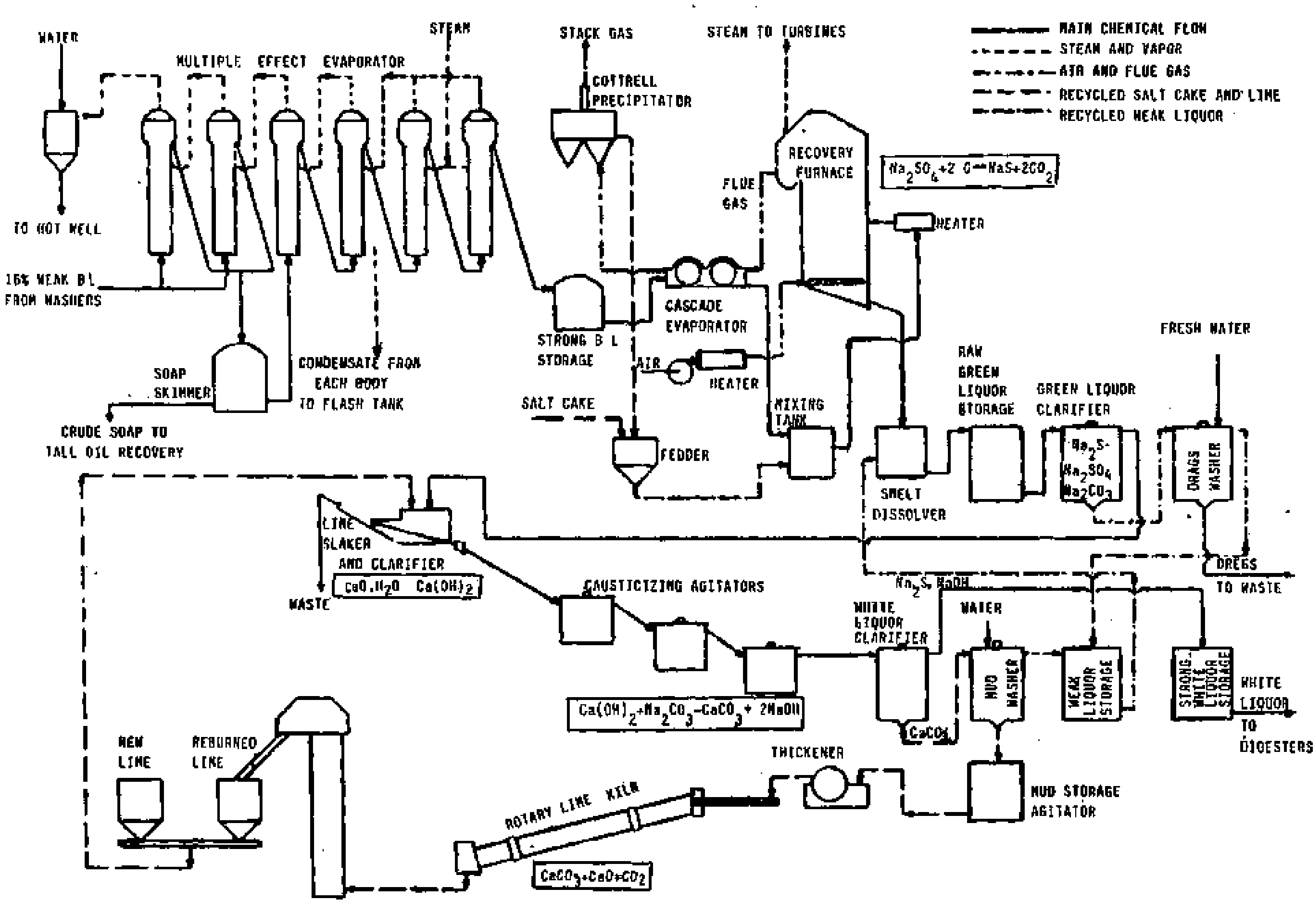

FIGURE 3.3 : Recovery and causticising flow sheet

3.5.1.3 Cooking Variables

The final quality of the pulp is determined by several factors :-

(i) species and quality of wood
(ii) digestion time
(iii) digestion temperature
(iv) sulphidity
(v) chemical to wood ratio
(vi) chemical concentration

Sulphate cooking consists of sodium hydroxide with a certain amount of sodium sulphide as given in Table 3.1. The hydroxide is consumed during cooking but equilibrium is partly maintained by the reversible reaction of the sulphide :-

$$Na_2S + H_2O \rightleftharpoons NaOH + NaSH$$

The sulphide increases the rate of lignin removal by a solubilisation process. During cooking all non-condensable gases and air are removed from the digester to maintain the proper temperature.

Cooking times and temperatures vary but are typically 1 to 4 hour and at 150 to 170°C. During cooking, turpentine and other volatiles and mercaptans are formed.

The pulping process also modifies the non-cellulosic carbohydrates and the residual cellulose is progressively depolymerised. Normally the sulphate digestion is stopped when the degree of polymerisation (DP) is above 1 500 glucose units.

Hardwoods have short fibres of 1 to 1,5 mm and softwoods 3 to 4 mm. Denser woods require longer cooking times than softwood for the same yield.

TABLE 3.1 : Material Balance for Kraft Pulping

Wood : air dry is 10% moisture

White Liquor

Chemical	g/l as Na_2O	g/l
Na2S	36,2	45,5
NaOH	75,9	97,9
Na2CO3	20,8	35,6
Na2SO4	1,0	2,2
	133,9	181,2

Digester Balance : % on air dry pulp

Component	Water	Solids
Wood	20,3	18,9
White liquor	25,4	51,6
Black liquor	39	7,8
Steam	149	-
Washer water	150	-

3.5.1.4 White Liquor and Lime Recovery

Chemical recovery is an economic necessity as well as being a pollution control measure for modern pulp mills. The recovery-furnace smelt is dissolved in washwater to form green liquor and this is causticised, as shown in Figure 3.4, with slaked lime to form white liquor.

3.5.2 Sulphite Pulping

The classical calcium acid sulphite pulping process has shown little expansion since 1950 because it is only suitable for wood containing small amounts of resin, has heat recovery problems due to scaling and non-recovery of process chemicals. Conversion of many mills to ammonium or magnesium-based chemistry has occurred.

Sulphite pulps are manufactured in three main types : unbleached, bleached and dissolving (chemical) cellulose. Unbleached pulp is used to improve the strength of groundwood sheets such as newspaper. Bleached sulphite pulp is used in the manufacture of bonds and book papers and dissolving cellulose for the production of rayon, plastics and cellulosic chemicals. Compared to Kraft pulp, sulphite pulps are usually of lower mechanical strength but are easier to bleach to a high degree of whiteness.

After the cooking process, the pulp is blown into a blow tank or pits. Washing is carried out either on multi-stage vacuum drum washers using counter-current washing or in the case of blow pits, by diffusion washing (Figure 3.5). Thereafter the pulp is diluted, screened, centrifugally screened and deckered to the desired stock chest consistency for bleaching.

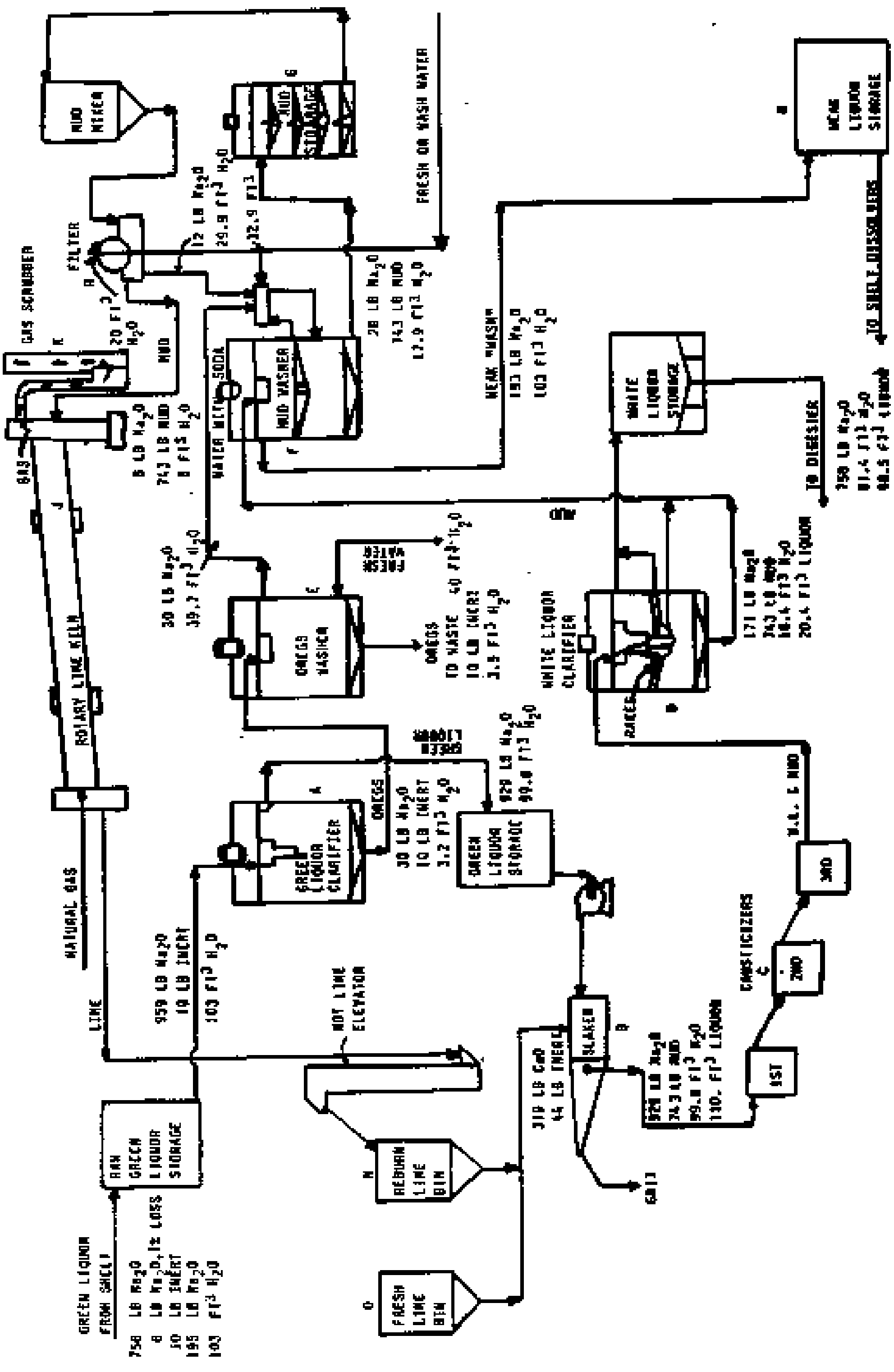

FIGURE 3.4 : Typical causticizing flow diagram

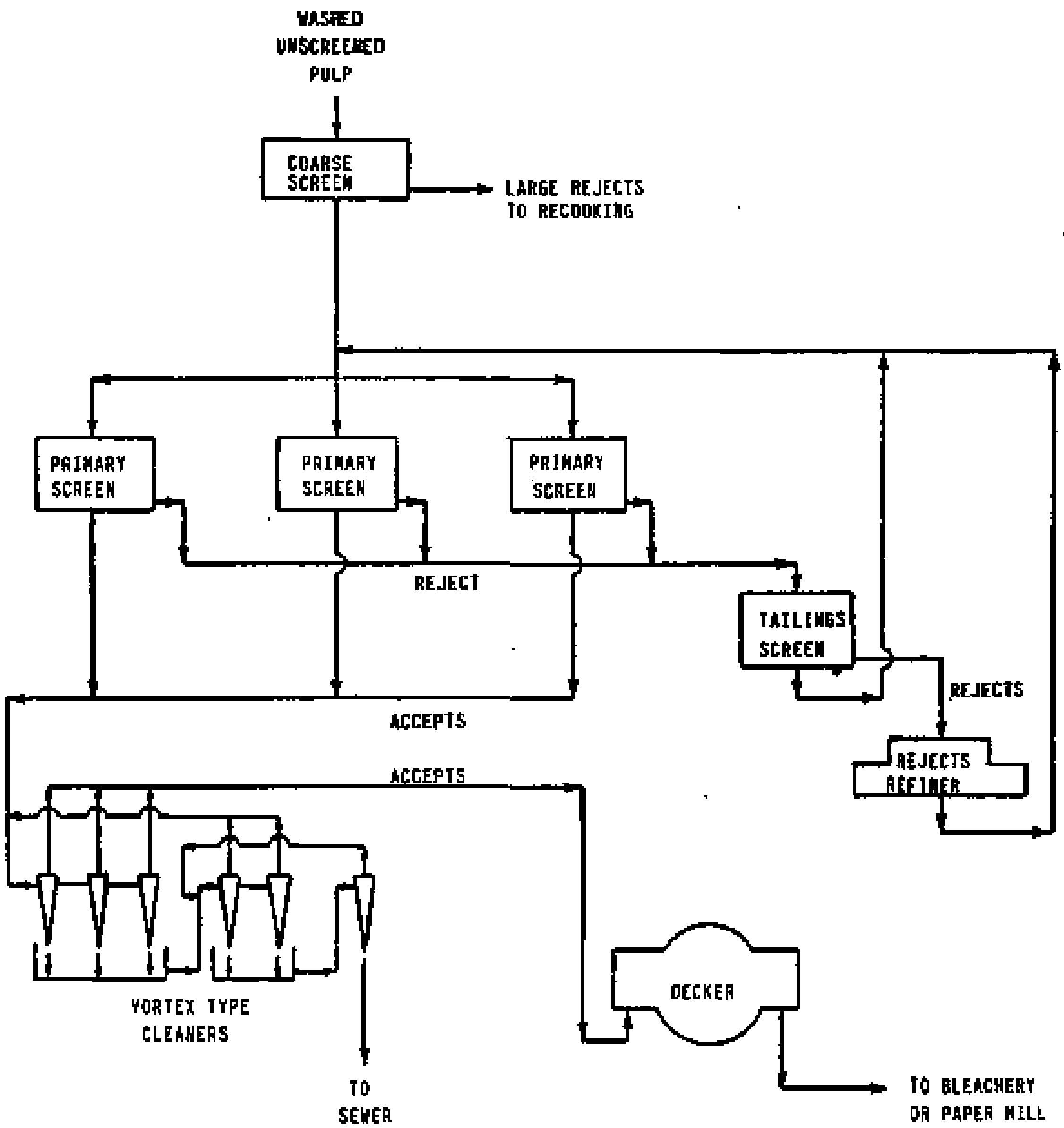

FIGURE 3.5 : Typical screening and cleaning system

3.5.2.1 Calcium-Based Sulphite Pulping

This is outlined in Figure 3.6. Delignification occurs due to the action of acid bisulphite to form lignosulphonates. Cooking is in batch digesters, typically of 10 to 35 ton batch size, at 130°C for 4 to 8 hours. Yield of unbleached sulphite pulp ranges from 43 to 48% by weight.

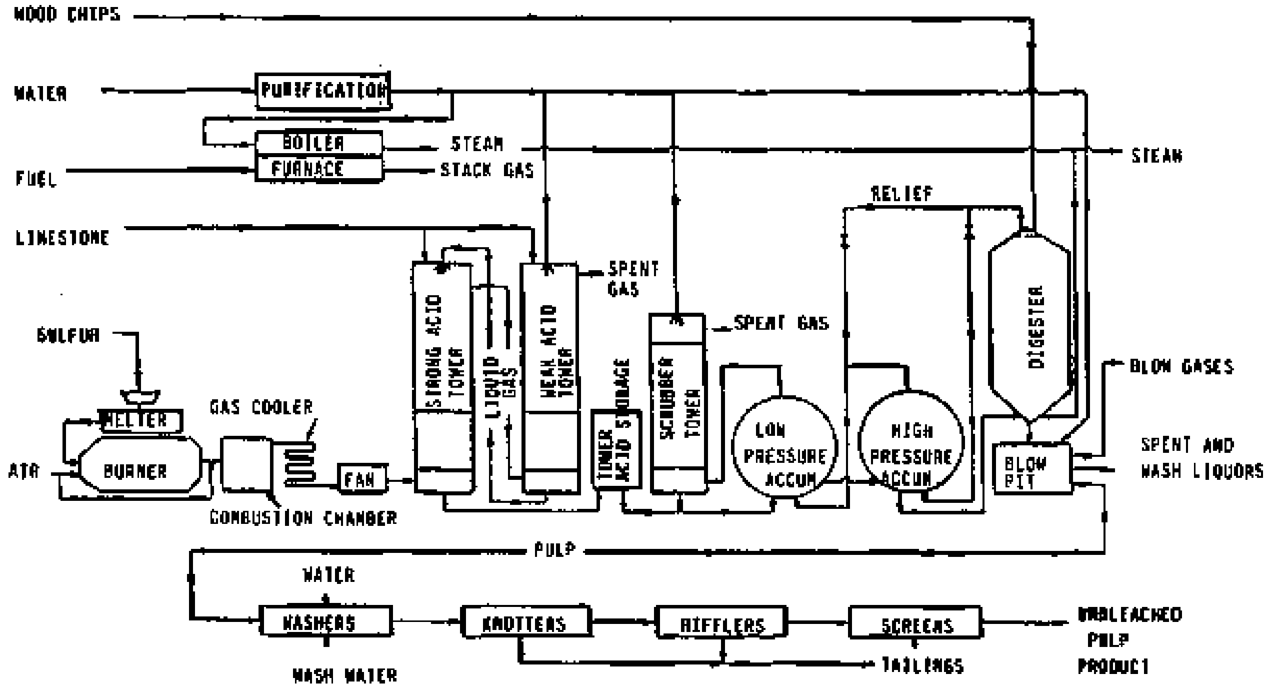

FIGURE 3.6 : Simplified flow sheet for calcium-base sulfite pulping process

The spent sulphite liquor (SSL) contains lignosulphonates, fermentable sugars (hexoses and pentoses), lower fatty acids and residual calcium bisulphite. Significant effort have been made to recover some of these compounds as by-products. These include fermentation to industrial alcohol or fodder yeast and recovery of lignosulphonates and vanillin.

3.5.2.2 Ammonia-Based Sulphite Pulping

A considerable number of calcium-based sulphite mills were converted to ammonia-based operation. The procedures for carrying out the pulping operations are similar to those for calcium-based systems except that the greater solubility of ammonium-based salts allows a lower combined sulphur dioxide concentration to be used when more rapid pulping and higher yield of pulp.

3.5.2.3 Magnesium-Based Sulphite Pulping

The advantage of magnesium-based sulphite pulping is that chemical recovery is possible :-

$$Mg\ SSL + O_2 \longrightarrow MgO + SO_2 + CO_2 + H_2O$$

With calcium and sodium-based spent sulphite liquors substantially higher temperatures are needed and these are difficult to attain in practice.

This pulping process is outlined in Figure 3.7

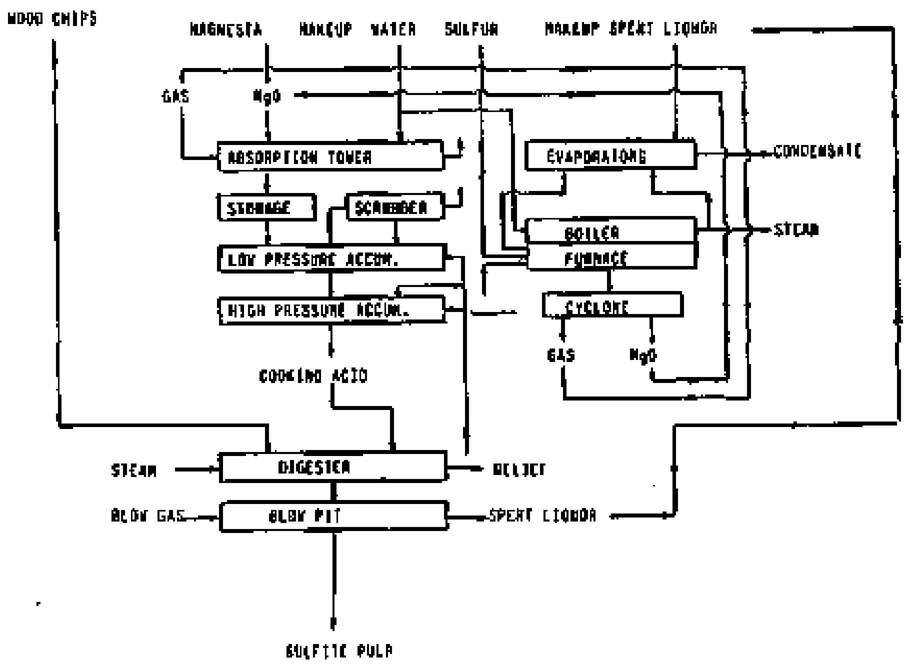

FIGURE 3.7 : Simplified flow sheet for magnesium-based sulfite pulping process with heat and process chemical recovery

3.5.3 Semi-Chemical and Chemi-Mechanical Pulping

These pulping processes fall between the classical groundwood and chemical pulping methods. These intermediate processes are broadly classified as :-

(i) mild chemical treatment to partially degrade the fibrebond, followed by

(ii) mechanical treatment (defibring) to cause fibre separation to permit papermaking.

Pulp yields in the range 55 to 95% as given in Table 3.2. Chemi-mechanical pulping is differentiated from semi-chemical pulping as there is no major change in the lignin of the fibre bond.

Semi-chemical pulping processes have been developed when the objectives of timber preservation and cost reduction. Hardwood are mainly used.

TABLE 3.2 : Pulping Yields

Process	Yield (%)
Groundwood	90 - 95
Chemi-groundwood	85 - 90
Chemi-mechanical	85 - 95
Semi-chemical	65 - 85
High yield chemical	50 - 65
Chemical	40 - 50

Semi-chemical pulps are used for corrugated and linear boards, speciality boards, newsprint, tissue and wrapping paper.

3.5.3.1 Semi-Chemical Pulping

The chemical stage of this process is to weaken the lignin-carbohydrate complex of the fibre bond and the chemical processes of acid sulphite, neutral sulphite, Kraft and soda are used. In the second mechanical stage the partially pulped fibres material undergoes defibrering. The pulping system is outlined in Figure 3.8 (neutral sulphite semi-chemical - NSSC).

The neutral sulphite semi-chemical (NSSC) digestion process usually uses 5 to 20% sodium sulphite-based on the moisture free weight of wood. Buffering agents (sodium bicarbonate, sodium carbonate or Kraft green liquor) are added to neutralise the organic acids formed by pulping of the wood. Pulping is carried out at fairly high temperatures of 160 to 185°C for 0,25 to 2 hours.

The commercial application of acid sulphite pulping had been limited.

The mechanical stage of ring are disk mills usually followed by refiners. Neutral sulphite semi-chemical (NSSC) pulps may be bleached or brightened.

Chemical recovery in the sodium-based neutral sulphite semi-chemical (NSSC) process is considerably more difficult than in the Kraft process. The spent liquor is low in solids with a high inorganic to organic ratio and does not burn easily. At some mills the liquor is evaporated and burnt without recovery of the chemical-base. In sodium-based mills a fluidized bed is use in Kraft mill liquor systems.

3.5.3.2 Chemi-Mechanical Pulping

Usually soda or neutral sodium sulphite are used for this chemical treatment.

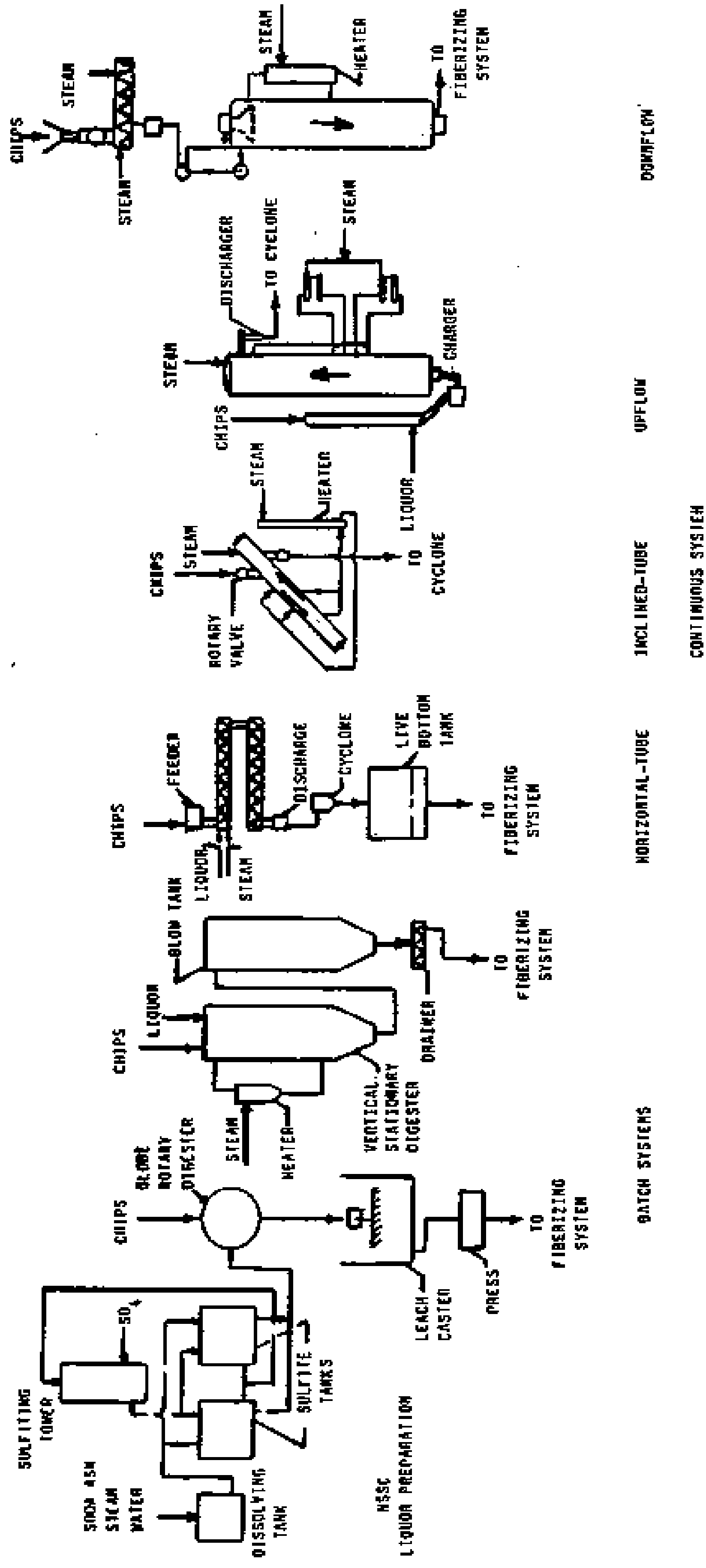

FIGURE 3.8 : Semi-chemical pulping systems

3.5.4 Mechanical Pulping

3.5.4.1 Groundwood Pulping

Groundwood pulping utilizes all the wood and is mainly used for newsprint. It is made by forcing the pulpwood against a rapidly revolving grindstone. Water is used as a coolant, a carrier for the pulp and for dilution. After dilution, the pulp is screened, centricleaned and then thickened on a decker for bleaching or mill use. In refiner groundwood pulping, the wood chips are generally washed prior to two stages of refining. Disc type refiners are used and these consist of one fixed and one rotary disc between which the wood chips pass with a stream of water. After cleaning the pulp is handled in the same manner as outlined above.

3.5.4.2 Chemi-Groundwood Pulping

This is used for hardwoods of dense structure to allow grinding to remove whole fibres rather than fine particles. The process is outline in Figure 3.9. Typically sodium sulphite and sodium carbonate are used in a soaking process. After this treatment, the logs or chips follow the groundwood pulping stages.

3.5.4.3 Thermo-Mechanical Pulping

The wood chips are presoftened with heat and refined under pressure before being screened.

3.6 BLEACHING

Bleaching is used to improve whiteness or brightness. The operations and processes depend on the character of the unbleached pulp and the desired quality of the bleached pulp. Two main types of bleaching are used -:

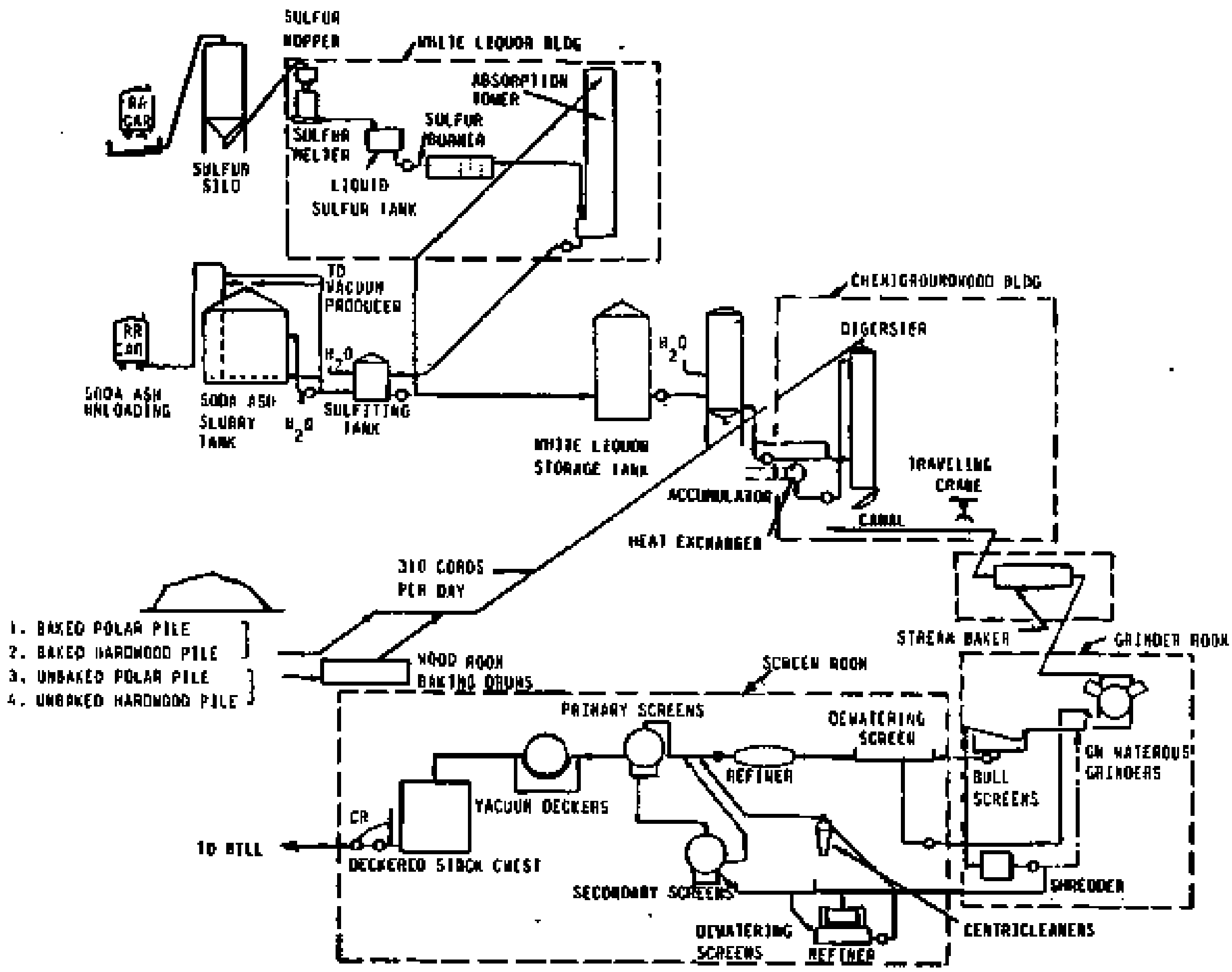

FIGURE 3.9 : Chemi-groundwood process flow diagram

(i) **lignin bleaching** to improve brightness of mechanical and semi-chemical pulps. Little removal of lignin is achieved and hydrosulphite or peroxide is used.

(ii) **lignin removal** to give high brightness and improve paper quality of semi-chemical and high yield chemical pulps. Chlorination is used for the degradation of lignin, followed by alkali extraction for dissolution of the degradation products and then an oxidation step. Delignification is a continuation of the pulping stage by the use of selective, but more expensive, chemicals. During bleaching, carbohydrate removal and deresination occur and these improve paper quality. The control of strength loss and depolymerisation (viscosity adjustment) are important bleaching parameters.

3.6.1 Bleaching Chemicals

Bleaching is frequently carried out in several stages in which different chemicals are used often with a washing stage in between. Commonly used chemicals are :-

A	acid treatment or dechlorination
C	chlorination
D	chlorine dioxide
E	alkaline extraction
H	hypochlorite
HS	hydrosulphite
O	oxygen
P	peroxide
PA	peracetic acid
W	water soak
/	successive chemical addition without a washing stage

A common sequence in Kraft bleaching is CEDED with each chemical stage followed by a washing stage (Figure 3.10). Sulphite pulps use a shorter bleaching sequence such as CEH (Figure 3.11) Mechanical pulps are brightened usually in a single stage with sodium hydrosulphite, sodium peroxide or hydrogen peroxide. Secondary fibres are usually only brightened and deinked groundwood - free stocks are bleached with hypochlorite.

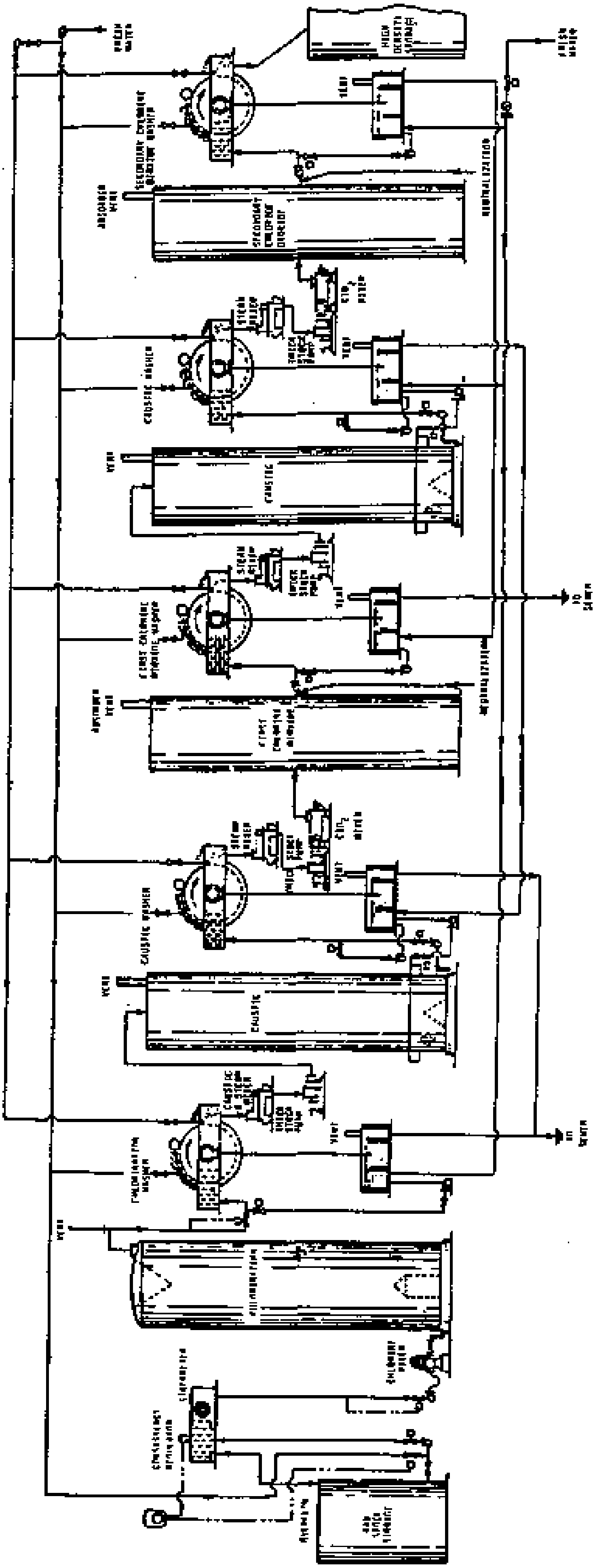

FIGURE 3.10 : Multi-stage bleach plant

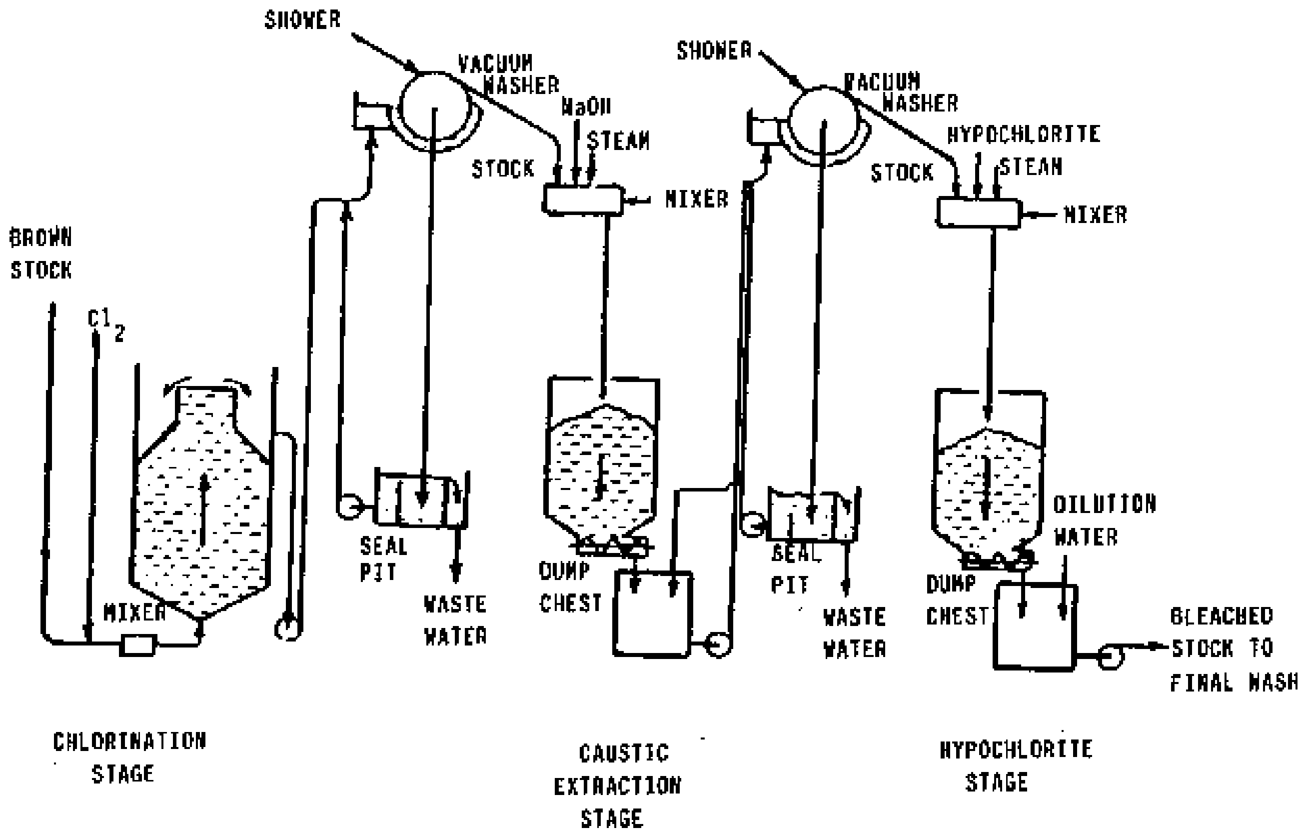

FIGURE 3.11 : Three-stage bleaching process

3.6.2 Bleaching of Chemical Pulp

Bleaching is carried out in stages to preserve the strength of the pulp and to control consistency and temperature in accordance with the chemical treatment method. Three stages are generally used for semi-bleached Kraft and sulphite paper-grade pulps. Since Kraft pulps are dark, particularly when made from soft-woods, high brightness Kraft pulps require five or six bleaching stages.

Chlorine, hypochlorite and chlorine dioxide are used as bleaching agents and the reaction products extracted with alkalis such as caustic soda or calcium hydroxide. Peroxide or peracetic acid are used as finishing agents and sulphur dioxide or sodium sulphite as anti-chlor agents to stabilise pulp brightness.

Bleaching is carried out in reaction towers and then washed on vacuum drum washers or diffusers. Displacement bleaching with a high consistency pulp is a new process gaining ground in the industry.

The SAPOXAL process (3), developed in response to environmental considerations of the high chloride load of conventional bleach effluents, uses the AAODED sequence instead of CEHDED. This gives a 78% reduction in dissolved solids and COD in the effluent. The effluent from the oxygen treatment stage can be combined with digester liquor from the pulping process and the sodium hydroxide and sodium sulphate recovered.

3.6.3 Bleaching of Mechanical Pulp

Bleaching chemicals are usually peroxide or hydrosulphite. After bleaching the pulp is neutralised and washed.

3.6.4 Bleaching of Secondary Fibres

Deinked fibres consisting of primarily bleached chemical pulp are bleached in one step with chlorine or hypochlorite. Pulps containing significant amounts of lignin use the CED bleaching sequence.

3.7 PAPERMAKING

Once pulp has been prepared from wood, deinked stock or wash paper, further mixing, blending and addition of non-cellulosic materials, if appropriate, are needed to produce a 'furnish' for making paper or board materials. Modern stock preparation systems are automated to control blending, addition of additives, refining, mixing and distribution of furnish.

Two or more types of pulp are often blended to produce desired characteristics. Often, relatively long fibre softwood pulp is used to create a fibre network and to provide wet strength and tear resistance. Hardwood Kraft pulps contribute properties such as smoothness, opacity, good printability and porosity. To develop maximum strength, fibres are refined to open their structure and provide more bonding surfaces during papermaking.

Additives include clay, calcium carbonate, talc and titanium dioxide for printing papers to improve smoothness, brightness and opacity. Increased ink of or water resistance is obtained by the use of starch either during forming or as a coating stage.

The basic papermaking process consists of depositing a layer of fibre from a dilute water suspension on a fine screen or 'wire'. The wire permits water to drain through. The pulp layer is removed from the wire, pressed and dried. The two main types of machines are a cylinder machine which rotates in the pulp furnish and a fourdrinier in which the pulp furnish is deposited on an endless wire belt. In the fourdrinier operation, dilute pulp at about 0,5% consistency is deposited from the head-box onto the wire screens. A suction pich-up roll transfers the sheet from the wire to presses which increase density to about 35 - 40% consistency and increase smoothness. Thereafter the sheet is dried and may be calendered.

Coatings are becoming increasingly important and various chemicals such as colour pigments, adhesives, binders and PVC are used depending on the application.

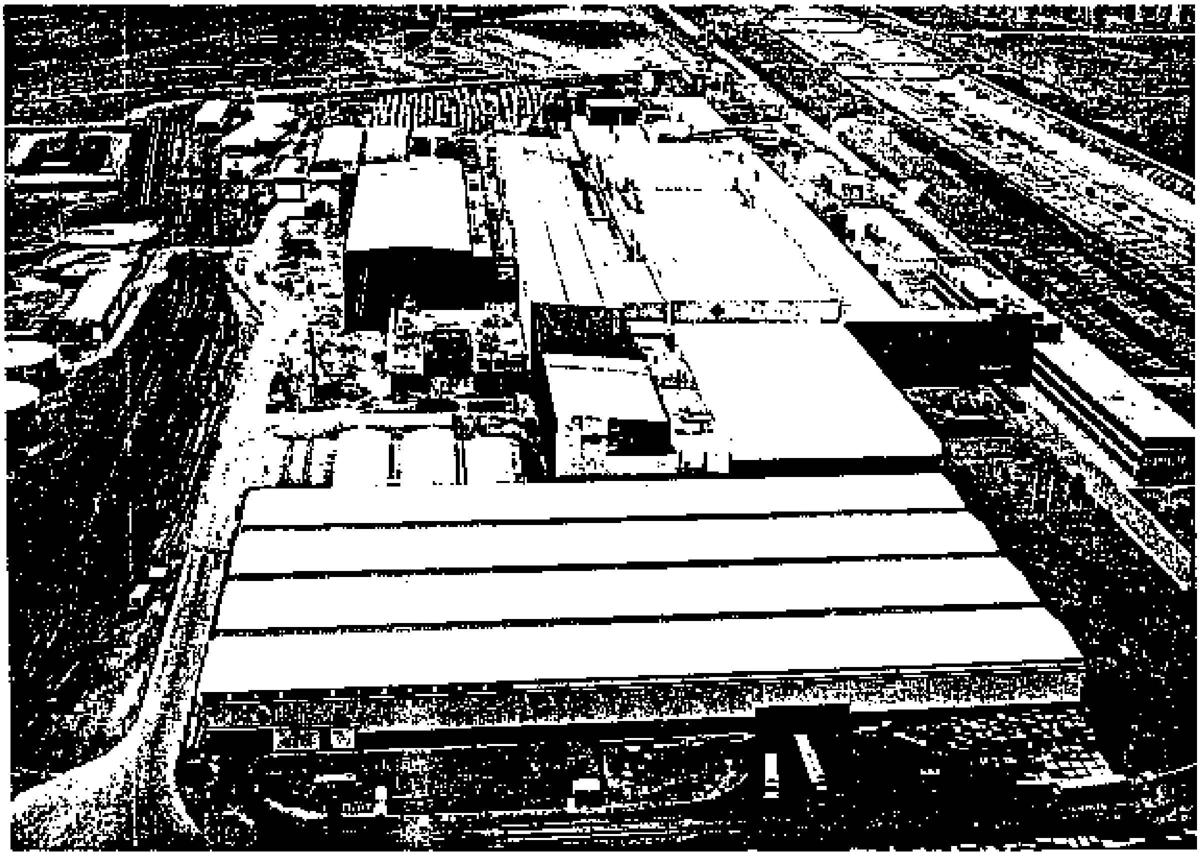

FIGURE 3.12 : View of Mondi Paper Company

The pulp and paper industry has three main segments : integrated, secondary fibres and non-integrated and may be categorised or outlined in Table 4.1. Mills where pulp alone or pulp and paper or paperboards are manufactured are termed integrated mills. Mills which use wastepaper as their primary raw material are referred to as secondary fibre mills. Those that manufacture paper or paperboard but not pulp are termed non-integrated mills.

TABLE 4.1 : Categorisation of Pulp and Paper Industry

A. INTEGRATED
1. KRAFT
Dissolving Kraft Market Bleached Kraft Board, Coarse and Tissue Bleached Kraft Fine Bleached Kraft
2. SODA
3. UNBLEACHED KRAFT
Linerboard Bag and Miscellaneous
4. SEMI-CHEMICAL
5. UNBLEACHED KRAFT AND SEMI-CHEMICAL
6. DISSOLVING SULPHITE PULP
Nitration Viscose Cellophane Acetate
7. PAPER-GRADE SULPHITE
8. GROUNDWOOD
Thermo-Mechanical Coarse and Newsprint Fine Paper Chemi-Mechanical
9. MISCELLANEOUS

TABLE 4.1 (CONTINUED)

B. SECONDARY FIBRES
1. DEINK Fine Papers Tissue Papers Newsprints
2. TISSUE FROM WASTE
3. PAPERBOARD FROM WASTE
4. MOLDED FROM WASTE
5. BUILDERS PAPER AND ROOFING FELT
6. MISCELLANEOUS
C. NON-INTEGRATED
1. FINE PAPERS
2. TISSUE PAPER
3. HIGHWEIGHT
4. FILTER AND NON-WOVEN
5. PAPERBOARD
6. MISCELLANEOUS

The industry in general is highly diversified in terms of their raw materials, processing methods and product ranges. The industry is sensitive to changing demands for paper and paperboard products and operations are frequently expanded or modified to accommodate new product demands.

The USA, Canada, Japan, China and Scandanavia are major production centres. The USA has about 700 mills in operation and their 1980 pulp production is summarised in Table 4.2.

TABLE 4.2 : USA Pulp Production (1977)

Type		Production
Dissolving		1 465
Sulphite	Bleached	1 653
	Unbleached	389
Alkaline	Bleached	14 929
	Semi-bleached	1 523
	Unbleached	18 411
Groundwood		4 481
Semi-Groundwood		3 876
Other Mechanical		2 941
TOTAL		49 777
Market Pulp		4 881
Waste Pulp		14 015

(Units : 1 000 short tons)

Wastewater discharge methods for the USA mills is given in Table 4.3. At over half the mills wastewater is treated on-site in treatment systems operated by mills personnel. Biological treatment systems are currently employed extensively at direct discharging pulp, paper and paperboard mills to reduce the organic and TSS loads. Aerated stabilisation is the most commonly used treatment process. At a relatively large number of plants in the non-integrated and secondary fibre sectors only primary treatment is employed.

4.1 RSA PULP AND PAPER INDUSTRY

South Africa's timber and related products industry has grown rapidly in the last fifty years. In 1910 only 100 000 ha were afforested but this has risen to over 1 million ha of commercial forest (Table 4.3).

TABLE 4.3 : Ten Forestry Growth Point Areas in South Africa

Forestry growth point area Characteristic	Belfast/ Middel-burg	Ngodwana	Piet Retief	Richards Bay	Tugela/ Mandini	Durban/ Pieter-maritz-burg	Estcourt/ Colenso	Donny-brook/ Umkomaas	Weza	Ugie/ Umtata
Priority	9	4	8	1	7	10	6	2	5	3
Present afforested area (ha)	55 000	269 000	131 000	86 000	70 000	55 000	69 000	105 000	87 000	26 000
Current production (kl/year)	601 000	4 079 000	1 675 000	1 464 000	884 000	825 000	971 000	1 641 000	1 234 000	316 000
Percentage of area afforested and afforesable (%)	50	29	28	32	20	15	15	22	48	31
Total potential afforested area (ha)	155 000	317 000	309 000	284 000	193 000	136 000	244 000	356 000	474 000	357 000
Total potential timber volume (kl/year)	1 213 000	4 700 000	3 800 000	3 491 000	2 332 000	1 980 000	3 022 000	5 153 000	5 859 000	4 134 000
Percentage overlap with other areas (%)	30	30	0	35	44	73	38	74	48	0

Source : Forestry Guide Plan for RSA

The timber industry consists of about 150 sawmills ; 15 pulp, paper and board mills ; 50 mining timber installations ; 30 pole impregnation factories ; 5 wattle extraction plants and 3 match factories. Integration of the various sectors of the industry is becoming important.

The forest products industry has made a significant contribution to RSA's overall economy. It employs over 150 000 people and export earnings were R300 m in 1981 (Table 4.4). Sales of wood products, furniture and paper products reached nearly R4 billion in 1982, accounting for about 6% of total industrial output.

TABLE 4.4 : Export Contribution of Timber and Timber Products

	1974 (%)	1981 (%)	Jan-June 1982 (%)
Pulp :	70,3	46,8	41,3
Dissolving pulp	39,0	41,0	41,2
Unbleached sulphate pulp	31,0	5,4	-
Other	0,2	0,4	0,1
Paper :	24,0	36,6	43,2
Paper and board	12,0	31,6	39,2
Other	12,0	5,0	4,0
Sawn Timber :	1,3	2,6	2,5
Softwood (sawn lengthwise)	1,0	2,3	2,3
Other	0,3	0,3	0,2
Sawlogs :	0,3	0,8	0,3
Charcoal :	-	1,2	1,2
Pulpwood :	-	0,6	0,8
Woodchips :	-	6,4	7,3
Other :	4,1	5,0	4,4
	100,0	100,0	100,0

Source : Directorate of Forestry.

The pulp, paper and board industry employs over 15 000 people and consumes over 2,5 million tons of timber annually. The two large pulp and paper companies are Mondi and SAPPI. SAICCOR have a large dissolving pulp plant and Nampak has significant holdings in the paper and packing sector. Two new capital projects (Mondi Richards Bay and SAPPI Ngodwana) will cost R1,5 billion and will consume a further 4 million tons of timber. Significant exports in this sector are SAICCOR's 400 000 t/a of dissolving pulp, Mondi's 200 000 t/a of newsprint and Central Timber Co-Operative (CTC) 500 000 t/a of wood chips.

The RSA industry uses about 400 000 tons of wastepaper and has one of the world's lowest water usages at 14 to 120 kl/ton of pulp against 50 to 700 kl/ton worldwide.

Although the South African market for paper and board is the largest on the African continent, it is still small by world standards. Our present annual consumption is about 40 kg per capita compared to other 1979 figures of 23 kg for Brazil, 37 kg for USSR, 130 kg for UK, 143 kg for West Germany, 203 kg for Sweden and 274 kg for USA.

A summary of the mills and their production in 1979 is given in Table 4.5 and their locations on the map of Figure 4.1. The production and consumption of different paper and board products for 1979 is given in Table 4.6.

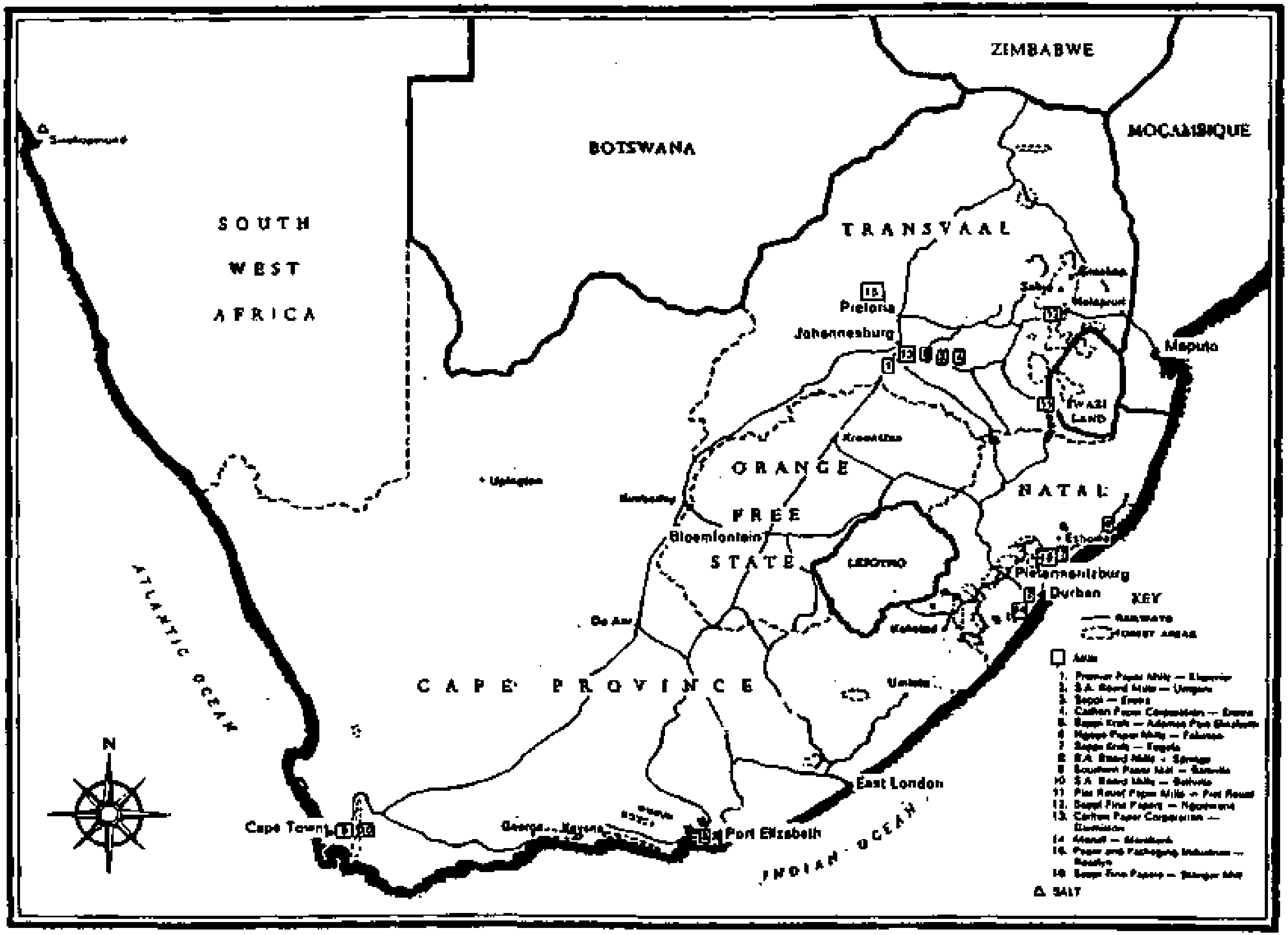

FIGURE 4.1 : Location of paper mills in South Africa

TABLE 4.5 : Association of Pulp, Paper and Board Manufacturers of RSA
Production and Apparent Consumption of Paper and Board in South Africa
for the Year 1979

(Data in Metric Tons)

	Production	Stock 1.1.1979	Stock 31.12.79	Imports	Exports	Apparent Consumption 1979	Apparent Consumption 1978
Tissue and cellulose wadding	73 282	7 290	6 447	3 756	9 809	68 072	65 841
Newsprint	223 651	15 816	7 690	3	86 404	145 376	139 524
Mechanicals	22 461	450	876	33 451	3 458	52 028	58 530
Linerboard: all types	235 631	5 720	5 116	2 993	6 930	232 298	196 039
Fluting	159 270	3 220	1 280	-	40 581	120 629	112 692
Other Kraft and Imitation Kraft	99 823	2 738	2 907	11 047	7 381	103 320	110 974
Printing and writing paper	159 795	9 318	6 986	21 728	14 076	169 779	153 881
Paperboard	129 743	3 800	7 735	46 633	3 423	169 018	163 567
Fibreboard	7 545	238	242	2 445	2 484	7 502	6 970
Other papers	10 751	163	270	32 374	266	42 752	36 494
	1 121 952	48 753	39 549	154 430	174 812	1 110 774	1 044 512

Foreign Exchange equivalent to RSA Rand

1 Rand = 1,3 US\$ = 0,55 Sterling = 2,29 German Mark = 5,3 French Francs

TABLE 4.6 : Mills; Location; Production and Consumption of Paper 1979

Grades	1979 RSA Consumption	Manufactured By	Location of Mills	1979 RSA Production
Paperboard	169 018	RSA Board Mills Ltd	Springs Durban and Cape Town	129 743
Fibreboard	7 502	SAPPI Kraft (Pty) Ltd SAPPI Fine Papers	Port Elizabeth Springs	7 545
Mechanicals	52 028	Mondi Paper Company	Durban	22 461
Newsprint	145 376	Mondi Paper Company SAPPI Fine Papers	Durban Springs	225 651
Woodfree printings and writings	169 779	SAPPI Fine Papers Mondi Paper Company SAPPI Kraft	Springs/Stanger Durban Port Elizabeth	159 795
Kraft and other packaging	456 247	SAPPI Kraft Piet Retief Ngoye Paper Mill Premier Paper Mill Paper and Packaging Industry	Mandini, Port Elizabeth Piet Retief Felixton Kliprivier Rosslyn	494 724
Tissue	68 072	Carlton Paper Company Southern Paper Mill SAPPI Fine Papers	Springs Germiston Bellville Stanger	73 282
Other grades	42 752	Mainly imported		10 715
Total	**1 110 774**			**1 121 952**

4.2 DESCRIPTION OF MILLS

4.2.1 Mondi Group

4.2.1.1 Mondi Paper, Merebank, Durban

Mondi Paper started production in 1971 with a high speed newsprint machine (90 000 t/a). A second machine for newsprint and fine writing papers was introduced in 1972 and the third machine commissioned in late 1976 raised annual production to 260 000 t/a. A further two machines have been added and production is about 500 000 t/a.

A thermo-mechanical pulping plant was installed in 1979.

4.2.1.2 Mondi, Richards Bay

This mill is presently under construction and will produce 1 500 t/d of pulp and 600 t/d of kraft linerboard.

4.2.1.3 RSA Board Mills

This subsidiary of Mondi has mills in Durban, Springs and Bellville. Total company production is 150 000 t/a and wastepaper is used as the primary raw material.

The Durban plant has three machines, the Springs plant two machines and the Bellville plant one machine.

4.2.1.4 Ngoye Paper, Felixton, Natal

This fluting mill was started in 1953 and used bagasse as a raw material. Current production is 90 000 t/a. A continuous soda pulp plant was installed in 1977 with a production capacity of 150 t/d.

4.2.1.5 Piet Retief Paper Mill

This is also a fluting mill and was established in 1963 to produce 22 000 t/a using semi-chemical pulping of local eucalyptus. In 1971 a continuous digestion plant was installed and current production is 85 000 t/a of fluting and test liner.

Mondi also control the 175 000 t/a Usutu Pulp Mill in Swaziland.

4.2.2 SAPPI Fine Papers

4.2.2.1 Enstra Mill, Transvaal

The country's first integrated pulp and paper mill was established in 1938 at Enstra, Springs with a capacity of 14 000 t/a of writing and printing papers and cardboard. In 1948 the pulping section was converted from handling mainly straw to timber. Fine papermachine capacity was raised in stages to 65 000 t/a in 1979.

In 1961 a newsprint machine was commissioned with a production of 36 000 t/a and this has been raised to 70 000 t/a. Oxygen bleaching was introduced in 1970 and in 1979 a new hardwood pulp and plant, which doubled pulp capacity, was started using the soda process instead of the kraft process to lower the environmental impact of the mill.

Current production is about 130 000 t/a of bleached pulp, 65 000 t/a of fine paper and 70 000 t/a of newsprint.

4.2.2.2 Ngodwana Mill, Eastern Transvaal

The mill was commissioned in 1966 with an initial capacity of 70 000 t/a of unbleached softwood pulp using the kraft process. It was later uprated to 90 000 t/a.

The current R800 million extensions to Ngodwana will have a 70 000 t/a newsprint machine. A new pulping and bleaching plant is also being installed.

4.2.2.3 Stanger Mill, Natal

The Stanger Mill, started in 1976 by Reed International, was acquired by SAPPI in 1979. It uses bagasse fibres as its main raw material and produces 60 000 t/a of pulp mainly for the production of 35 000 t/a of coated paper and 20 000 t/a of tissue wadding.

4.2.3 SAPPI Kraft

4.2.3.1 Tugela Mill, Natal

This Kraft pulp and paper mill was commissioned in 1954 with a capacity of 54 000 t/a of linerboard, fluting, bag and wrapping papers. Major extensions and additions were added in 1963 to increase production to 82 000 t/a. In 1966 a newsprint mill (mechanical pine) was commissioned with a capacity of 64 000 t/a. A 85 000 t/a neutral sulphite semi-chemical (NSSC) mill was started in 1972 and the batch kraft digesters were replaced with a 750 t/d continuous kraft pulp digester in 1979. Drum debarking was introduced and papermachine enhancements raised production to 270 000 t/a.

Pulp production is 700 t/d of unbleached pulp (Kraft 430 and neutral sulphite semi-chemical (NSSC) pulp 270) and approximately 800 t/d of paper.

4.2.3.2 Adamas Mill, Port Elizabeth

Started in 1952, the Adamas Mill was acquired by SAPPI in 1964. The mill produces 26 000 t/a of packaging and fine papers and 4 000 t/a of fibre board.

4.2.3.3 Cape Kraft Mill, Milnerton, Cape

This is a modern mill (1981) producing 30 000 t/a of packaging paper (fluting and linerboard) from from wastepaper. The mill has extensive water recycling facilities.

4.2.4. SAICCOR

SAICCOR is one of the world's largest producers of dissolving wood pulp which is used for the production of rayon and cellophane films. Production capacity is 400 000 t/a and most of this is exported. Started in 1956, production capacity has increased over ten-fold since then.

The mill is presently being expanded to 500 000 t/a.

4.2.5 NAMPAK

4.2.5.1 Paper and Packaging Industries Ltd, Rosslyn, Transvaal

This privately owned mill was started in 1970 with a capacity of 15 000 t/a of imitation kraft liner and fluting, corrugated board and boxes based largely on wastepaper. Capacity was increased to 30 000 t/a in 1974 and to 42 000 t/a in 1977. It was acquired by Nampak in 1979.

4.2.5.2 Premier Paper Ltd, Kliprivier, Transvaal

This mill was established in 1920 and has two papermachines producing over 30 000 t/a of test liner, fluting, wrapping paper, envelope and cover paper together with speciality papers on the original machine. Wastepaper is the main raw material.

Nampak acquired a majority shareholding in 1979.

4.2.5.3 Southern Paper Mill, Bellville, Cape

This mill was started in 1958 with a toilet tissue machine. Three machines are now installed together with a deinking plant and produces 14 000 t/a of flat and toilet tissue.

4.2.5.4 Carlton Paper Corporation, Transvaal

This company operates two tissue machines at Wadeville (Germiston) and the machines are linked to converting facilities to produce toilet tissue, facial tissue, serviettes and paper towels.

CHAPTER 5 : WATER USAGE AND EFFLUENT CHARACTERISATION OF PULP AND PAPER MILLS IN RSA

5.1 SURVEY

The pulp and paper mills in RSA were surveyed on a confidential basis (Appendix A) with the following aims :-

(i) to identify water management and pollution control problems within the industry,

(ii) to identify areas where improvements may be made,

(iii) to assess the need for a co-ordinated research and development programme for the industry on a national basis.

The questionnaire was followed up by visits to some of the factories to assess the management attitudes to water and effluent management and to inspect treatment facilitites. The response to the questionnaire was limited to returns from ten companies.

The USA Pulp, Paper and Board Industry was surveyed by the US Environmental Protection Agency in 1980 (4) and their results are summarised in Table 5.1 for the different industry sub-categories. These may be used for comparison purposes.

The RSA pulp and paper mills are listed in Table 5.2 and the paper/board producers in Table 5.3. Because of the diversification of the industry and the relatively small numbers in each sector, no meaningfull interpretation or comparison of mills within RSA is possible.

TABLE 5.1 : Water Usage and Effluent Characterisation of USA Mills

Category	Flow kl/ton	TSS kg/ton	BOD_5 kg/ton
Dissolving Kraft	198	111	70
Market bleached Kraft	159	45	35
BCT bleached Kraft	150	49	48
Alkaline fine	117	79	37
Unbleached Kraft linerboard	47	16	17
Unbleached Kraft bag etc	104	31	24
Semi-chemical	31	30	26
Unbleached Kraft + semi-chemical	53	27	18
Dissolving sulphite	296	141	182
Sulphite papergrade	171	48	67
Groundwood thermo-mechanical	57	42	21
Groundwood papers	109	69	22
Groundwood fine papers	68	54	18
Deink fine	88	174	37
Deink tissue	121	240	83
Tissue : waste	80	62	20
Paperboard : waste	18	11	10
Molded : waste	68	14	7
Builders paper	8	6	6
Non-integrated fine	77	38	14
Non-integrated tissue	85	28	10
Non-integrated lightweigh	236	57	20
Non-integrated nonwoven	165	27	12
Non-integrated paperboard	106	59	25

TABLE 5.2 : RSA Pulp and Paper Mills

Process	Raw Material	Company	Processes
Kraft	Pine + Gum	SAPPI, Tugela	P/B/PM
	Pine + Gum	SAPPI, Ngodwana	P/B/PM
Sulphite	Eucalyptus	SAICCOR	P/B/PM
NSSC	Gum + Wattle	SAPPI, Tugela	P/B
	Wattle	Mondi Board, Piet Retief	P/B/PM
Soda	Bagasse	Mondi Board, Felixton	P/B/PM
	Bagasse	SAPPI, Stanger	P/B/PM
Soda/Oxygen	Gum + Wattle	SAPPI, Enstra	P/B/PM

P = chemical pulping
B = bleach
PM = papermachines
NSSC = neutral sulphite semi-chemical

TABLE 5.3 : RSA Paper and Board Producers

Type	Company
Boards	Paper and Packaging, Pretoria
	RSA Board Mills, Durban
	RSA Board Mills, Bellville
	SAPPI, Adamas
	SAPPI, Enstra
Industrial	RSA Board Mills, Springs
Liner/Fluting/Packaging	Mondi, Felixton
	Mondi, Piet Retief
	Paper and Packaging, Pretoria
	Premier Paper, Kliprivier
	SAPPI, Adamas
	SAPPI, Tugela
	SAPPI, Cape Kraft
Fine Papers, Coated Papers	Mondi, Durban
	SAPPI, Adamas
	SAPPI, Stanger
	SAPPI, Enstra
Tissue	Carlton, Springs
	Carlton, Germiston
	NAMPAK Southern Paper, Bellville
Newsprint	Mondi, Durban
	SAPPI, Enstra
	SAPPI, Tugela

5.2 WATER USAGE

The water usage of the RSA pulp and paper mills is summarised in Table 5.4. Comparison with RSA mills averages (Table 5.1) indicates the very low water usage of the RSA mills in all categories. A more valid comparison can be made with California mills (5) surveyed in 1980 at *8 760 gpd/ton (36 kl/ton)* as California is a relatively water-short state. This comparison also emphasises the low water usage of many RSA mills.

TABLE 5.4 : Water Usage

Mill Type	Production t/a	Water Intake '000 kl/a (mains/other)	Steam '000 t/a	Water Usage kl/t
Integrated				
A	429 000	8217/3118	1001	26
B	263 000	4380/6100	1211	40
C	1 550 000	7000	(720)	5
D	245 000	10290	-	42
E	55 000	5900	-	107
Non-Integrated				
A	42 000	1260	91	30
B	14 000	215/139	38	25
C	32 000	1104	111	35
D	87 000	40/227	244	3

5.3 EFFLUENT PRODUCTION

Effluent production is summarised in Table 5.5 suspended solids loads varied from 0,8 to over 10 kg/ton of product ; COD from 4 to 30 kg/ton and TDS from 28 to 112 kg/ton.

TABLE 5.5 : Effluent Production

Mill Type	Production	Effluent	Analyses			Pollution Load			Discharge
			SS	COD	TDS	SS	COD	TDS	
	t/a	'000 kl/a		mg/l			kg/ton		
Integrated									
A	1 550 000	3 500	-	-	-	-	-	-	I
B	429 000	8 750	54	210	1 440	1,1	4,3	29,4	I
C	263 000	11 360	-	-	-	-	-	-	E
D	55 000	5 600	45-85	300	1 100	4,6-8,6	30,5	112	E
E	245 000	11 620	105	660	-	5,0	31,3	-	E
Non-integrated									
A	31 500	885	75-145	625	1 000	2,1-4,1	17,5	28	S
B	28 000	146	500	-	7 800	0,8	-	40,7	S
C	42 000	1 000	-	-	-	-	-	-	S
D	14 050	310	500	-	1 290	11,0	-	28,5	S

I = irrigation
E = environment
S = sewer

Effluent discharge methods were either to sewer, the environment or by irrigation. Integrated mills used the latter two methods and non-integrated mills the former.

The effluent treatment methods used by the mills is covered in the next section. Mill B in the integrated sector has biological effluent treatment and its COD load is significantly lower when compared to other mills. Mill B in the non-integrated sector has a very low SS loading but high TDS loading due to the very high water recycling practiced.

Pulp and paper mill effluents contains a wide variety of substances including several substances which may be problematic on discharge. These include :-

(i) chlorinated lignin compounds from bleaching,
(ii) fungicides and other biocides used in biological control of recycled water,
(iii) dyes, resins, surface active acids used in papermaking.

5.4 FACTORY EFFLUENT MANAGEMENT PROFILES

Factory A (Integrated Mill)

This factory has extensive effluent treatment facilities consisting of primary settling, with partial recycle of fibre back to the mill ; extended aeration lagoons ; secondary settling and spray irrigation. The suspended solids is reduced from 800 to 78 mg/l and the COD from 378 to 210 mg/l. The TDS of the discharge effluent is 1 440 mg/l.

Some of the fibre removed is returned to the plant and some sold as cattle feed. The biological treatment stage has a 6 day residence and is reseeded once or twice per week. Irrigation is carried out on kikuyu and lucerne with good results.

The factory has a strict pollution management programme aimed at maintaining water consumption at a low level, reuse of fibre and minimising accidental spillages. Extensive research has also been carried out on irrigation methods.

The factory is facing increasing pressure from the authorities to improve the quality of their discharged effluent with regards to COD, SS and TDS.

Factory B (Integrated Mill)

This factory has extensive reuse of process wastewaters and the effluent after primary settling and chemical addition to adjust the sodium absorption ratio is used for irrigation.

Research is being carried out on effluent treatment methods to reduce the TDS and chloride content of the effluent.

Factory C (Wastepaper Mill)

This mill has an extensive water reuse system involving chemical flocculation of the effluent, settling and recycling back to process. Control of the TDS build-up is made by a bleed stream to a municipal sewer. A very high percentage of the suspended solids from the clarifier is reused by the papermachine.

The high TDS in the recycled water causes settling problems with the poor removal of fines, affects papermachine formation and corrosion problems.

Factory D (Non-Integrated Mill)

The factory is pretreated with dissolved air flotation prior to municipal sewer discharge. This reduces the SS to 74 to 144 mg/l (6). About one-third of the effluent is reused. Suspended solids carry-over causes blockages of sprays.

Polyelectrolytes have proven more effective in the flotation system than has alum and the float solids is 3,5 to 4% and is mainly reused.

Factory E (Integrated Mill)

The effluent from this factory is chemically flocculated prior to clarification and then discharged to the environment. Suspended solids above the discharge limit of 50 mg/l is a major problem.

About 60 to 70% of the clarifier solids are reused and extensive recycling of the papermachine effluent is carried out. However fines in the recycled effluent causes problems on reuse.

The NSCC plant has an evaporator and the condensate is reused for pulp washing, log handling and other duties.

Factory F (Integrated Mill)

The factory effluent prior to discharge to river is treated by clarification, extended aeration lagoons and a maturation pond. COD is reduced from 2 400 to about 350 mg/l by the treatment.

Factory G (Non-Integrated)

The effluent is screened, flocculant dosed, clarified and filtered. The sludge is belt-filtered and then sent to a waste disposal firm. 67% of the effluent is reused by the factory.

Factory H (Non-Integrated Mill)

The effluent is discharged to municipal sewer.

Factory I (Integrated Mill)

Effluent is clarified prior to discharge to a sea outfall after dilution with secondary municipal effluent. The settled sludge is dewatered by centrifugation prior to landfull dumping.

Factory J (Wastepaper Mill)

The effluent is treated by extended aeration and a clarfier. A significant portion of the treated effluent is reused by the mill and the remainder discharged to municipal sewer. Approximate mill savings are about 75% by reuse of the clarified water.

Factory K (Wastepaper Mill)

Effluent is extensively reused after screening.

Factory L (Wastepaper Mill)

Effluent is treated with a chemical flocculant and centrifuged. Part of this treated effluent is recycled and the excess discharged to municipal sewer.

Factory M (Integrated Mill)

Effluent is clarified, treated in an aerobic lagoon and then discharged to the environment.

Factory N (Integrated Mill)

Effluent is pumped to a holding dam and used for spray irrigation onto pasture.

Factory O (Integrated Mill)

The mill effluent is screened and then discharged to the environment.

Factory P (Non-Integrated Mill)

The effluent is clarified prior to sewer discharge.

Factory Q (Non-Integrated Mill)

The effluent is clarified prior to sewer discharge.

Factory R (Non-Integrated Mill)

The effluent is clarified prior to sewer discharge.

5.5 SURVEY CONCLUSIONS

5.5.1 General Conclusions

5.5.1.1 A high percentage of mills have implemented pollution control measures and view water and effluent management as a high priority.

5.5.1.2 Most mills have implemented partial treatment of their effluent particularly for reuse purposes.

5.5.1.3 Mill management are aware that environmental pressure is increasing and would like a co-ordinated long term plan to be worked out with the authorities to phase in effluent treatment when warranted for their particular mill.

5.5.1.4 Extensive water reuse is practiced on papermachines at most mills. A recurring problem is the poor removal of suspended solids fines using existing save-all devices.

5.5.1.5 Good-housekeeping varied from good to poor with, in general, insufficient detail paid to effluent management particularly in the handling of spills and having a suitable person responsible for effluent matters.

5.5.1.6 Co-ordination of effluent management and treatment was, in general, reasonably good but technical decision making was often at a low level within the company. A clearly defined effluent management strategy was lacking in several cases.

5.5.2 Integrated Mills

5.5.2.1 Treatment of black liquor for chemical reuse and heat energy recovery has been common-place in RSA for sometime.

5.5.2.2 To reduce chloride loads from bleaching. SAPPI developed the SAPOXAL oxygen bleaching process and this has been implemented at their bleach plants.

5.5.2.3 Extensive process wastewater cascading and recycling is practiced and this minimizes effluent discharges.

5.5.2.4 The two main areas of effluent production are bleaching and papermachines.

5.5.2.5 SAICCOR, until recently was not able to treat black liquor (spent-sulphite liquor) because of the chemistry base, has recently upgraded and extended their mill with alternative technology involving black liquor treatment.

5.5.2.6 RSA mills in general have been very successfull in reducing water consumption and using secondary water sources (secondary sewage) in response to the relatively high cost and scarcity of water.

5.5.3 Non-Integrated Mill

5.5.3.1 Extensive reuse of papermachine effluent is practiced. Nearly all mills reported difficulties with suspended solids fine blocking showers and some reported increased corrosion problems.

5.5.3.2 The high recycling of effluent at some mills was causing problems with the discharge of bleed streams due to high TDS, SS and COD contents.

5.5.3.3 Not all mills can practice high recycling levels due to colour and other contaminants brought in with wastepaper. This would only be achievable if the effluent were further treated after primary treatment (clarification or filtration) to remove these undesirable compounds.

6.1 POLLUTION SOURCES

The main pollution sources of a pulp and paper mill are given in Figure 6.1 and Table 6.1. The major pollutants are suspended solids, organic materials and dissolved salts.

6.1.1 Suspended Solids

The main suspended solids load are :-

(i) fine bark particles and silt from the debarkers.
(ii) fibres and fibre particles from pulp and papermaking operations.
(iii) coating and filling materials from papermaking.

The settleable solids portion is usually in the range 75 to 90% of the total suspended solids. Much of the non-settleable solids is very fine and colloidal material is difficult to remove by conventional methods. Inorganic consistuents are often 10 to 40% of the TSS concentration.

6.1.2 Soluble Organics

These include wood sugars, carbohydrates and lignin compounds removed from the wood during pulping and bleaching. Depending on the pulping procedure, up to half the wood is dissolved and becomes a pollution load. The soluble organic have a high COD or BOD load and hence their direct discharge to the environment may cause serious deterioration of the receiving stream.

TABLE 6.1 : Water Sources

WOOD PREPARATION Washwater Reject dewatering effluent Floor Drains	**MACHINE ROOM** Overflows Save-all filtrates Size tank washout Cooling waters Overflows Floor drains
EVAPORATORS Condenser effluent Cooling water Floor drains Evaporator Washout tail water Liquor storage overflows	**CAUSTICISING AND LIME** Dregs Slaker grit drainings Overflows Cooling waters Floor drains
PULPING Blow-down condensate Relief condensate Cooling water Turpentine decanter water Tall oil processing water Floor drains Overflows Pulp washing overflow Chest washouts	**POWER PLANT AND WATER** Ash drainage Cooling water Boiler blow-down Softener regeneration Filter backwash Sedimentation blow-down
BLEACHING Chemical preparation Chlorination effluent Acid effluent Extraction effluent Floor drains Overflows	

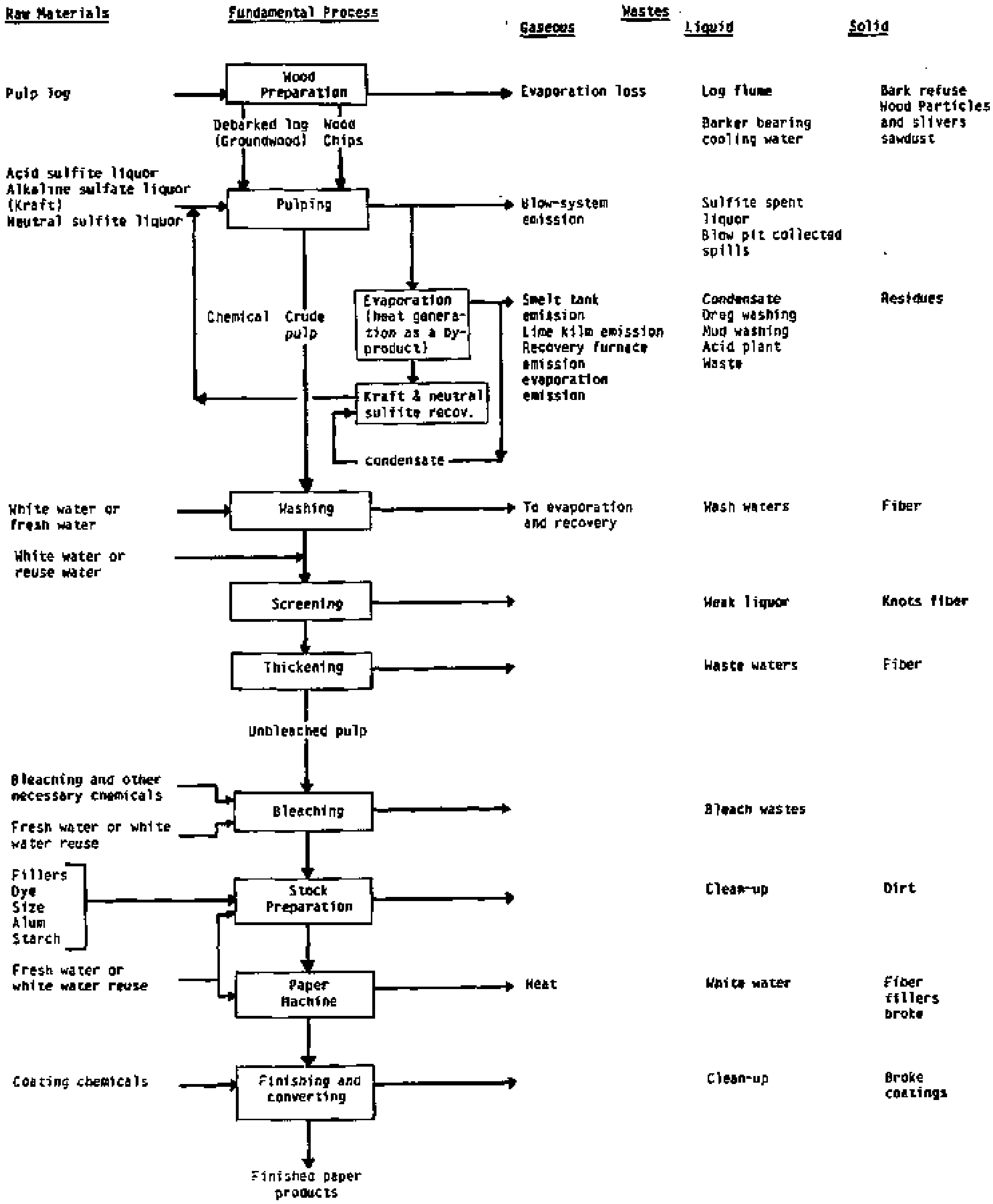

FIGURE 6.1 : General flow sheet
Pulping and papermaking process

When chemical recovery of pulping effluents is practiced, particularly in the Kraft process, a major proportion of the organic material is destroyed by combustion to produce heat energy.

Bleach effluents are not normally recovered and become the major pollution source of many pulp mills. This effluent is high in colour and chlorinated lignin compounds, colour reductions may be obtained by hypochlorite or oxygen bleaching technique or by physico-chemical effluent treatment.

The yield loss in bleaching for various types of pulp is given in Table 6.2. Bleaching effluents are very complex (7) and contain a wide range of low and high molecular weight compounds including, for example, oxalic acid, dichlorophenol, chloroform, trichloroethene and pentachlorobenzene. Spent chlorination and alkali extraction liquors are considered to be mildly toxic to fish and other aquatic organisms, with the chlorinated catecohols contributing significantly to the toxicity. Certain compounds in bleach effluents have also been shown to be mutagenic (chloroacetone, chlorofuranone and chloropropenol) and carcinogenic. However, a recent evaluation of three major inland receiving waters in Sweden (8) identicated that the pollution risk was extremely low as on dilution these compounds were at a concentration below those of identical compounds formed during the disinfection of drinking water by chlorination.

TABLE 6.2 : Yield Loss (kg/ton) of Pulp in Bleaching

Source	Kraft Pulp		Sulphite Pulp	
	Softwood	**Birch**	**Paper**	**Raylon**
Lignin Polysaccharides Extractives	50 19 1	20 22 3	35 12 8	12 70 8
Total	70	45	55	90

6.1.3 Soluble Inorganics

Pulping liquors contain the pulping chemicals and when not recovered produce high TDS effluents. To a limited extent, pulping liquors are found in the final effluent due to black liquor spills, washing liquors, pulp mill overflows and chemical storage tank overflows. The inorganic compounds are largely salt cake, sodium, calcium, carbonates, sulphates and may be of high pH and temperature.

Bleaching liquors are usually high in chloride and these are usually discharged as effluents.

6.2 POLLUTION CONTROL IN PRACTICE

Pollution control is extensively practiced in the pulp and paper industry because of the high pollution load of their effluents. The two methods practiced are :-

(i) production process controls,
(ii) effluent treatment.

Most mills use a combination of hence two methods. In some cases, both methods can yield comparable results. For example, for suspended solids removal, equipment may be employed internally to allow reuse of clarified water in process and recovered solids in the product, or externally, end-of-pipe for suspended solids removal from the effluent.

6.2.1 Production Process Controls

Production process control are used for pollution control and more importantly for control of loss of product, product characteristics and improvement of process economics.

Commonly used methods are listed in Table 6.3.

TABLE 6.3 : Commonly Used Production Process Controls

High level alarms on tanks
Reuse of decker filtrate (e.g. to vacuum wash showers or dilution)
Reuse of evaporator condensate (e.g. to brown stock washing)
Recooking of screen room rejects
Reuse of chlorine dioxide acid for tall oil manufacture
Reuse of green liquor filter dregs
White water showers or wire cleaning
Broke storage and overflow prevention
Save-alls
Use of wastewater in woodyard
Turpentine collection
Soap collection
Sulphite red liquor evaporation and disposal
Counter-current washing
Reuse of decker filtrate in screen room
Counter-current or jump stage washing in bleaching
Evaporator condensate reuse for causticising make-up
White water storage during upsets and reuse in repulping
Cooling water segregation and reuse
Dry barking
Spill collection
Reuse of vacuum pump sealing waters
Stock and liquor spill collection
Lime mud pond
Reuse of press effluent
High pressure showers for wire and felt cleaning

The control methods applicable to the various areas of the mills are discussed in more detail (Table 6.4).

TABLE 6.4 : Production Process Controls and Effluent Treatment Technology

PRODUCTION PROCESS CONTROLS
1. WOODYARD/WOODROOM
a) Close-up or dry woodyard and barking operation
b) Segregate cooling water
2. PULP MILL
a) Reuse relief and blow condensates
b) Reduce groundwood thickener overflow
c) Spill collection
3. WASHERS AND SCREEN ROOM
a) Add 3rd or 4th stage washer or press
b) Recycle more decker filtrate
c) Reduce cleaner rejects and direct to landfill
d) Replace sidehill screens
4. BLEACHING
a) Counter-current or jump stage washing
b) Evaporate caustic extract filtrate
5. EVAPORATION AND RECOVERY AREAS
a) Recycle condensate
b) Replace barometric condenser
c) Boil out tank
d) Neutralize spent sulfite liquor
e) Segregate cooling water
f) Spill collection
6. LIQUOR PREPARATION AREA
a) Green liquor dregs filter
b) Lime mud pond
c) Spill collection
d) Spare tank

TABLE 6.4 (continued)

7. PAPER MILL

a) Spill collection
   1. Papermachine and bleached pulp spill collection
   2. Color plant
b) Improve save-all
c) High pressure showers for wire felt cleaning
d) White water use for vacuum pump seal water
e) Papermachine white water shower wire cleaning
f) Additional white water storage upsets and pulper dilution
g) Recycle press effluent
h) Reuse of vacuum pump water
i) Broke storage
j) Wet lap machine
k) Separate cooling water
l) Cleaner rejects to landfill

8. STEAM PLANT AND UTILITY AREAS

a) Segregate cooling water
b) Lagoon for boiler blow-down and backwash waters

9. RECYCLE OF EFFLUENT

a) Filtrate
b) Sludge

OTHER TECHNOLOGIES

a) Oxygen bleaching process
b) Rapson/Reeve process
c) Oxygen pulping process

EFFLUENT TREATMENT TECHNOLOGIES

1. Primary clarification
2. Biological treatment
   a) Activated sludge
   b) Aerated stabilization basin
3. Chemically assisted clarification
4. Foam separation
5. Activated carbon adsorption
6. Steam stripping
7. Reverse osmosis
8. Filtration
9. Dissolved air flotation
10. Ultrafiltration
11. Polymeric resin adsorption
12 Amine treatment
13. Electro-chemical treatment

6.2.1.1 Woodyard

Applicable control methods are :

(i) conversion to dry systems,
(ii) close-up wet operations,
(iii) segregation and reuse or direct discharge of uncontaminated cooling waters.

6.2.1.2 Pulp Mill

Applicable control methods are :

(i) reuse of digester relief and blow condensates,
(ii) reduction of groundwood thickener overflow,
(iii) spill collection in the brown stock, digester and liquor storage areas.

Reuse of digester condensates is applicable to all Kraft and soda mills and they may be reused in various mill areas for brown stock washing, mud washing or black liquor make-up. Wastewater BOD_5 reductions of 0,9 to 3 kg per ton of pulp have been demonstrated.

Spill collection is relatively straight forward and savings of 1,5 to 3,5 kg BOD_5/ton pulp have been recorded.

6.2.1.3 Brown Stock Washers and Screen Room

Control methods include :

(i) improve washer efficiency by adding more stages,
(ii) recycle more decker filtrate,
(iii) discharge cleaner rejects to landfill.

Improved washing efficiency is applicable to most mills and in most sectors. Improved washing results in lower bleaching chemical costs and gives BOD_5 load reductions of about 2,5 to 4 kg/ton of pulp.

Increasing the reuse of decker filtrate for brown stock washing is applicable to Kraft, soda, groundwood and deinking mills and also reuse in the screen room as diluted water gives substantial effluent and BOD load reductions of approximately 4 kl/ton and 0,5 to 1 kg/ton respectively.

Centricleaner and continuous screen rejects may be dry collected for separate discharge to landfill. Load savings on final effluents are typically 2 to 3 kg TSS/ton pulp.

6.2.1.4 Bleaching

Bleaching effluent is a major source of wastewater from most integrated mills. Applicable control methods are :-

(i) counter-current washing,
(ii) evaporation of caustic extraction filtrate at sulphite mills.

Counter-current and jump-stage washing is applicable to Kraft and soda mills and many sulphite mills. Details depend on the bleaching sequences and materials of construction of equipment. Flow reductions of 8 to 25 kl/ton at Kraft/soda mills are 30 kl/ton at papergrade sulphite mills are possible.

The caustic extraction filtrate at sulphite mills is highly polluting and its segregation and evaporation will reduce BOD_5 loading by 40 to 123 kg/ton of pulp.

6.2.1.5 Evaporation and Recovery Systems

Applicable control methods include :-

(i) recycle of condensate
(ii) replacement of barometric condenser with a surface condenser
(iii) addition of a boil-out tank
(iv) neutralisation of spent sulphite liquor

(v) segregation of cooling water
(vi) spill collection.

These measures are implemented at most mills.

6.2.1.6 Liquor Preparation Area

Reduction in pollution loads may be achieved by spill collection, filtration of green liquor dregs at Kraft or soda mills and the use of a lime mud pond at Kraft mills.

6.2.1.7 Papermachines

Applicable control methods include :-

(i) papermachine, furnish and colour plant spill collection.
(ii) Save-all improvements.
(iii) High pressure showers for felt and wire washing.
(iv) White water use for vacuum pump cooling.
(v) White water showers for wire cleaning.
(vi) White water storage for upsets and paper dilution.
(vii) Recycle of press effluent.
(viii) Reuse of vacuum pump water.
(ix) Provision of additional broke storage.
(x) Installation of wet lap machines.
(xi) Segregation of cooling water.
(xii) Collection of cleaner rejects for landfill disposal.

Improvements to papermachine are illustrated in Figure 6.2. Spill collection can result in substantial stock savings and a reduction of TSS load of up to 2,5 kg/ton.

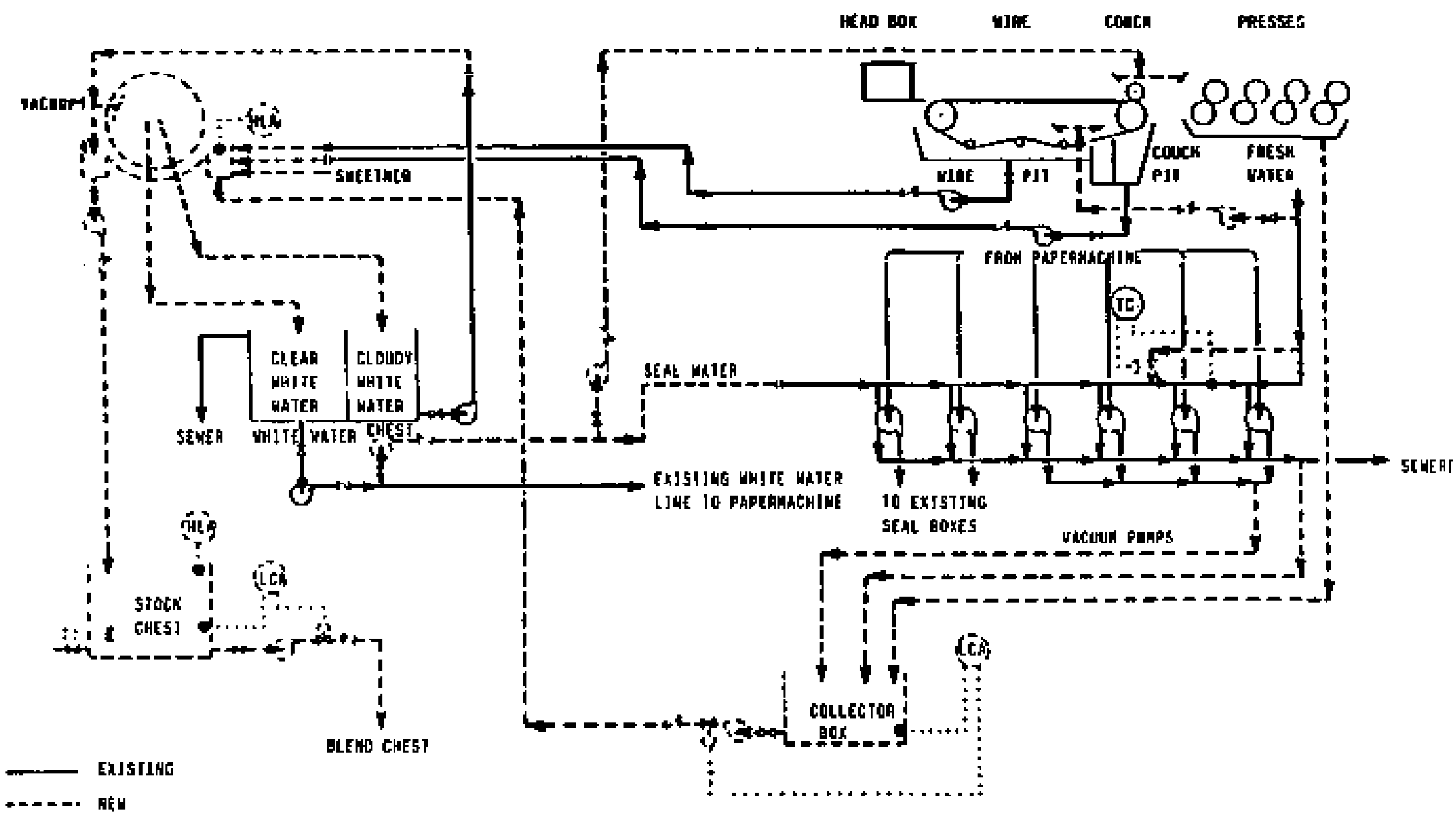

FIGURE 6.2 : **Paper Mill Improvements - Unbleached Kraft**

Save-alls are employed on all types of machine and the incorporation of the vacuum disk type filter is more widespread. Their use results in flow and solids reductions. Nearly all the stock saved may be reused and the filtered white water reused in the mill instead of fresh water. Flow reductions are in the range of 1 to 42 kl/kg depending on the type of mill and level of white water reuse.

The use of high pressure for vacuum pump sealing and wire cleaning depends on being able to clarify the white water to a suitable standard and an assessment of corrosion aspects.

The other control methods are general control methods to improve efficiency of operation and good house keeping.

6.2.1.8 Steam Plant and Utilities

Reuse of cooling waters from miscellaneous sources such as pump and bearing cooling, air compressor cooling, turbine and condensor cooling provides a flow reduction measure and also provides for energy savings.

Boiler blowdown and filter/ion-exchange washwaters should be segregated and discharged separately or considered for reuse in non-critical water use areas.

6.2.1.9 Recycle of Effluent

In the secondary fibre and non-integrated sectors of the industry, water usage may be reduced by recycling clarified effluent to various mill areas. In addition the recycle of clarifier solids can yield substantial savings in raw material costs and reducing solids disposal costs.

6.2.1.10 Chemical Substitution

Chemical substitution may assist in reducing undesirable chemicals in the mill effluent. One example is the replacement of zinc hydrosulphite with sodium hydrosulphite used in the bleaching of mechanical pulps to eliminate zinc from the effluent. Others are replacement of ammonia and phosphate based chemicals and the use of more environmentally compatible slimecide and bactacide formulations.

6.2.2 Process Control Technology Advances

Several treatment related process control advances have been made particularly related to bleaching systems :-

(i) Oxygen bleaching.
(ii) Billerud Uddeholm ion-exchange system.
(iii) Rapson-Reeve closed-cycle bleaching.

6.2.2.1 Oxygen Bleaching (9,10)

Oxygen bleaching is currently used at only one mill in the United States, the Chesapeake Corporation in Virginia (11), at one mill in Canada, one in South Africa, one in France, one in Japan, and three in Sweden (12).

The advantage of oxygen bleaching come from the recycling of the alkaline O_2 stage effluent to the black liquor recovery system. In order to recycle the effluent, it is necessary to keep the chloride content of the O_2 stage at a low level. For this reason, the O_2 bleaching sequences being used generally have the O_2 stage preceding any Cl_2 or ClO_2 stage. The exception to this is at the Chesapeake Corporation, where a COD sequence is used that does not allow for recycle of the O_2 stage to the recovery system.

In work done by the NCASI, effluent characteristics from conventional and oxygen bleaching sequences were compared. The conventional sequence CEHDED and CEDED were compared in the lab to those from OCEDED and OCED for both hardwood and softwood alkaline pulps. By recycling all of the O_2 stage effluent, a BOD_5 reduction of 81% and a colour reduction of 89% over the conventional sequences were achieved for softwood pulps. For hardwood, reductions of 81% of BOD_5 and 92% of colour were achieved (13).

At the Cellulose d'Aquitaine mill in St. Gaudens, France, total BOD_5 load and the total colour load have reportedly been reduced by about 30 to 50%, respectively. An existing CEDED sequence has been converted to an OCEDED sequence (9). The claimed operating cost for the new oxygen bleach sequence is \$2,10/ton (1975) less than for the old sequence.

The Enstra oxygen bleaching operation in South Africa has achieved a cost reduction of \$5,00/ton (1972) with an AODED sequence. The capital cost of adding an oxygen stage was given as \$2,0 million (1972) for a 270 kkg/day (300 tons/day) mill and \$4,0 million (1972) for a 680 kkg/day (750 tons/day) mill (10). The technology is still being developed and is not routinely used in alkaline pulp mills in the United States.

6.2.2.2 Rapson-Reeve Closed-Cycle Process (14,15)

The Rapson-Reeve closed-cycle process encompasses some standard design features likely to be employed at many Kraft pulp mills in the future. The concepts of the closed-cycle mill, as proposed by ERCO-Envirotech, Ltd. and illustrated in Figure 6.3, are included in the system under development at Great Lakes Paper Company, Ltd., Thunder Bay, Ontario.

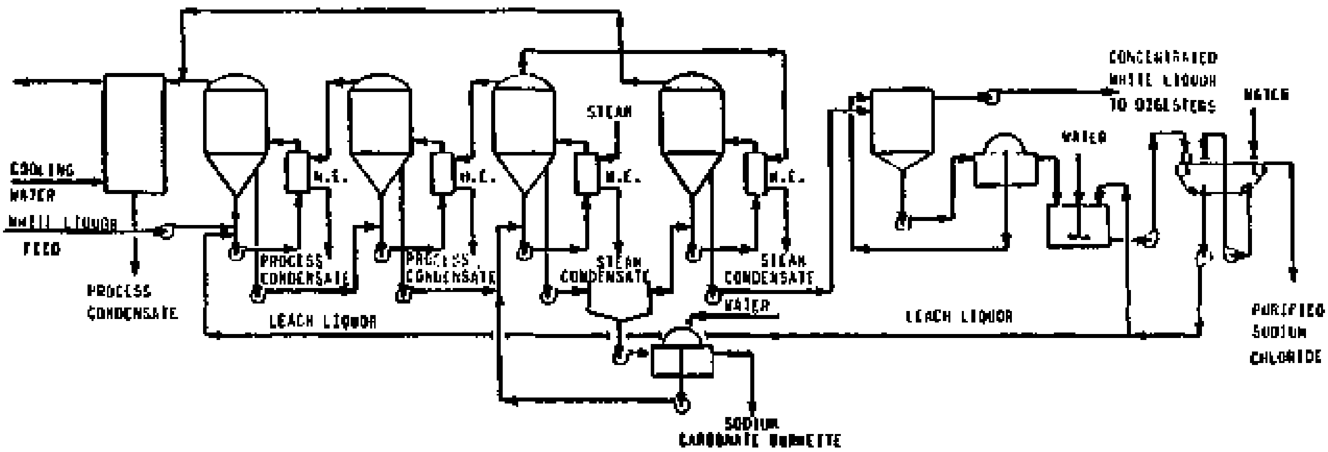

FIGURE 6.3 : Rapson-Reeve Closed-Cycle Mill Salt Recovery System

One of the features, of the closed-cycle process is the use of approximately 70% chloride dioxide in the first stage. It has been claimed that the use of chlorine dioxide will decrease effluent BOD_5, colour chemical oxygen demand (COD), dissolved solids, and toxicity even at a mill that is not completely closed (16). The bleach sequence for the closed-cycle bleached Kraft is DCEDED. The washing design is straight counter-current; excess E_1 stage filtrate can be pumped to the salt recovery process, used for cooking liquor dilution, or used on the brown stock washers. The DC filtrate can be used for brown stock washing, screen room dilution, or sent to the lime kiln scrubber.

Of these features, the only one that is unique to the closed-cycle mill is the salt recovery process. The salt recovery process (SRP) is necessary in the closed-cycle mill in order to remove the sodium chloride that would otherwise build up in the system. In the closed-cycle mill, the white liquor is evaporated and sodium chloride is crystalized and removed from the white liquor. Recovered salt is to be reused for the generation of ClO_2 ; however, some must be purged from the cycle.

ERCO-Envirotech have stated that use of the design features of the closed-cycle mill will result in a :-

a) energy savings
b) fibre savings
c) yield increase
d) decreased water consumption
e) decreased chemical costs and
f) savings in effluent treatment costs.

According to ERCO-Envirotech, for a closed-cycle Kraft mill producing 635 air dry kkg/day (700 air dry tons (ADT) per day), an SRP system would have a capital cost of $4.2 million (1977). Implementation of production process controls could run as high as $3.8 million (1977), making the total cost for a closed-cycle mill about $8 million or more. The additional ClO_2 generating capacity and any major bleachery modifications requiring more corrosion resistant materials will results in yet higher costs (17). Original estimates predicted that savings of $4 million per year (1977) could be achieved when compared to a mill having none of the features of the closed-cycle mill.

Full-scale operating experience has been less favorable than the early literature had projected. Some contaminated effluent is being discharged and, while the salt recovery system has been operated, the recovered salt has not been used on-site (17,18). It was originally thought that chemical costs would be lower for a closed-cycle mill than for conventional mill. However, actual chemical costs at Great Lakes Paper Co., Ltd. have been higher than for a conventional mill (16).

On implementation of the closed-cycle system, corrosion problems occurred at the Thunder Bay facility. A combination of high temperatures (480°C (900°F)) and high chloride levels resulted in badly corroded tubes in the recovery boiler superheater. The damaged equipment was replaced with equipment made of Incaloy 880 and the superheater has been operated at lower temperatures (390°C (730°C)). This has permitted operation of the system without noticeable pitting (19).

The Thunder Bay facility was designed to operate effluent-free at a production rate of 730 kkg/day (800 t/d). However, actual production has been increased to about 870 kk/day (960 t/d) and the SRP has been unable to handle the resulting increased load (16). Liquor pump failures and evaporator scaling are the primary problems now being experienced in the SRP. At the request of representatives of the government of the province of Ontario, mill personnel are now planning the construction of a biological treatment system to be completed by the end of 1981. While the goal of an effluent-free mill has not been realised, reductions in the BOD_5 raw waste load of 50 to 75% of that of a typical market bleached Kraft mill have been attained. Even higher reductions have been achieved when the SRP has been operated within the specified design load (19).

6.2.2.3 Sequential Chlorination

Another method of reducing the pollution load from the bleach plant is with sequential chlorination.

Sequential chlorination is based on initially contacting the unbleached pulp with ClO_2 equal to a portion of the equivalent chlorine demand. The reaction is rapid, the remainder of the chlorine demand is satisfied with chlorine addition. Strength and viscosity improvements have been noted and total chemical applications has been reduced (20).

MacMillian Bloedel Research views the use of sequential chlorination as an interim solution while oxygen bleaching technology, ClO_2 generation, and salt recovery systems are developed. When these technologies are fully developed, lower capital expenditures may be realized (21).

Hooker Chemical has investigated the use of sequential chlorination ; their work has dealt with modification of fully bleached sequences. The first sequential chlorination system studied by Hooker Chemical was the APS-I. In this system, the standard CEHD or CEDED sequence is modified by replacing conventional chlorination with sequential chlorination at a D:C ratio of 50:50 and substituting a hypochlorination stage for the first extraction stage. The system can be used for hardwood or softwood pulps. Substantial reductions in effluent colour and toxicity and moderate reductions in BOD_5 are reported (20).

Chemical costs for the APS-I system are reported to be equivalent or slightly higher than for conventional sequences. Estimated capital cost range from $20,000 to $500,000 (1973) depending on the mill size and condition of the existing bleach plant. Pulp quality is equivalent to that from conventional bleaching sequences.

The Hooker APS-II and APS-III systems operate differently than the APS-I. Chlorination is replaced by sequential chlorination, at a D:C ratio (75:25) and conventional caustic extraction is employed. This minimizes the chloride content of the bleach plant effluent and permits recycling of the effluent into the Kraft recovery system to allow incineration of a major organic waste load. The APS-II and APS-III systems suggest a sequence of antipollution steps that my be implemented one at a time. These steps and the BOD_5 and colour reductions obtained through implementation of each step are shown in Table 6.5. This process is reported to involve the use of existing or slightly modified bleach plant equipment and produces pulp with properties equivalent to or superior to that of conventional processes. Hooker also claims reduced chemical and operating costs. The process allows for a recovery of caustic, sodium sulfate, and sodium chloride that would normally be sewered.

TABLE 6.3 : Waste Load Reductions from Implementation of Hooker APS-II and APS-III Systems (20)

Step No., Operation	Effluent		BOD_5		% BOD_5	Colour		% Colour
	kl/kg	(kgal/t)	kg/kkg	(lb/ton)	Reduction	kg/kkg	(lb/t)	Reduction
Control standard	75,1-83,4	(18-20)	12,5	(25)	-	325	(650)	-
APS-II								
1. Counter-current wash-jump stage, split flow	45,9-54,2	(11-13)	12,5	(25)	-	325	(650)	-
2. Replace chlorination with sequential chlorination - 75:25 D:C ratio	45,9-54,2	(11-13)	11,0	(22)	12	188	(376)	42
3. Recycle D/C effluent to dilute incoming brown stock	25,0-33,4	(6- 8)	11,0	(22)	12	188	(376)	42
4. Dilute sequential chlorination stock with part E_1 and recycle remainder to recovery via brown stock washers and smelt dissolving system	16,7-25,0	(4- 6)	5,0	(10)	60	43,5	(87)	87
5. Use salt separation process to purge NaCl and separate Na_2SO_4 from precipitator catch	16,7-25,0	(4- 6)	5,0	(10)	60	43,5	(87)	87
APS-III								
6. Treat D/C effluent in a resin packed column and regenerate resin with a portion of E_1 effluent	16,7-25,0	(4- 6)	4,5	(9)	64	11,5	(23)	96

Displacement bleaching is used at the Temple Eastex mill in Evadale, Texas, where operation began in 1975. This was followed by the start-up of a system at Weyerhaeuser Corporation in Plymouth, North Carolina, in 1976. Both systems are Kamyr designed, with a conventional D/C first stage tower and washer preceding an EDEDW displacement tower. The caustic is applied at the repulper of the conventional washer. The pulp is then pumped into the bottom of the displacement tower (D_1) at about 10% consistency. The displacement tower has a retention time of about 90 minutes. Each stage in the tower is followed by a stage of diffusion washing with the filtrate being extracted to a seal tank and then partially reused (22). A final displacement tower (D_2) provides up to 4 hours detention and washing using papermachine white water at the Plymouth mill.

6.2.3.4 Displacement Bleaching (23)

There are four filtrate tanks for the displacement towers. These tanks are of a stacked design with one set of tanks for each caustic extraction stage and one set for each chlorine dioxide stage. Caustic extract is generally reused on the conventional washer and is mixed with the NaOH added at the repulper of the conventional washer prior to pumping to the displacement tower. Some chlorine dioxide stage filtrate is also mixed with ClO_2 to be reused on the D_1 and D_2 stages. Overflow from the seal tanks are sewered. Water use for a D/CEDED displacement bleach sequence is typically 12,5 to 18,8 kl/kkg (3,0 to 4,5 kgal/t) compared to conventional tower washer system often exceeding 50,0 kl/kkg (12,0 kgal/t) (23).

The benefits associated with displacement bleaching are lower water use and slightly lower initial capital costs. Based on limited data, it appears that chemical usage may actually be higher than for conventional bleaching systems (23).

6.3 EFFLUENT TREATMENT PRACTICES

6.3.1 Preliminary and Primary Treatment

Wastewater must often be screened to remove materials that could seriously damage or clog downstream treatment equipment. Automatically cleaned screen are commonly empolyed prior to primary treatment and generally represent the preferred practice.

The initial process of removing organic and inorganic solids can be accomplished by sedimentation (with or without flocculants or coagulants), flotation, or filtration. Primary treatment can involve mechanical clarifiers, flotation units, or sedimentation lagoons.

The most widely applied technology for removing solids from pulp, paper, paperboard mill wastewaters is the mechanical clarifier. In the mechanical clarifier, solids are removed by simple sedimentation. Dissolved air flotation (DAF) units have also been applied to remove solids from paper mill effluents (24). DAF units are somewhat limited in use because of their inability to handle high pollutant concentrations and shock load. Fine screens, microstrainers, and pressure filters are not commonly used in the industry for solids removal. Adequate fine screening system cost approximately the same as an equivalent clarifier and reportedly have more inherent operating problems (25).

Because of the biodegradable nature of a portion of the settleable solids present in pulp, paper, and paperboard mill wastewaters, clarification can result in some BOD_5 reduction. Typical BOD_5 removal through primary clarification of integrated pulp and paper mill effluent can vary between 10 and 30%. The exact BOD_5 removal depends on the percentage of soluble BOD_5 present in raw wastewater. Primary clarification can result in significantly higher BOD_5 reductions at non-integrated mills than at integrated mills. Responses to the data request program indicate that approximately 50% of the raw wastewater BOD_5 is commonly removed at non-integrated mills through the application of primary clarification.

Easty has recently observed that very little reduction of fatty acids, resin acids, or their chlorinated derivatives occurs during primary clarification (26). This observation suggests that these compounds are not associated with the raw wastewater solids measured in the TSS test procedure.

Polychlorinated bi-phenyls (PCBs) have been observed to undergo significant reductions through primary treatment (27). At a wastepaper tissue mill, PCBs were reduced from 25 to 2.2 micrograms per litre (ug/l) through primary clarification, while TSS were reduced from 2,020 to 77 milligrams per litre (mg/l)(27). It has not yet been established whether reductions occur for other chloro-organic compounds.

6.3.2 Biological Treatment

Currently, the most common types of biological treatment used, in the pulp, paper, and paperboard industry include oxidation basins, aerated stabilization basins, and the activated sludge process or its modifications. Other biological systems that have been used include rotating biological contactors and anaerobic contact filters.

A principal benefit obtained from biological treatment is the reduction of oxygen demand. Significant reductions in toxic pollutants have also been observed through applications of biological treatment. Biological treatment systems have been designed and operated to achieve 80 to 90% and higher BOD_5 reductions when applied to pulp, paper, and paperboard mill effluents. Biological treatment can also yield a nontoxic effluent a higher percentage of the time (28).

A recent study involved investigation of influent and effluent concentrations of toxic and non-conventional pollutants after full-scale biological treatment (26). Removal rates of these pollutants, as derived from the published design and treatment data, are shown in Table 6.6. The relative removal rates generally agree with those obtained in laboratory studies (26,29).

TABLE 6.6 : Calculated Toxic and Non-Conventional Pollutant Removal Rates(a) (26)

	Mill 9(b) 10 - Day ASB	Mill 11(b) 6 - Day ASB	Mill 12(c) 3,5 - Hr AS	Mill 13(b) 12 - Day ASB	Mill 14(b) 7 - Day ASB	Mill 15(b) 15 - Day ASB
RESIN ACIDS						
Abietic	0,85	0,86	0,3	1,5	1,0	0,45
Dehydroabietic	1,05	2,65	0,6	1,85	1,1	0,72
Isopimaric	0,30	0,37	0,26	1,25	3,0	0,12
Pimaric	0,10	0,14	0,3	0,3	0,3	0,15
UNSATURATED FATTY ACIDS						
Oleic	-	0,7	0,35	0,55	-	0,67
Linoleic	-	2,6	0,30	0,15	-	0,47
Linolenic	-	0,4	-	-	-	-
OTHER ACIDICS						
Epoxysteric acid	-	-	-	-	-	0,03
Dichlorosteric acid	-	-	-	10,4	-	0,12
CHLORINATED RESIN ACIDS						
Monochlorodehydroabietic	-	0,10	0,006	0,03	-	0,01
Dichlorodehydroabietic	-	0,05	0,019	0,10	-	0,03
CHLORINATED PHENOLICS						
Trichloroguaiacol	-	0,03	-	-	-	-
Tetrachloroguaiacol	-	0,02	-	-	-	-
CHLOROFORM	-	2,2	2,1	-	-	-

(a) Removal rates shown as micrograms removed per milligrams/litre (mg/l0) of biomass per day.
(b) Aerated stabilization basin (ASB) biomass assumed to be 200 mg/l
(c) Activated sludge (AS) biomass reported to be 2,500 mg/l.
Note : Blank blank spaces indicate no data.

BOD_5 and toxic pollutant removals from bleached Kraft wastewater through application of activated sludge treatment and aerated stabilization were investigated in an attempt to establish a relation between pollutant concentration and toxicity (28). The authors conclude that, in general, a reduction in BOD_5 to about 45 mg/l was sufficient to achieve detoxification of the waste. Also, a total resin and fatty acid concentration of less than 1 mg/l was necessary to effect detoxification. The correlation between total resin and fatty acid content and toxicity was better than the correlation between BOD_5 and toxicity.

6.3.2.1 Oxidation Basins

The first type of biological treatment system used in the pulp, paper, and paperboard industry were oxidation basins. These are large natural or manmade basins of various depths, natural aeration from the atmosphere is relied on as the primary oxygen source. Additionally, limited oxygen is provided by algal photosynthesis. The amount of oxygen provided through photosynthesis is dependent upon the basin configuration (depth) and its restriction in light penetration. Since oxidation through natural aeration is a relatively low-rate process, large land areas are required to effectively treat high strength wastes. Because of availability of land and a warm climate that enhances bioactivity, most oxidation basins are found in southern states. This technology can be more effective if settleable solids are removed from the wastewater prior to discharge to the basins. Solids can contribute significantly to the BOD_5 wastewater loads. In addition, excess settleable solids tend to fill the basins, thus reducing detention time.

Typical design BOD_5 loads range from 56 to 67 kilograms per hectare (kg/ha) of surface area/day. Retention times can vary from 20 to 60 days or more (30). This method of treatment has two principal advantages :

(a) it can be capable of handling (buffering) accidental discharges of strong wastewater without significant upset and,

(b) it requires no mechanical devices with inherent maintenance problems.

Oxidation basins have been used to effectively treat pulp, paper and paperboard industry wastewaters. Generally, suspended solids are effectively removed in oxidation basins. However, high levels of suspended solids have been noted due to algal carryover. Literature presenting data on the removal of toxic and non-conventional pollutants through application of oxidation basin technology is limited.

6.3.2.2 Aerated Stabilization Basins (ASB)

The aerated stabilization basin (ASB) evolved from the necessity of increasing performance of existing oxidation basins due to increasing effluent flows and/or more stringent water quality standards. Induced aeration provides a greater supply of oxygen, thus substantially reducing the retention time required to achieve treatment comparable to that attained in an oxidation basin. Nitrogen and phosphorus (nutrients) are usually added prior to the ASB if the wastewater is determined to be nutrient deficient. These additions are commonly made in the form of ammonia and phosphoric acid. The longer the retention period of the waste undergoing biological oxidation, the lower the nutrient requirement. The specific detention time used depends upon the characteristics of the wastewaters to be treated. Retention times of 8 to 10 days, and sometimes up to 15 days, have been used in order to obtain BOD_5 levels of less than 30 mg/l (31, 32, 33). The specific detention time used depends upon the characteristics of the wastewaters to be treated.

Aeration is normally accomplished using either mechanical surface aerators or diffused air. Oxygen transfer efficiencies under actual operating conditions range from 0,61 to 1,52 kilograms (kg) of oxygen per kilowatt-hour (kWh), or about (1,0 to 2,5 lb of oxygen per horsepower-hour) depending on the type of equipment used, the amount of aeration power per unit volume, basin configuration, and the biològical characteristics of the systes (34, 35). It is necessary to maintain a dissolved oxygen (DO) level of 0,2 to 0,5 mg/l in the basin to sustain aerobic conditions.

BOD_5 and suspended solids levels, oxygen uptake, and DO levels throughout the basins are related to aerator location and performance and basin configuration. There have been extensive studies of eleven existing aerated stabilization basins that have led to development of design criteria to aid in the design of future basins (36).

Some solids accumulated in the bottom of ASBs that can be removed with periodic dredging. Solids accumulation diminishes as the detention time and degree of mixing within the basin increases. At some mills, a quiescent zone, settling basin, or clarifier is used to improve effluent clarity and to reduce suspended solids.

Aerated stabilization basins provide a high degree of BOD_5 reduction and also can remove or reduce the wastewater toxicity. ASB capital and operating cost may be lower than those for the activated sludge process. The treatment efficiency is not as dependent on ambient air temperatures as with oxidation basins ; however, efficiency can be more dependent on ambient air temperature for ASB's than for higher rate processes (i.e. activated sludge).

6.3.4 Activated Sludge

The activated sludge process is a high-rate biological wastewater treatment process. The biological mass (biomass) growth in the aeration basins is settled in a secondary clarifier and varying amount of this biomass are returned to the aeration basins, building up large concentration of active biological material. It is common to maintain 2 000 to 5 000 mg/l of active biological solids in the aeration basin section of the activated sludge system compared to the 50 to 200 mg/l common to aerated stabilization basins. Loading in excess of 1,6 kilograms of

BOD_5 per cubic meter (100 lbs of BOD_5 per 1 000 ft^3) of aeration capacity per day are sometimes used, allowing for relatively small aeration basins.

The characteristically short detention times tend to make the activated sludge process more susceptible to upset due to shock loads. When the process is disrupted, it may require several days for biological activity to return to normal. Particular operator attention is required to avoide such shock loadings at mills where this process is employed. The necessity for strict operator attention can be avoided through provision of sufficient equalization to minimize the effect of shock loadings.

Compared with aeration stabilization basins, the activated sludge process has less shock load tolerance, greater solids handling requirements, and higher costs. However, the activated sludge process requires less land than ASBs. Thus, it may be preferred in cases where sufficient land for ASB installation is either unavailable or too expensive.

The activated sludge process is very flexible and can be adapted to many waste treatment situations. The activated sludge process has many modifications that can be selected as most appropriate. Various types of activated sludge processes that have been applied to treat pulp, paper, and paperboard wastewaters include :

(a) conventional
(b) complete-mix
(c) tapered aeration
(d) step aeration
(e) modified aeration
(f) contact stabilization
(g) extended aeration
(h) oxidation ditch
(i) pure oxygen.

Another process, the Zurn-Attisholz process consists of a two stage system. Table 6.7 summarises standard design parameters for the activated sludge process and several of its modifications.

TABLE 6.7 : Typical Design Parameters for Activated Sludge Processes

Process Modification	Parameter		
	Volumetric loading ($lb\ BOD_5/1\ 000\ cu\ ft$)	MLSS (mg/l)	Detention Time V/Q (hr)
Conventional	20 - 40	1 500 - 3 000	4 - 8
Complete-mix	50 - 120	3 000 - 6 000	3 - 5
Step aeration	40 - 60	2 000 - 3 500	3 - 5
Modified aeration	75 - 150	200 - 500	1,5 - 3
Contact stabilization	60 - 75	(1 000 - 3 000)*	(0,5 - 1,0)*
		(4 000 - 10 000)1	(3 - 6)
Extended aeration	10 - 25	3 000 - 6 000	18 - 36
Pure oxygen systems	100 - 250	6 000 - 8 000	1 - 3

* Contact unit
1 Solids stabilization unit
MLSS = Mixed liquor suspended solids
V = Volume (kl)
Q = Flow (kl/h)

6.3.5 Rotating Biological Contactors

This system involves a series of discs on a shaft supported above a basin containing wastewater. The discs are 40 to 45 percent submerged in the wastewater and are slowly rotated ; a biological slime grows on the disc surfaces. Closely spaced discs with a diameter of 3,7 meters mounted on a 7,6 meter shaft can result in 9 300 square meters of surface area.

Pilot-scale evaluation of an RBC system treating bleached Kraft wastewater with an average influent BOD_5 concentration of 235 mg/l have resulted in substantial BOD_5 reductions (37). Secondary waste solids production reportedly ranged from 0,3 to 0,5 kg of solids per kg of BOD_5 removed (0,3 to 0,5 lb of solids per lb of BOD_5 removed).

Two pilot-plant evaluations reported essentially complete detoxification of board mill, integrated Kraft, and magnesium-based sulfite mill effluents (38). Final effluent BOD_5 of 59 mg/l for the Kraft mill, 65 mg/l for the board mill, and 338 mg/l for the sulfite mill were reported. Raw wastewater BOD_5 levels for these mills were 290 mg/l, 285 mg/l, and 1 300 mg/l, respectively. No TSS data were reported (38). This pilot-plant work indicates good toxicity and BOD_5 reduction capabilities. However, to date, mill-scale systems in the United States treating pulp mill wastewater have encountered operating difficulties.

6.3.6 Anaerobic Contact Filter

This process involves the use of a basin filled with crushed rock or other media. Wastewater is passed through the media at a temperature of 32°C to 35°C (90° to 95° F) under anaerobic conditions ; detention times on the order of three days are common. Steam stripping, nutrient addition, neutralization, and dilution of waste liquor with washwater may be required as pre-treatments.

A laboratory study of the process showed that 80 to 88% BOD_5 removal from sulfite wastewaters to levels as low as 34 mg/l have been achieved (39). The major advantage of the process is a low solids production rate of 0,08 kilograms of solids per kilogram of BOD_5 removed. This results because methane gas is the by-product of anaerobic digestion rather than biological solids. The author concludes that the cost for the anaerobic process was approximately the same as that for aerated stabilization.

Partial detoxification of sulfite mill wastewater was obtained in a laboratory-scale system (32). The anaerobic contact filter altered the LC-50 from 4,5% to 7,8% for rainbow trout. No specific data concerning specific toxic pollutants were reported.

6.3.7 Chemical Clarification

Dissolved and colloidal particles in treated effluents are not readily removed from solution by simple settling. These particles can be agglomerated by the addition of chemical coagulants. Coagulants in common use include lime, alum, ferric chloride, ferric sulfate, and magnesium. Detailed discussions of the chemistry of coagulants are available (40).

Rebhum and others suggest that the most efficient method of pulp and paper mill effluent flocculation is a solids-contact type clarifier (41). Ives suggests a theory for the operation of solids-contact clarifiers that considers their integrated role as flocculators, fluidized beds, and phase separators (42). His theory suggests that the criterion for good performance is the dimensionless product of velocity gradient, time, and floc concentration. He suggests that model floc blanket studies can be meaningful for full-scale operation provided that the concentration of floc in the blanket and the blanket depth are the same in both model and prototype (42).

Ives also suggests a number of design considerations for solids-contact clarifiers. For floc particles to form a blanket in a circular tank, the upflow velocity of the water must be equal to the hindered settling velocity of floc suspension. It is important that the floc removed from the blanket balance the rate of floc formation. The clarifier should be symmetrical ; the inlet flow should be uniformaly dispersed and the collection at the outlet should also be uniform. The clear water zone should have a minimum depth equal to half the spacing between collection troughts.

Upon floc formation, settling is accomplished in a quiescent zone. The clarification process results in waste solids that must be collected, dewatered, and disposed. The quantity, settleability and dewaterability of the waste solids depend largely on the coagulant employed. In some cases the coagulant can be recovered from the waste solids and reused.

Case Studies - Full-Scale Systems

Several full-scale, chemically assisted clarification systems have been constructed in the pulp, paper, and paperboard industry and in other industrial point source categories. Data on the capability of full-scale systems to remove conventional and non-conventional pollutants are presented below.

Conventional Pollutants

Recent experience with full-scale alum assisted clarification of biologically treated Kraft mill effluent suggests that final effluent levels of 15 mg/l each of BOD_5 and TSS can be achieved. The desired alum dosage to attain these levels can be expected to vary depending on the chemistry of the wastewater to be treated. The optimum chemical dosage is dependent on pH.

Chemical clarification following activated sludge is currently being employed at a groundwood (chemi-mechanical) mill. According to data provided by mill personnel, alum is added at a dosage of about 150 mg/l to bring the pH to an optimum of 6,1. Polyelectrolyte is also added at a rate of 0,9 to 1,0 mg/l to improve flocculation.

Neutralization using NaOH is practiced prior to final discharge to bring the pH within acceptable discharge limits. The chemical/biological solids are recycled through the activated sludge system with no observed adverse effects on biological organisms. Average reported results for 12 months of sampling data (as supplied by mill personnel) show a raw wastewater to final effluent BOD_5 reduction of 426 mg/l to 12 mg/l and TSS reduction of 186 mg/l to 12 mg/l.

In October, 1979, operation of a full-scale chemically assisted clarification system treating effluent from an aerated stabilization basin at a Northeast bleached Kraft mill began. This plant was designed and constructed after completion of extensive pilot-scale studies. The purpose of the pilot-plant was to demonstrate that proposed water quality limitations could be met through the use of chemically assisted clarification. After demonstrating that it was possible to meet the proposed levels, studies were conducted to optimize chemical dosages. The tests conducted showed that the alum dosage could be reduced significantly by the addition of acid for pH control, while still attaining substantial TSS removal. In the pilot-plant study, it was shown that total alkalinity, a measure of a system's buffering capacity, was a reliable indication of wastewater variations and treatability. Through this study, it was shown that there is a direct relationship between total alkalinity and alum demand. High alkalinity (up to 500 mg/l) caused by discharge of black liquor or lime mud results in high alum demands. Therefore, a substantial portion of alum dosage can be used as an expensive and ineffective means of reducing alkalinity (pH) to the effective pH point (5 to 6) for optimum coagulation. The use of acid to assist in pH optimization can mean substantial cost savings and reduction in the alum dosage rate required to effect coagulation. In one instance, use of concentrated sulfuric acid for pH reduction, reduced alum demand by 45%. Acid addition was also effective in reducing alum dosage for wastewater with a low alkalinity (approximately 175 mg/l) (43).

Table 6.8 summarises effluent quality of the full-scale system since start-up ; this system has been operated at an approximate alum dosage rate of 350 mg/l without acid addition. Recent correspondence with a mill representative indicated that, with acid addition, this dosage rate could be reduced to 150 mg/l (44). However, this lower dosage rate has not been confirmed by long-term operation.

TABLE 6.8 : Final Effluent Quality of a Chemically Assisted Clarification System Treating Bleached Kraft Wastewater

Date	BOD (mg/l)		TSS (mg/l)	
	Average for month	Maximum day	Average for month	Maximum day
September 1979	11	21	87	254
October 1979	8	12	40	92
November 1979	9	18	28	47
December 1979	21	83	21	56
January 1980	8	16	28	36
February 1980	7	14	31	68
March 1980	13	46	44	113
April 1980	9	16	32	96
May 1980	11	22	38	80

Scott, et.al. (45) reported on a cellulose mill located on the shore of Lake Baikal in the USSR. The mill currently produces 200,000 kkg (220,000 tons) of tire cord cellulose and 11,000 kkg (12,100 tons) of Kraft pulp per year. Average water usage is 1,000 kl/kkg (240 kgal/t). The mill has strong BOD_5 for the weak wastewater system (100 mg/l), while the strong wastewater BOD_5 is 400 mg/l. Only 20% of the total wastewater flow is included in the strong wastewater system. Each stream receives preliminary treatment consisting of neutralization of pH 7.0, nutrient addition, and aerated equalization. Effluent from equalization is discharged to separate aeration and clarification basins. These basins provide biological treatment using a conventional activated sludge operation. Aeration is followed by secondary clarification. Suspended solids are settled and 50% of the sludge is returned to the aeration process. Waste sludge is discharged to lagoons. The separate streams are combined after clarification and are treated for colour and suspended solids removal in reactor clarifiers with 250 to 300 mg/l of alum and 1 to 2 mg/l of polyacrylamide flocculant, a non-ionic polymer. The clarifiers have an overflow rate of approximately 20,4 cu m per day/sq m (500 gpd/sq ft).

Chemical clarification overflow is discharged to a sand filtration system. The sand beds are 2,9 m (9,6 ft) deep with the media arranged in five layers (46). The sand size varies from 1,3 mm (0,05 in) at the top to 33 mm (1,3 in) at the bottom. The filter is loaded at 0,11 cu m per minute/sq m (2,7 gpm/sq ft). Effluent from sand filtration flows to a settling basin and then to an aeration basin ; both basins are operated in series and provide a seven hour detention time.

The effluent quality attained is as follows :

Parameter	Raw Waste	Final Effluent
BOD5 (mg/l)	300	2
Suspended solids (mg/l)	60	5
pH	-	6,8 - 7,0

Individual treatment units are not monitored for specific pollutant parameters.

Non-Conventional Pollutants

The development of coagulation processes for colour removal has been traced by many investigators. Investigators concluded that lime precipitation was a coagulation process for colour removal which afforded the possibility of chemical recovery utilizing existing mill equipment. Based on the results of this early work, research continued towards development of a lime precipitation process. The overriding problem in this work continued to be the difficulty of dewatering the lime-organic sludge. Specific studies were conducted for resolving the sludge problem with limited success (47, 48).

Continuing efforts to improve the dewatering of the lime sludge led to consideration of using large dosages of lime for colour reduction. It was believed that a large quantity of rapidly draining materials would reduce the effect of the organic matter on dewatering. This thinking led to the development and patenting of the "massive lime" process by the National Council for Air and Stream Improvement. In this process, the mill's total process lime is slaked and reacted with a highly coloured effluent stream, usually the caustic extraction effluent. The lime sludge is then settled, dewatered, and used for caustising green liquor. During the causticising process, the colour bodies are dissolved in the white liquor and eventually burned in the recovery furnace. Although the massive lime process had been demonstrated as an effective colour removal system, the process was not taken beyond the pilot stage for several years.

The first installation of the massive lime colour system was operated at a mill in Springhill, Louisianna. The 33,4 litre per sec (530 gpm) demonstration plant was used to treat the bleach plant caustic extraction and unbleached stock decker wastewaters. These streams contributed 60 to 75% of total mill colour. In the process, the lime slurry dosage was 20 000 mg/l.

The demonstration plant at Springhill was first tested using 100% bleach plant caustic extraction effluent. Various amounts of unbleached decker effluent were then added until 100% decker effluent was treated. Colour removal ranged from 90 to 97% with an average of 94 to 95% (49). Organic carbon removal ranged from 55 to 75% and generally increased with higher coloured effluent. The values reported are shown in Table 6.9. BOD_5 removals of 25 to 45% were reported with lower values found during treatment of most highly-coloured effluent. The net effect of the process was estimated at a 72% reduction of total mill colour.

TABLE 6.9 : Colour and Organic Carbon Removal After Application of Massive Lime Treatment (49)

Composition of Treated Effluent: Bleach plant caustic extraction stage effluent %	Kraft decker effluent %	Effluent Colour (APHA Colour Units): Before treatment	After treatment	Colour removal (%)	Organic carbon (mg/l): Before treatment	After treatment	Organic carbon removal (%)
100	0	21,546	1,265	94,2	1,446	373	74,2
67	33	14,325	745	94,8	1,016	253	75,1
60	40	12,125	594	95,1	905	248	72,6
50	50	10,043	451	95,5	798	245	69,3
33	67	6,612	331	95,0	569	183	67,8
20	80	4,660	298	93,6	450	173	61,6
0	100[1]	1,640[1]	140[1]	91,5[1]	270[1]	120[1]	55,6[1]
0	100[2]	900[2]	234[2]	74,0[2]	268[2]	126[2]	53,0[2]

[1]Very little paper mill white water reuse for decker pulp washing or a make-up water.
[2]Practically all water used in decker system was white water from paper mill.

The massive lime process, as developed, required lime dosages of approximately 20 000 mg/l. Because of this, only a relatively small effluent stream could be treated with the quantity of lime used for causticising green liquor. Additionally, this process required modifications to the recovery system. These restrictions led to the development of an alternative process employing "minimum lime" processes (50). Previous EPA documents have reported data on full-scale minimum lime treatment systems (50). Two systems treating unbleached Kraft and neutral sulphite semi-chemical (NSSC) effluents are known to be operating. Colour levels of 1 200 to 2 000 colour units are reported to be 80 to 90% removed with lime dosages of 1 000 to 1 500 mg/l. A full-scale system treating the first caustic extract of a bleached Kraft mill had been shut down. When operating, lime dosages of 1 500 to 3 000 mg/l were used to remove 90% of a colour load that ranged from 8 000 to 10 000 colour units (50).

6.3.8 Filtration

This process refers to granular bed (rather than membrane) filtration. The granular material may be sand, or coal, diatmoaceous earth, and/or garnet in combination with sand. The various media, grain sizes, and bed depths may be varied for optimal results. It is common to vary grain sizes, with the larger sizes at the top of the filter bed, to improve TSS removal and to extend filter run time between backwashings. The addition of a proper chemical flocculant prior to filtration can further improve performance.

Filtration technology was evaluated as part of a recent study conducted for the EPA (51). Results obtained during this study of nine pulp, paper, and paperboard and other industrial facilities where filtration is used are shown in Table 6.10.

At those facilities where chemical coagulants were not utilized, final effluent levels of TSS ranging from 5,9 to 35 mg/l were achieved across the filter ; TSS reductions ranged from 45 to 79%. Those were coagulants were used prior to filtration achieved final effluent TSS levels ranging from 5,0 to 27,5 mg/l with removals of 52 to 85%. At the paperboard mill employing single medium sand filtration without chemical addition, an effluent TSS level of 7 mg/l was attained.

TABLE 6.10 : TSS Reduction Capabilities and Related Factors for the Filtration Technology when no Chemicals are Used

Source of Data	Source of Wastewater	Biological Treatment Process Description	Filter Influent TSS Concentration & Source of Data	Filter Influent TSS Size – Percent Microns*	Hydraulic Loading	Filter Media: No. of Media; Depth, U.C., E.S.; Type of Filtration	TSS Filter Effluent	Percent Removal Across Filter, Ave. for Period of Data
A – 7	Paperboard product	Activated sludge : complete mix, 20,5 lb BOD/1 000 cu ft F/M – 0,5, MLSS 3,500 mg/l DO min – Detention time – 12 hrs @ 2 MGD Average flow – 2,0 MGD	ND	ND	at 2,0 MGD & 3 filters – 3,7 gpm/sq ft	1 media: sand sand – 6,0" ; ES – 2-3 mm, Sp. Gr. – 2,7	7,0 mg/l, average of 5 monthly average Feb 76 – June 76	ND
A – 4	Manmade fibre processing	Activated sludge : 18 lb BOD/ 1 000 cu ft, F/M – MLSS – DO min – Detention time – 48 hrs @ 0,5 MGD Average flow – 2,8 MGD	4,9 mg/l average of 2 monthly averages Does not include old aeration system flow	ND	at 2,03 MGD & 3 filters – 2,15 gpm/sq ft	4 media: 2 coal sand, garnet – coal – 12" Sp. Gr. – 1,49 UC & ES – ND coal – 12" Sp.Gr. – 1,5 UC & ES – ND sand – 9", UC & ES – ND garnet – 3", UC & ES – ND ND	16,2 mg/l, average of 2 monthly average	67%, include post aeration researchers
Literature Greater Southern Paper Co. Cedar Springs, GA, Pilot study	Kraft neutral sulphite semi-chemical pulp and paper	Aerated stabilization basin :	Average for 3 runs – 68 mg/l	ND	2 gpm/sq ft	ND	Average for 3 runs – 35 mg/l	50% Reported by researchers
Literature New Brunswick Research & Productivity Council Pilot Plant	Pulp mill	Aerated lagoon – lb BOD/1 000 cu ft – DO min – Detention time – 12,5 days Total aeration only 8 days Average flow –	40 mg/l grab samples	5 – 60% between 5 & 10 38%	2,4 to 3,6 gpm/sq ft	3 media – 7" of coarse coal, 3" media sand – ES – 0,56, UC – 1,37 5" of coarse sand – ES – 1,42, UC – 1,34	21 mg/l	50%

*Based on one grab sample
ND = No Data

6.3.9 Activated Carbon Adsorption

Currently, there are two basic approaches for the use of activated carbon :

(a) use in a tertiary sequence following primary and biological processes and
(b) use in a "physical-chemical" treatment in which raw wastewater is treated in a primary clarifier with or without chemical coagulants prior to carbon adsorption.

The tertiary approach involves the reduction of biodegradable organics prior to discharge to the carbon system. This provides for longer carbon life. In a physical-chemical treatment mode, biodegradable and refractory organics are removed solely through adsorption on the activated carbon. Activated carbon can achieve high removals of dissolved and colloidal pollutants in water and wastewater. When applied to the well treated biological effluent, it is capable of reducing BOD_5 to less than 2,0 mg/l (52).

The primary means by which removal occurs is by surface adsorption. The key to the carbon adsorption process is the extremely large surface area of the carbon, typically 3,54 to 9,92 square meters per gram (sq m/g) (17 300 to 48 500 sq ft/lb) (53).

Activated carbon will not remove certain low molecular weight organic substances, particularly methanol, a common constituent of pulping effluent (54). Additionally, carbon columns do a relatively poor job of removing turbidity and associated organic matter (55). Some highly polar organic molecules such as carbohydrates also will not be removed through the application of activated carbon treatment (55, 56). However, most of these materials are biodegradable and, therefore, should not be present in appreciable quantities in a well bio-oxidizing effluent.

Activated carbon may be employed in several forms including :

(a) granular
(b) powdered
(c) fine.

The ultimate adsorption capacities for each may be similar (57). The optimal carbon form for a given application should be determined by laboratory and/or pilot testing. Each of the three forms of carbon listed above is discussed below.

Granular Activated Carbon

Granular activated carbon has been used for many years at municipalities and industrial facilities to purify potable and process water. In recent years, it has been used for removal of organics in wastewater (58).

Granular activated carbon (GAC) treatment usually consists of one or more trains of carbon columns or beds, including one or more columns per train. The flow scheme may be down through a column, up through a packed carbon bed, or up through an expanded carbon bed. The optimum column configuration, flow scheme, and carbon requirements can best be determined through field testing. Design aspects for various systems are readily available in the literature (53).

It is economically advantageous in most granular activated carbon applications to regenerate the exhausted carbon. Controlled heating in a multiple-hearth furnace is currently the best procedure for removing adsorbed organics from activated carbon. Typically, the regeneration sequence is as follows :

- Pump exhausted carbon in a water slurry to the regeneration system for dewatering.
- After dewatering, feed the carbon to a furnace at 816° to 927°C (1 500° to 1 700°F) where the adsorbed organics and other impurities are oxidized and volatized.

- Quench the regenerated carbon in water.
- Wash the carbon to remove fines ; hydraulically transport the regenerated carbon to storage.
- Scurb the furnace off-gasses and return the scrubber water for treatment.

The West Wastewater Treatment Plant at Fitchburg, Massachusetts treats combined papermill and sanitary wastes at a 57 000 cu m/day (15 mgd) chemical coagulation/carbon adsorption facility (59). Approximately 90% of the flow originates from three papermills, with the remaining 10% originating from municipal sanitary wastewater. The industrial wastewater undergoes 5 minutes of rapid mixing and 30 minutes of flocculation prior to mixing with the chlorinated sanitary wastewater. The combined waste is then settled after lime and alum addition. The wastewater is then pumped to twelve downflow pressure carbon filters. Initial operation of the system has resulted in a 96% suspended solids reduction and a 39% BOD_5 reduction in the pre-treatment system. The granular activated carbon filters initially yielded total reductions of suspended solids and BOD_5 of 99 an 97%, respectively. Final effluent concentrations were reported as 5,0 mg/l BOD_5 and 7,0 mg/l TSS. No data have been reported concerning toxicity or toxic pollutant removal/reduction from the plant.

Since the plant was started up in late 1975, it has been plagued with a number of mechanical and operational problems. As a result, the system has been unable to achieve the removal capabilities predicted after initial operation. The plant was designed to produce an effluent quality of 8 mg/l of BOD_5 and TSS on a monthly average. The pre-treatment facility has consistently yielded a 55% BOD_5 reduction and 95% TSS reduction. The carbon filters have provided 55% BOD_5 reduction and 70% TSS reduction of the remaining pollutants after pre-treatment. Overall, the system is anticipated to achieve 80% BOD_5 reduction and 98% TSS reduction once the steady state conditions are met (60).

Condensate streams account for only about 2 to 10% of total wastewater flow, but contribute significantly higher proportions of toxicity and BOD_5 when discharged. Tests by Hasen and Burgess showed that 70 to 75% of the BOD_5, COD, and TOC in Kraft evaporator condensate could be removed using 0,46 kg of carbon per 1 000 litres (3,8 lb of carbon per 1 000 gallons) of wastewater (56). Treatment with granular activated carbon reduced the effluent toxicity effects on bay mussls by a factor of up to 17. The toxicity removal efficiency was found to be much more dependent on contact time than were BOD_5 and COD removals.

6.3.10 Powdered Activated Carbon

A recent variation of activated carbon technology involves the addition of powdered activated carbon to biological treatment systems. The adsorbant quality of carbon, which has been known for many years, aids in the removal of organic materials in the biological treatment processes (61). This treatment technique also enhances colour removal, clarification, system stability, and BOD_5 and COD removal (62, 63). Results of pilot testing indicate that this type of treatment, when used as a part of the activated sludge process, is a viable alternative to granular carbon system (63, 64). Pilot tests have also shown that powdered activated carbon can be used successfully with rotating biological contactors (65).

6.3.11 Fine Activated Carbon

Timpe and Lang (57) have developed a fine activated carbon system for which they have filed a patent application (57). It is a multi-stage, counter-current, agitated system with a continuous transfer of both carbon and liquid. One of the major aspects of the fine activated carbon system is the use of an intermediate-size carbon in an attempt to combine the advantages of both powdered and granular carbon while minimizing their limitations. Equipment size and carbon inventory are decreased due to the increased adsorption rate of the intermediate-size carbon.

Timpe and Lang report that the fine activated carbon system showed distinct advantages over the granular activated carbon system. They ran extensive pilot-plant tests for treating unbleached Kraft mill wastewater with granular and fine activated carbon (57). Four different treatment processes were investigated using a 110 litre per minute (30 gpm) pilot-plant :

(a) clarification followed by downflow granular activated carbon columns,
(b) lime treatment and clarification followed by granular activated carbon columns,
(c) biological oxidation and clarification followed by granular activated carbon columns,
(d) lime treatment and clarification followed by fine activated carbon effluent treatment (subject of a patent application).

All treatment processes were operated in an attempt to obtain a treated effluent with less than 100 APHA colour units and less than 100 mg/l TOC that would allow for reuse of the wastewater in the manufacturing process. The lime-carbon treatment achieved the desired effluent criteria and was considered the most economical of three processes utilizing carbon columns. A relatively small lime dosage of 320 to 600 mg/l CaO without carbonation prior to carbon treatment was reported to be the optimum operating condition for the lime-carbon process. It was determined that the effluent should contain about 80 mg/l Ca for successful optimization of treatment. The required fresh carbon dosage was 0,3 kg of carbon per 1 000 litres treated (2,5 lb per 1 000 gallons treated).

Timpe and Lang reported lower rates of adsorption, resulting in larger projected capital and operating costs, for the biological-carbon and primary carbon processes in treating unbleached Kraft mill effluent (57). The lower rates of adsorption were believed to be caused by coagulation of colloidal colour bodies on the carbon surface. They also determined that the use of sand filters prior to the activated carbon was not necessary. The carbon columns operated with a suspended solids concentration of 200 mg/l without problems when backwashed every day or two. Filtration or coagulation of the effluent from the fine activated carbon process was necessary in order to remove the colour bodies that formed on the outer surfaces of the activated carbon granules.

It was found that non-adsorptive mechanisms accounted for a significant amount of colour and TOC removal in the clarification-carbon process. It was felt that the removals were not due to any biological degradation that might have occurred in the carbon columns. The colour colloids were subsequently removed as large settleable solids during the backwashing process (57). Table 6.11 tabulates the pilot-plant results obtained from Timpe and Lang's investigation.

6.3.12 Foam Separation

Foam separation techniques have been evaluated to determine their effectiveness in treating surface active substances (i.e., resin acids) in pulp, paper, and paperboard mill wastewaters. This process involves physical removal of surface active substances through foam generation. In this process, fine air bubbles are introduced into a basin or structure containing the effluent. The air bubbles cause generation of foam in which the surface active compounds are concentrated. Jet air dispersion has been found to be the most efficient technique for foam generation when compared to turbine and helical generation systems (66).

Several full-scale separation facilities have been built for the removal of detergents from municipal wastes (67, 68). The Los Angeles County Sanitation District system operated a system treating a flow of 45 000 cu m/day (12 mgd) at a seven minute detention. Water reclamation was the primary purpose of the unit, which operated successfully and trouble-free during two years of continuous operation (69). This system, like other municipal systems, has ceased operation due to regulations that required the use of biodegradable detergents.

TABLE 6.11 : Results of Pilot-Scale Activated Carbon Treatment of Unbleached Kraft Mill Effluent (57)

Description of Carbon Process	Columns Preceded by Biological Oxidation and Clarification			Columns Preceded by Primary Clarification			Columns Preceded by Primary Clarification			Columns Preceded by Lime Treatment and Clarification			FACET System		
	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal
BOD (mg/l)	-	-	-	-	-	-	-	-	-	26% Removal		-	-	-	-
TOC (mg/l)	148	57	61%	220	83	62%	310	121	61%	177	100	44%	158	101	36%
Turbidity (JTU)	-	-	-	-	-	-	-	-	-	-	5-15	-	-	-	-
Colour (Pt-Co Units)	740	212	71%	925	185	80%	1160	202	83%	252	76	70%	157	73 (a)	-
Hydraulic Load (gpm/sq ft)	2,13		-	1,42		-	0,71		-	1,42		-	-		-
Carbon	Granular		-	Granular		-	Granular		-	Granular		-	Intermediate		-
Contact Time (min)	140		-	-		-	-		-	108		-	-		-
Fresh Carbon Dosage (lb carbon/1 000 gal.)	8		-	n 20,5		-	28		-	2,5		-	3,9		-
pH	-		-	-		-	-		-	11,3		-	-	-	-

(a) Filtered

A bleached Kraft whole mill effluent was analysed for total resin acid content before and after treatment in a pilot-scale foam separation unit (69). Two mill effluents were treated in a two hour detention time foam separation pilot unit. The resin acid content in all cases was reduced by between 46 and 66%. The range of total resin acid content in the influents and effluents were 2,6 to 5,1 mg/l and 0,1 to 1,0 mg/l, respectively. In all cases the treated effluent was rendered non-toxic to fish.

Pilot studies have been performed using foam separation as a pre-treatment prior to the application of activated sludge and aerated stabilization treatment of bleached Kraft effluent (70). These studies have shown the detoxification efficiency of biological treatment to improve from 50 to 85% of the time without foam separation to over 90% of the time with foam separation (70).

6.3.13 Microstraining

At two non-integrated papermills, full-scale coagulation/ microstraining facilities are used for treating rag pulp and fine paper effluents (71, 72). Coagulant usage includes the addition of 1 mg/l of polymer plus the addition of alum or caustic for pH adjustment. Typically, suspended solids and BOD_5 reductions to 10 mg/l and 50 mg/l, respectively, are achieved. When properly operating, treatment approaching that achievable through the application biological treatment has been obtained. It has been observed that upsets caused by such practices as papermachine washup with high alkaline cleaners affect the effectiveness of the technology (71).

6.3.14 Electro-Chemical Treatment

Electro-chemical treatment technology involves the application of an electrical current to the effluent to convert chloride to chlorate, hypochlorite, and chlorine. The chlorine and hypochlorite can oxidize organic compounds and be reduced again to chloride ions. The process then repeats in a catalytic fashion. The oxidation of organic compounds reduces the BOD_5, colour, and toxicity of the effluent. A significant advantage of the process is that no sludge is produced.

Oher found that whole mill bleached Kraft effluent could be reduced in colour by 80% and caustic extract could be reduced in colour by more than 90% through electro-chemical treatment (73). Similar results were achieved when using a lead dioxide or a graphite anode. The lead dioxide anode required less energy. No toxicity or toxic pollutant data were reported.

In a variation of the process, Barringer Research Ltd. investigated the use of a carbon fibre electro-chemical reactor to treat Kraft caustic bleach extracts (74). The high surface to volume ratio of the carbon greatly decreased the reactor volume requirements. At an effluent to water volume ratio of 60% (v/v), toxicity was reported to be reduced from 10% mortality in 22 hours to zero percent mortality in 96 hours. Colour reduction of 90% and BOD_5 and COD reductions of 50% and 60%, respectively, were reported. This process is a full-scale used in the mining industry but no pilot or mill-scale unit has been applied in the pulp, paper, and paperboard industry (75). The primary drawback of the process is failure of the carbon cell to perform for extended periods (75).

Another variation to this process involves the use of hydrogen gas bubbles generated in the process to float solids and separate scum. Selivanov found that an electro-chemical unit with graphite anodes and stainless steel cathodes could cause coagulation in Kraft white water (76). Release of hydrogen bubbles in the process caused solids removal by flotation. Total suspended solids were reduced to 2 to 4 mg/l. No toxicity data were reported.

Herer and Woodard found significant colour and TOC reductions in bleachery wastes by application of electrolytic cells using an aluminium anode (77). Colour removals from chlorination and caustic extraction effluents were 92%, respectively, while

TOC removals were 69% and 89%, respectively. Specific concentrations, however, were not reported.

6.3.15 Ion Flotation

This process involves the addition of a surfactant ion of opposite charge to the ion to be removed. The combining of these ions results in a precipitate, the colligend. The colligend is removed by passing of air bubbles through the waste and collection of the resulting floating solids.

Many of the chromophonic (colour production) organics in pulp, paper, and paperboard mill wastewaters are negatively charged, making this process suitable for the removal of colour. Chan investigated this process on a laboratory scale (78). A variety of commercial grade cationic surfactants were tested and Aliquat 221 produced by General Mills was found to be very effective. The process removed over 95% of the colour from bleach Kraft effluents. No specific removals of toxicity or toxic pollutants were reported.

6.3.16 Air/Catalytic/Chemical Oxidation

Complete oxidation of organics found in pulp, paper, and paperboard mill wastewaters to carbon dioxide and water is a significant potential advantage of oxidation processes. Partial oxidation coupled with biological treatment may have economic and/or technical advantages over biological treatment alone.

Past studies of oxidation processes have dealt principally with COD or TOC as a measure of performance. Barclay has done a through compilation of related studies and found that most were performed with wastewater other than those resulting from the production of pulp, paper, and paperboard (79). Some tentative conclusions, though, may still be draw :

- Complete oxidation with air can occur under extreme temperature and pressure, high intensity irradiation, with air at ambient conditions in the presence of excessive amounts of strong oxidants (O_3, H_2O_2 or ClO_2), or air or oxygen in the presence of catalysts such as certain metal oxides.

- Sulfite wastes can be partially detoxified by simple air oxidation for a period of seven days.
- Ozone oxidation achieved slight detoxification of sulfite wastes after two hours and partial detoxification after eight hours (79).
- Major BOD_5 reductions can only be achieved under conditions similar to those required for nearly complete oxidation.

No data specifically relating to toxic pollutant removal were reported.

6.3.17 Steam Stripping

Steam stripping involves the removal of volatiles from concentrated streams. Hough reports that steam stripping at a Kraft mill is capable of removing 60 to 85% of the BOD_5 from condensate streams (80). The ability of the process to remove specific pollutants (including toxic and non-conventional pollutants) depends on the relative boiling points of the pollutants with respect to water (i.e., the pollutants must be volatile). Resin acids have boiling points in the range of 250°C (482°F) and thus are not readily stripped through application of this process (81).

Steam stripping was evaluated for its ability to detoxify condensates from sulfite waste liquor evaporators (82). This stream accounts for 10% of the whole mill effluent toxicity and 28% of the total BOD_5 load. Toxicity in the condensate stream was attributed to acetic acid, furfural, eugenol, juvabione, and abietic acid. The application of steam stripping had no observable effect on the toxicity of the stream, although the total organic content was reduced.

Steam stripping of Kraft mill digester and evaporator condensates was employed on a mill scale for control of total reduced sulfur (TRS) compounds and toxicity (83). The 96 hour LC-50 of the condensate was altered from 1,4% to 2,7%. Thus, the stream remained highly toxic, even after steam stripping. The process did remove 97% of the TRS compounds. Production process changes such as minimizing condensate volume, installation of spill collection systems, reduction of fresh water use, and conversion to dry debarking along with the application of steam stripping resulted in a non-toxic effluent.

6.3.18 Ultrafiltration

Ultrafiltration utilizes membranes of a specific molecular size rejection to treat wastewater. The process relies on an external pressure (i.e., pumping) to input the driving force to the wastewater as it is transported through the membranes. The size opening for the ultrafiltration membrane depends on the size of the molecules to be removed from wastewater.

Data are available from Easty for non-conventional pollutant removal from two bleached Kraft caustic extraction effluents utilizing two types of ultrafiltration systems (26). Good removals of epoxystearic acid, dichlorostearic acid, trichloroguaiacol, and tetrachloroguaiacol were obtained in each case. Chlorinated resin acids were effectively removed by one system but not the other.

The first system employed only one spiral wound membrane, with a surface area of 3,7 sq m (40 sq ft). Filtration of suspended solids larger than 10 micrometers (0,004 in) was accomplished prior to ultrafiltration. The system was operated at 28,4 litres per minute (7,5 gpm) and a pH of 11 to 11,5. The system achieved 50 to 80% reduction of chlorinated phenolics but only 0 to 15% removal of chlorinated resin acids. The lower percent removals of chlorinated resin acids reflect a low initial concentration of these pollutants in the waste.

The second system treated an effluent volume of 12,5 litres per minute (3,3 gpm) using a tubular cellulose acetate membrane with a surface area of 1,1 sq m (12,1 sq ft). The system operated at a pH of 9,5 to 10,5 and inlet and outlet pressure of 1,50 MPa (220 psi) and 0,68 MPa (100 psi), respectively. Filtration of all particles larger than 10 micrometers (0,004 in) was accomplished prior to ultrafiltration. This system removed approximately 80 to 85% of all chlorinated resin acids, chlorinated phenolics, and other acids.

Colour, lignosulphonate, COD, and solids removals from sulfite liquor after the application of ultrafiltration was studied by Lewell and Williams (84). Removals on the order of 30 to 50% were observed for colour, lignosulphonate, COD, and TSS. No toxicity or toxic pollutant data was reported. Costs (1971) were estimated at $5,70/kl ($1,50/kgal) for a 3 785 cu m (1,0 mgd) permeate flow. It was concluded that ultrafiltration could not complete economically with lime as a means of removing lignosulphonate, colour, COD, and solids (84).

6.3.19 Reverse Osmosis/Freeze Concentration

Reverse osmosis employs pressure to force a solvent through the membrane against the neutral osmotic force. This is the same type of process as ultrafiltration except that the membranes used for reverse omsosis reject lower molecular weight solutes. This means that lower flux rates occurs ; there is also a need for a higher operating pressure difference across the membrane than those necessary for ultrafiltration.

Reverse osmosis is employed at a Midwest neutral sulphite semi-chemical (NSSC) mill where 270 kkg/day (300 to per day) of corrugating medium are produced. The system allows operation of a closed white water system. Easty reported that the system achieved BOD_5 reductions of approximately 90% and removed essentially all resin and fatty acids (26). The 320 litre per minute (85 gpm) reverse osmosis unit employs 288 modules, each with 1,55 sq m (16,7 sq ft) of area provided by 18 cellulose acetate tubes. The system operates at 4,1 MPa (600 psi) and 38°C (100°F). During Easty's testing the white water feed contained 300 mg/l TSS and 40 000 to 60 000 mg/l total dissolved solids. Initial resin and fatty acid levels were : abietic, 1,5 mg/l ; dehydroabietic, 2,62 mg/l ; isopimaric, 2,75 mg/l ; pimaric, 0,82 mg/l ; oleic, 4,86 mg/l ; linoleic, 7,23 mg/l ; and linolenic, 0,27 mg/l (26). The maximum removal capacity is not known since final concentrations were below detection limits.

Reverse osmosis can be followed by freeze concentration whereby the effluent is frozen to selectivity remove pollutants. Freeze concentration takes advantage of the fact that when most aqueous solutions freeze, the ice crystal is almost 100% water. This process was evaluated by Wiley on three bleachery effluents (85). Reverse osmosis alone resulted in a concentrate stream of roughly 10% of the volume of the raw feed. Freeze concentration reduced the concentrate stream volume by a factor of five while essentially all the impurities were retained in the concentrate. Thus the two processes employed in tandem resulted in a concentrate stream consisting of roughly 2% of the original feed volume that contained essentially all of the dissolved solids (85). It was reported that the purified effluent was of sufficient quality that it could be returned to the process for reuse (85). Wiley did not investigate final disposal of the concentrate.

6.3.20 Amine Treatment

This treatment is based upon the ability of high molecular weight amines to form organophilic precipitates. These precipitates are separated and redissolved in a small amount of strong alkaline solution (white water). By so doing, the amine is regenerated for use, with no sludge produced.

The Pulp and Paper Research Institute of Canada conducted a study to determine the optimum process conditions for employing high molecular weight amines for colour, BOD_5, and toxicity reductions of bleached Kraft mill effluents (86). While no specific data ion toxic or non-conventional pollutants were reported, whole mill bleached Kraft effluent remained toxic after application of the treatment in two reported tests. Likewise, acid bleach effluent could not be detoxified. However, alkaline bleaching wastewater was detoxified in three out of four samples at 65% dilution. Final effluent concentration for BOD_5, COD, and colour after treatment of bleached Kraft whole mill wastewater were 80 to 350 mg/l, 380 to 760 mg/l, and 80 to 450 APHA units, respectively. Reported removals were 10 to 74%, 36 to 78%, and 94 to 98%, respectively, using Kemaminest-1902D in a solvent of Soltrol 170.

6.3.21 Polymeric Resin Treatment

Polymeric resin treatment involves the use of resins in columns to treat wastewater. The process utilize adsorption and ion-exchange mechanisms to remove pollutants from the wastewater. The column are reactivated after the treatment of cycle is completed. Reactivation can be achieved by utilizing an acid or alkaline solution.

The resin adsorption approach is being pursued by three companies :

(a) Billerud Uddeholm
(b) Rohm and Haas
(c) Dow Chemical Company.

Rohm and Haas and the Dow Chemical processes are at the pilot-plant stage. The Billerud Uddeholm colour removal process has been operated as a full-scale batch process in Skoghall, Sweden, since 1973.

Based on the experience gained through operation of the full-scale system in treating E_1, caustic effluent, the concept has been expanded into treatment of the C_1 and E_1 effluents from the plant. The first full-scale continuous installation will start-up in the fall of 1980 at Skoghall, Sweden. In this system, a full counter-current wash will be used and the effluent from the E_1

stage will be reused on the C_1 stage washer after colour and toxicity removal through the application of resin adsorption (18, 87).

The pollutants may be removed from the resin by elution with caustic or oxidized white liquor. The eluate at 10% concentration is mixed with the weak black liquor to be evaporated and burned in the recovery boiler. The resin is reactivated with the chlorination effluent. As the chlorination stage effluent reactivates the resin, it is simultaneously decolourized and detoxified. The total mill BOD_5 load is reduced by 30% and the colour load by 90%. The flow diagram of this process is shown in Figure 6.4.

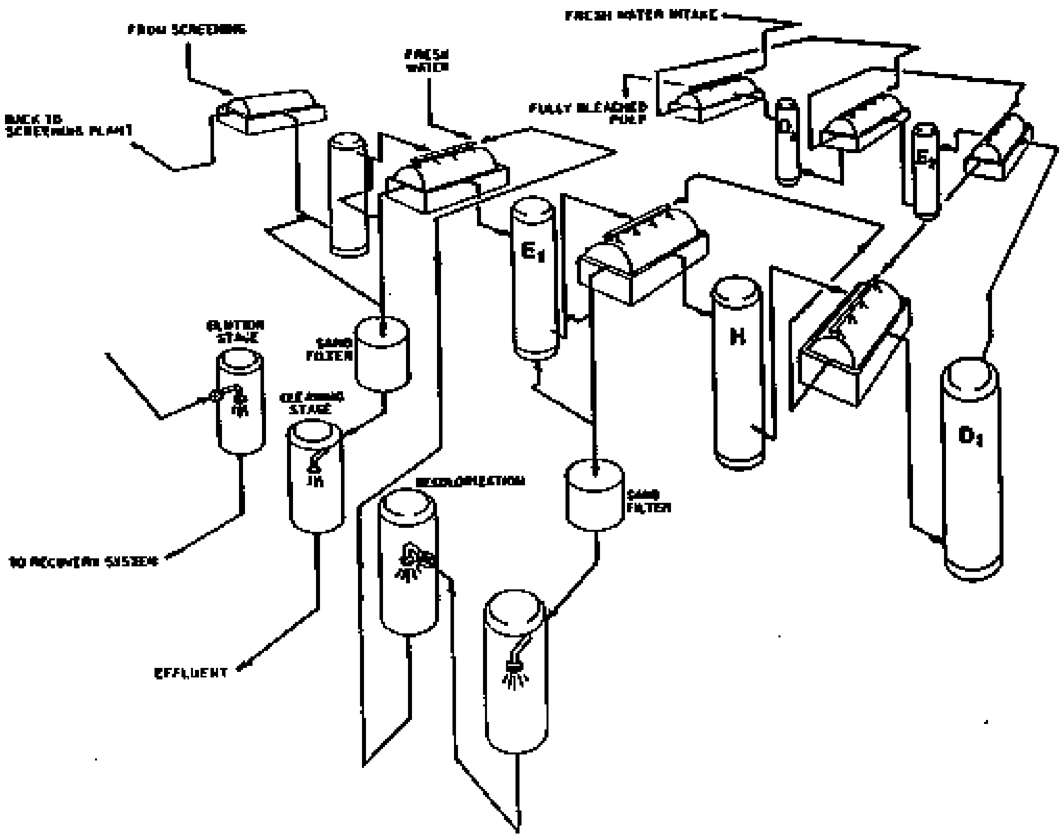

FIGURE 6.4 : Billerud Uddeholm Non-Polluting Bleach Plant

The operating costs for the Billerud Uddeholm system are reported as \$3,74 per kkg of production (\$3,40 per ton of production) (1980). The investment cost of an installation for treatment of the effluent from a 310 kkg/day (340 ton per day) Kraft pulp mill bleach plant is \$4 million (1980) including close-up of the bleach effluent. The cost will vary depending on wood species, kappa number, and local conditions (87). These costs are based upon a resin life of one and one-half years.

The Rohm and Haas process involves the use of Amberlite XAD-8 resin to decolourize bleaching effluent after filtration. The resin can be reactivated without the generation of waste sludge. This reactivation may be accomplished by using mill white liquor. In one study, the adsorption capacity of Amerlite XAD-2 resin was compared to Filtrasorb 300 activated carbon (88). The resin was more effective in removing most aromatic compounds, phthalate esters, and presticides ; carbon was more effective at removing alkenes. Neither adsorbant was effective in removing acidic compounds. The tests involved use a laboratory solutions of 100 organic compounds at an initial concentration of 0,10 mg/l.

Another study has shown synthetic resin to be comparable of removing a higher percentage of COD from biological effluents than carbon (89). Also, resin treated wastewater quality was improved when further treated with carbon, although the reverse was not true. The economics of this system could prove favourable since resin may be generated in situ. Thus, total regeneration costs may be more economical than for either system alone since carbon life could be significantly extended.

Elimination of toxic constituents from bleached Kraft effluents has been achieved with Amberlite XAD-2 resin (90, 91). Wilson and Chappel have reported that treatment with Amberlite XAD-2 resin resulted in a non-toxic semi-chemical mill effluent (92).

CHAPTER 7 : WATER AND BY-PRODUCTS RECOVERY IN RELATION TO THE PULP AND PAPER INDUSTRY

The Pulp and Paper Industry in RSA currently practices three types of water reuse :-

(i) reuse of secondary sewage effluent as process water,
(ii) internal reuse by cascading and after treatment,
(iii) agricultural reuse of effluent by irrigation.

The industry over the few decades has found that it can operate not only with less water but with quality of a poorer quality than mains water. Mains water (or its equivalent) will always be needed in some areas, for example, boiler feed and critical processing applications.

7.1 WATER QUALITY CONSIDERATION

The quality of process water affects the pulp and paper products and hence water quality requirements are dependent on the grade of paper being produced. The physical and chemical parameters most important in determining water reuse have been researched by the US National Council of the Paper Industry for Air and Stream Improvement (NCASI). As well as known chemical parameters, consideration of facts such as corrosiveness, foam, slime, scale, colour and temperature are equally important.

Generally, the brown grades of paper are most tolerant of recycled water, then newsprint and tissue types. Fine papers (high whiteness) are very sensitive to colour and certain metal ions particularly with respect to aging and colouring. The colloidal chemistry involving in paper sizing and resin applications is sensitive to phosphate and other dispersants and some metal ions.

Potential problems encountered in water reuse in paper and board manufacture are summarised in in Table 7.1. Biological growths, corrosion and scaling of equipment and discolouration of products are the main problem areas associated with water reuse.

TABLE 7.1 : Potential Problems of Water Reuse

TDS Build-Up	SS Build-Up	Temperature Build-Up
Corrosion	Dirt	Temperature
Sizing	Errosion	Sizing
Colour	Fines	Cooling
pH control	Felt plugging	Vacuum pumps
Precipitation	Wire plugging	
Scale	Shower plugging	
Odour	Reduced drainage	
Slime	Reduced equipment life	
Foam		

Typical water quality requirements are given in Table 7.2. Recycled water either internal process recycle or reuse of secondary sewage water has to meet the required quality standards.

7.2 PUBLIC HEALTH CONSIDERATION

The results of wastewater especially the use of treated sewage as process water and the irrigation of wastewaters involves public health issue. As many paper products are used for the packaging of food, clothes or other material which people come into direct contact, it is important that reclaimed water does not present a public health hazard.

Reclaimed effluent, provided it does not contain deleterious substances such as colour, is probably very suitable for the production of pulp without any fear of public health hazard because of the high chemical concentrations and temperatures used.

TABLE 7.2 : Summary of Specifications for Process Water Quality for the Manufacture of Various Papers (after McKee & Wolf[7,45]) (93)

Parameter	Concentration mg/l				
	Groundwood Paper	Soda and Sulfate Pulps	Kraft Paper Bleached	Kraft Paper Unbleached	Fine Paper
Turbidity as SiO_2	50*	25*	40	100	10
Colour in platinum units	30	5	25	100	5
Total hardness as $CaCO_3$	200	100	100	200	100
Calcium hardness a $CaCO_3$	-	50	-	-	50
Magnesium hardness as $CaCO_3$	-	50	-	-	-
Alkalinity to methyl orange as $CaCO_3$	150	75	75	150	75
Iron	0,3	0,1	0,2	1,0	0,1
Manganese	0,1	0,05	0,1	0,5	0,05
Silica as soluble SiO_2	50	20	50	100	20
Total dissolved solids	500	250	300	500	200
Free carbon dioxide as CO_2	10	10	10	10	10
Chlorides	75	75	200	200	-
Residual Chlorine	-	-	-	-	2,0

*Materials causing turbidity must not be gritty.

7.3 EXAMPLE OF WATER RECYCLING

7.3.1 Reuse of Municipal Effluent

7.3.1.1 SAPPI Enstra

SAPPI Enstra Mill was the first large manufacturer to use secondary municipal effluent as a major part of its water supply. Initially the effluent received only limited tertiary treatment (sand filtration and chlorination) but the water quality was insufficient for the manufacture of high brightness paper.

A full-scale treatment plant was built in 1970 and consists of alum and polyelectrolyte flocculation, dissolved air flotation, pH adjustment, chlorination and filtration (94). The purity is sufficient for high brightness papers and is used extensively in the mill. The cost of the treated wastewater was about half that of mains water and the annual savings were reported to be equal to the capital expenditure on the treatment plant.

7.3.1.2 Mondi, Durban

Mondi Paper takes secondary sewage effluent from the Durban Southern Wastewater Treatment Works and treat it using the steps of chemical flocculation, foam fractionation and activated carbon adsorption (95). The cost of the treated effluent is about equal to the mains supply.

7.3.1.3 RSA Board Mills, Belville

This mill producing coated and uncoated board uses a mixture of mains and treated secondary effluent.

7.3.1.4 Garden State Paper Mill

The Pomona wastewater treatment plant produces secondary effluent with characteristics of 2,1 mg/l SS, 4 mg/l BOD_5, 1,4 NTU turbidity and 7 colour units. This is used by Garden State for newsprint production without problems except for colour and biological growth.

7.3.2 Internal Mill Recycle

7.3.2.1 Simpson Paper Mill, Pomona, California

An example of internal water reuse is given in Figure 7.1 for the Simpson Mill which produces fine papers. This indicates the type of recycling that can be achieved for unclarified and clarified mill wastewater.

7.3.2.2 Papermachine Recycle

Papermachines use water for :-

(i) showers
(ii) dilution
(iii) sealing
(iv) heating and cooling
(v) miscellaneous including hose-pipes.

A schematic presentation is given in Figure 7.2 (95) and detailed water usage in Table 7.3. To reach this level of water use, the following changes have to be made :-

(i) institute external white water treatment for recycle back to the papermachine.
(ii) reuse excess papermachine white water in the pulp mill.
(iii) improve operation of save-alls to reuse more white water and decrease stock losses.

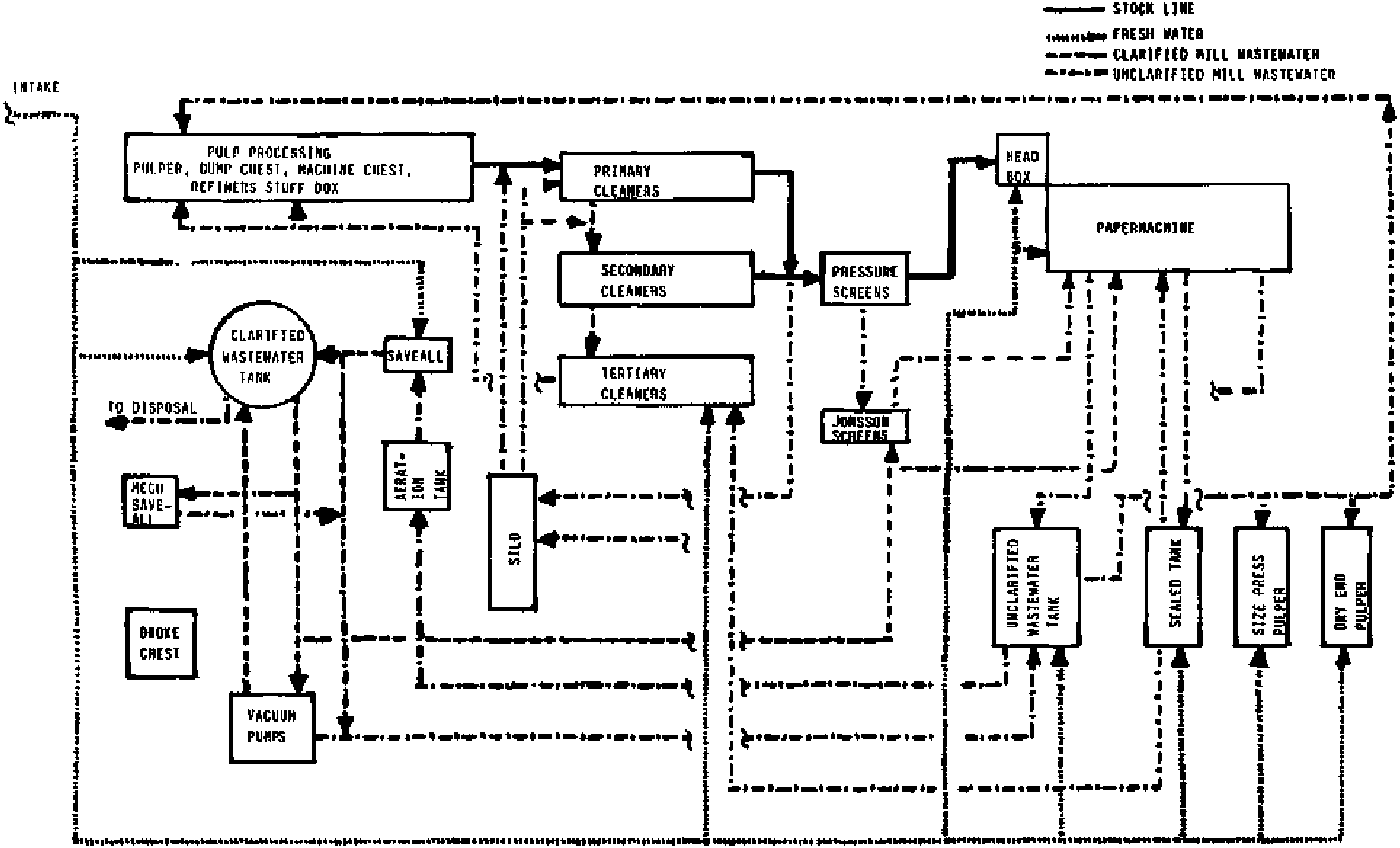

FIGURE 7.1 : Simpson-Pomona water circulation

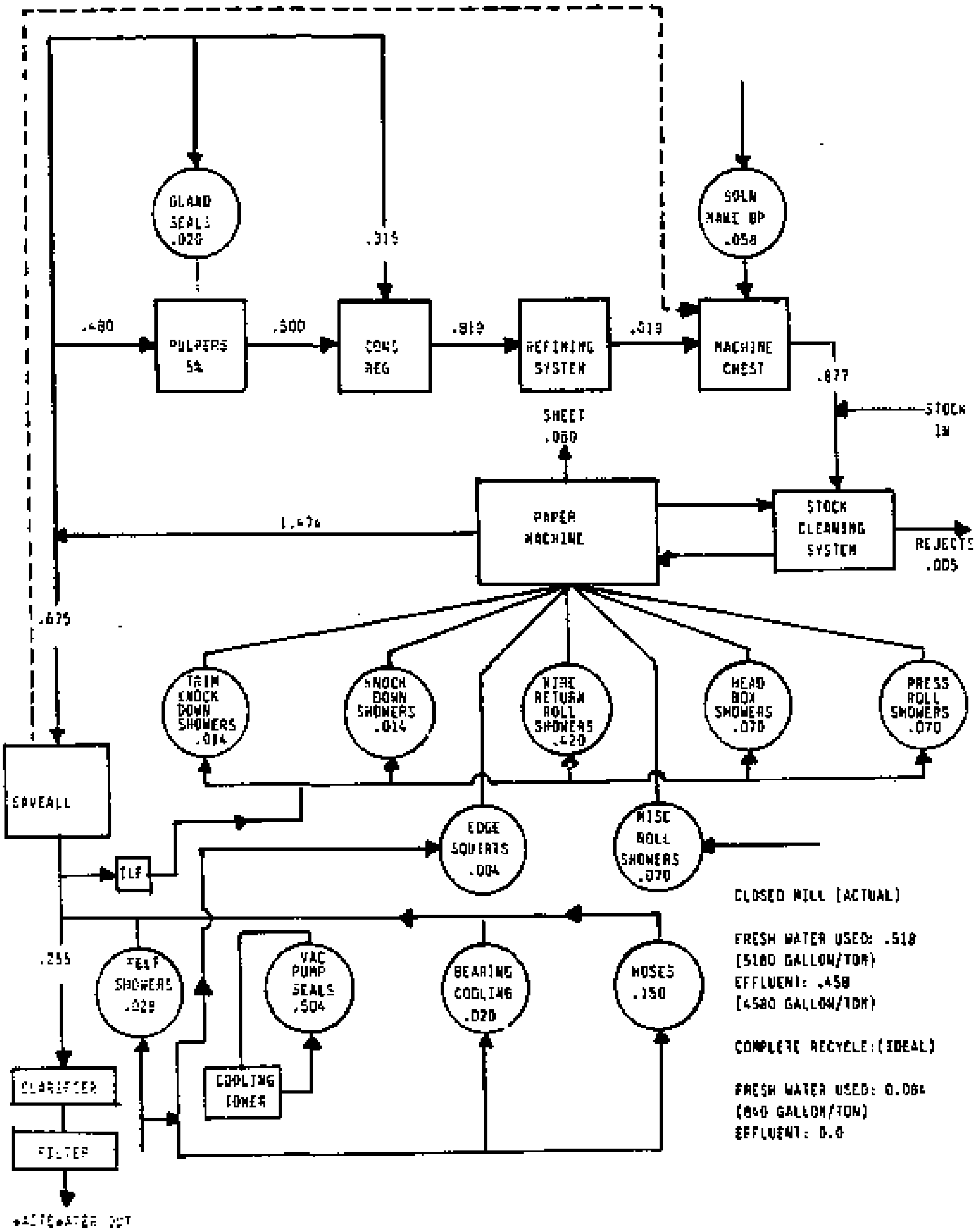

FIGURE 7.2 : Water requirements for paper producing process for 100 ton per day mill

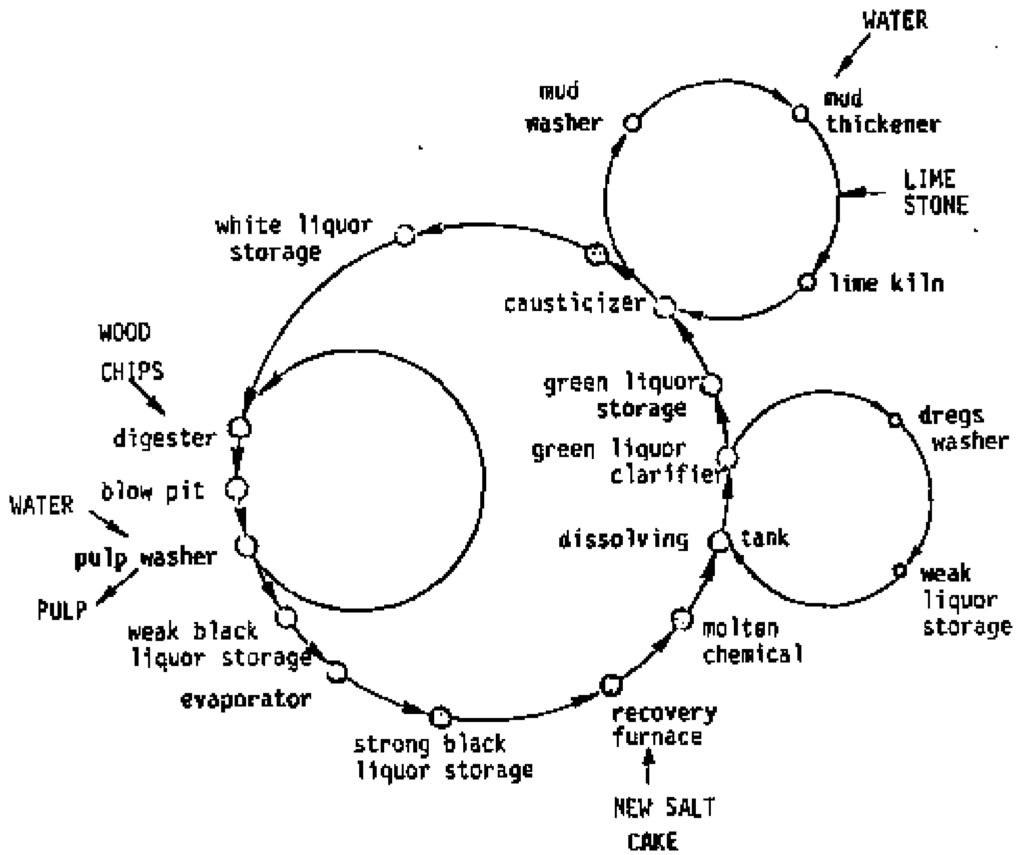

FIGURE 7.3 : Kraft pulping chemical recovery

(iv) installation of closed-loop systems for vacuum pump seal waters and press waters.

(v) change wire and press section showers to low-volume high pressure type,

(vi) increase use of excess white water for dilution on papermachine pumpers, broke chest, cleaners and screen rejects,

(vii) install hot and cold water systems to optimize energy conservation and water reuse.

TABLE 7.3 : Water Requirements for Paper Producing Process for 100 Ton Per Day Mill

Major Uses	Amount of Water Required (MGD)	Source Utilized	Effluent* Gallon/ Tons
Vacuum pump seals	0,504	Cooling water recycle, vacuum pump water recycle system, clarifier water, fresh	22 340
Pulper make-down water	0,480	White water, polydisc save-all waterclear leg, flotation save-all water	17 300
Wire return roll showers	0,420	Cooling water recycle, polydisc save-all water, clarifier water, fresh	12 000
Consistency regulation	0,319	White water, polydisc save-all water clear leg, flotation save-all water	8 370
Minor Uses			
Hoses	0,150	Clarifier water - filtered, flotation save-all water, fresh	5 180
Press roll showers	0,070	Clarifier water - filtered, polydisc and flotation save-all water, fresh	3 680
Misc. roll showers	0,070	----	2 980
Head box showers	0,070	Cooling water recycle, filtered clarifier water, flotation save-all water, polydisc save-all water, fresh	2 280
Solution make-up	0,058	Fresh - city, fresh - river	1 580
Felt showers	0,028	Clarifier water - filtered, fresh	1 000
Bearing cooling	0,020	Cooling water recycle, clarifier water filtered, fresh	720

TABLE 7.3 (continued)

Major Uses	Amount of Water Required (MGD)	Source Utilized	Effluent* Gallon/ Tons
Gland seals	0,020	Cooling water recycle, clarifier water filtered, fresh	520
Trim knock-down showers	0,014	Polydisc save-all water, clarifier water filtered, flotation save-all water, fresh	320
Wire knock-down showers	0,014	Polydisc save-all water, clarifier water, fresh	180
Edge squirts	0,004	Polydisc save-all water, clarifier water, clarifier water - filtered fresh	40

*Effluent discharge if each used in sequentially taken off freshwater.

(viii) installation of white water storage for surge capacity.
(ix) use of efficient suspended solids separation equipment to produce a reusable white water.

Various save-all advices in use include filtration, thickening, clarification, screening, straining and flotation and these processes are also used for external white water treatment.

Save-all operations normally reduce suspended solids to below 250 mg/l but additional treatment is needed before the white water can be used consistently for papermachine showers.

7.3.3 Reuse of Mill Effluent

This can be accomplished in one of two ways :-

(i) reuse by the mill after external treatment,
(ii) irrigation of some type.

Only the latter is presently practiced.

7.3.3.1 Simpson Paper Company, Anderson California

In 1975 this company started irrigating 400 acres at a rate of 4,5 kl/min to grow oats and hybrid wheat. Some sodium displacement was evident and gypsum or dolomitic limestone is to be added.

Another Simpson mill also uses irrigation, after clarification and oxidation ponds, for the growing of walnuts, alfalfa and corn.

7.3.3.2 SAPPI

The new SAPPI mill at Ngodwana plans to spray irrigate grassland for the support of cattle.

7.4 RECOVERY OF BY-PRODUCTS

7.4.1 Chemical Recovery of Kraft Pulping Liquor

This well-known chemical recovery system is shown schematically in Figure 7.3. The process is applicable to Kraft, soda-oxygen and partially to NSCC pulping effluents. Calcium based sulphite liquors cannot be recovered in this way economically.

7.4.2 By-Product Recovery

Spent sulphite liquor may be treated by ultrafiltration for the recovery of lignosulphonates and vanillan.

Single-cell protein using, pekilo yeast, torula yeast or microfungi is produced from pulp wastewaters (96, 97).

Furfural and organic acid recovery is under investigation but separation into relatively pure components is difficult.

Although many valuable organic compounds are present in pulping wastewaters, the only extensive method of commercially utilizing these has been through the fermentation process. The recovery of lignin and vanillan is limited to a small market. The most practical and economical methods of disposing of pulping washes still remains the evaporation/chemical recovery route in which the heat of combustion is recovered as useful energy for the evaporation stage and the inorganic residue is reconstituted as pulping liquor.

APPENDIX 1 : CONFIDENTIAL SURVEY : WATER AND EFFLUENT MANAGEMENT IN THE PULP AND PAPER INDUSTRY

Prepared by the Pollution Research Group, Department of Chemical Engineering, University of Natal, Durban for the Water Research Commission.

Information supplied is solely for use by the Water Research Commission to assess future research and development needs by Pulp and Paper Industry and will not be disclosed to other parties. The information will be treated on a confidential basis.

Please supply (if possible) line diagram of factory and water, steam, effluent and chemical lines and usage.

COMPANY

GROUP CONTACT Name : ______________________
Telephone : ______________________

FACTORY CONTACT Name : ______________________
Telephone : ______________________

Factory Manager : ______________________
Factory Engineer : ______________________
Technical Manager : ______________________
In charge of water and effluent services : ______________________

1. GENERAL

1.1 Name of Industry :

1.2 Address/Location of Factory :

1.3 Company History : (Please provide historical details if possible and copies of annual report for last three years).

1.4 No. of Employees :

1.5 Main Installed Machinery :

1.6 Annual Consumption of Raw Materials and Chemicals :

1.7 Annual Production and Types of Products :

2. SERVICE SUPPLY

2.1 Electricity Usage :

2.2 Cost of Electricity :

2.3 Steam Usage :

2.4 Cost of Steam :

2.5 Condensate Return Volume :

3. WATER SUPPLY

3.1 Water Permit :

3.2 Source and Cost of Water :

3.3 Total Volume of Water Intake from Each Source (kl per unit) :

3.4 Rate of Consumption Per Day :

Average :

Maximum :

3.5 Seasonal Fluctuation in Consumption?

4. QUALITY, USE AND REUSE OF WATER

4.1 For each manufacturer operation please indicate minimum water quality requirements :

4.2 Quality of existing process water :

4.3 Any particular requirements at any stage of manufacture :

4.4 Is water supply pretreated prior to use?

4.5 Any problems with water quality?

4.6 Is water recycle at any stage (if so please specify for what operations and volume).

(a) without pretreatment :

(b) with pretreatment :

4.7 Consumptive use of water.

(i) in product :

(ii) loss (e.g. on drying) :

(iii) other :

5. EFFLUENT FROM FACTORY

5.1 Permit no. and issue date :

5.2 Total volume (kl/annum) :

5.3 Rate of discharge per day

Average :

Maximum :

Seasonal fluctuation :

5.4 Average analysis :

5.5 Details of analysis and volumes generated by individual processing operations :

5.6 Pretreatment prior to discharge (please supply full details of treatment methods and results) :

5.7 Effluent discharge to :

5.8 Standards required on discharge :

5.9 Sludge/solids wastes

(i) quantity :

(ii) method of disposal

5.10 Annual cost of effluent discharge :

5.11 Formula for effluent discharge costs :

5.12 Proposed effluent pretreatment, treatment, or discharge in next 5 years :

6. PROBLEM AREAS ON WATER AND EFFLUENT MANAGEMENT

6.1 Immediate :

6.2 Short Term (0 to 3 years) :

6.3 Long Term (3 to 10 years) :

7. RESEARCH AND DEVELOPMENT NEEDS ON WATER AND EFFLUENT MANAGEMENT

(Please indicate how previous work in this area has been carried out and how you would like it to be carried out in the future) :

7.1 Internal company based :

7.2 External company based (e.g. consultants, contract research with Universities, CSIR) :

7.3 National base by Water Research Commission :

7.4 Support available by company for national programme :

Please indicate types of projects and funding levels available for :-

8. INVESTIGATIONAL AREAS OF INTEREST TO FACTORY

(Please indicate, in order of importance, areas of interest) :

8.1 In-house water management :

Reduction of water usage (l/kg of product)
Good housekeeping
Spill management
Segregation of effluents
Water quality requirements at each stage of manufacturing
Cascading
Point source characterisation

8.2 Effluent :

Segregation of high strength effluents
Pretreatment of total effluent
Pretreatment of segregated effluent (please specify) :

1.
2.
3.

Total effluent treatment prior to :

Discharge to ( )
For reuse in ( )

Effluent Treatment for segregated streams for :

Discharge from ( )
For reuse in ( )

8.3 Other Areas :

APPENDIX 2 : LITERATURE SURVEY OF WATER AND EFFLUENT MANAGEMENT IN PULP AND PAPER INDUSTRY

The recycling of process waters has been a traditional practice in the pulp and paper industry (98). In some instances, this practice is dicated by shortage of water, but primarily has been adopted because of the economic advantages resulting from it. These are namely fibre, filter and chemical savings, heat recovery and where its cost is high, conservation of water itself as well as effluent control. Economic reasons have probably had the greatest effect on present day practices and are indeed the initial reasons for recycling process wastewaters.

The industry will require a combination of reduction of wastewater generation, maximizing reuse of wastewater streams and development and application of new treatment techniques to achieve pollution abatement. Among the process measures which look promising to reduce wastewater discharges are : increasing pulp washing efficiency, closing down stock screening, oxygen or other bleaching, increasing dilution in washing, stripping condensates, collecting chemical spills, collecting fibre spills and dry barking. It may be possible to maximize reuse of wastewater streams and recover chemicals.

Rath (99) summarised the in-plant conditions and reuse potential of treated wastewater in the pulp and paper industry. In-plant reduction of wastewater volume is beneficial in reducing total effluent suspended solids, lowering capital cost of new treatment facilities and providing production cost savings and is essential for stable operation of an activated sludge plant. Treated effluent reuse potential for most integrated mills is in the range of 5 to 20% of total mill water requirements.

Common sense and environmental concerns dictate that water circulation is reused as often as possible (100). Benefits from a closed-water circulation system in paper mills include conservation of fresh water, chemicals and heat and reduced volumes of discharged effluents. Problems associated with water reuse may include machine operation difficulties such as corrosion, scale and microbiological deposits, pitch troubles and algal or bacterial slimes. These problem areas were discussed and possible counter measures were indicated.

According to Gossum and Sager, the most likely way the paper mill industry will solve its wastewater problems is through recovery and reuse of water, rather than treatment. A water management plan with emphasis on water reuse and product recovery was presented on a papermill which processes waste scrap paper into paper used in the manufacture of wallboard liners. Operating data illustrates how this plant is able to meet effluent guidelines with minimum end-of-pipe treatment due to an effective water management plan.

Thibodeaux et.al. (101) noted that the paper industry is one of the largest users of water and produces wastewaters high in pollution content. Treatment of these wastewaters so that they could be reused in the mill was the focus of this study.

The most logical first step toward reduced pollution at a pulp or paper mill is to maximize water recirculation and thus cut fresh water intake (102). This will both simplify the task and lower the costs of removing suspended solids and BOD from effluents.

Recycling of process waters is the best approach to reduction of effluent volumes in pulp and paper mills (103). Increased reuse of water requires improved measures for controlling deposits of a microbiological nature, such as slime growths and of non-biological deposits, such as scales. These deposits can cause losses in production, losses in heat and raw materials, reduced life of papermachine felts and wires and reduced product quality.

Closed-circuit processes have been used in the pulp and paper industry as a means of reducing the quantity of wastes requiring disposal and of recovering valuable substances in the wastewater (104). Waste treatment at a paper/board plant can involve primary treatment for recovery of water to be used in feed preparation ; secondary treatment for recovery of fibres, fillers and additives ; and tertiary treatment for reuse of the residual effluent. Advantages and disadvantages of adding tertiary treatment were discussed.

Edde (105) presented a brief history of pollution control efforts in the paper industry. Comments were made on several novel treatment methods for obtaining high quality effluents for process water reuse. Bush (106) defined the concept and implementation of the closed paper mill system, pointing out advantages and updating progress made by the industry in achieving this goal. Examples of closed mills were given and associated problems enumerated. Billings (107) presented a critical analysis of problems involved in increasing internal reuse to develop a closed-water system in the pulp and paper industry.

Gottsching and Dalpke (108) described the fundamental principles of paper mill closed-water systems. Effects of higher concentrations of inorganic salts and/or organic solutes on paper quality were considered. The water condition and products quality were reported for a tissue mill which has been operating with a closed-circuit for a long time, with an average discharge of one cubic meter of water per ton of product.

Brecht and Dalpke (109) presented a critical review of the literature reporting experience with the closing or partial closing of process water circulation systems in paper mills. Included were discussions on the planning and engineering stages involved in circuit closure, its advantages for pollution abatement and its disadvantages or problems.

The closure of pulp mill water circuits is attractive for several reasons, including pollution abatement, fresh water conservation and reduced fibre losses (110). Key points in closed production lines and some of the attendant problems were discussed.

Alexander and Dobbin (111) discussed the use of a closed mill water system as a means of pollution abatement for the pulp and paper industry. Closure of the paper mill water system eliminates the need for extensive secondary and tertiary water treatment facilities. However, closure may allow concentration of dissolved solids in mill water to be drastically increased through water reuse, possibly affecting water quality and paper properties. At complete closure the concentration of dissolved solids in the headbox can be up to 160 times the level anticipated for a completely open mill.

Although the paper industry uses large amounts of process water, only about 10% is actually consumed in the papermaking process (112). Since much of the polluting load of a paper mill effluent results directly from the presence of raw materials in the water, there is a strong economic incentive to recover these materials and recycle them. This has led to an increasing use of recovery systems in the papermachine white water system. Three devices for recovering suspended solids were discussed including gravity settling chambers, flotation devices and mechanical filters. When discharge requirements become very stringent, there are strong incentives to increase primary in-plant treatment, reduce process water requirements and increase water recycle rates. All of these steps approach the ideal goal of a totally closed mill system and reduce pollution.

Roberts (113) reported that efforts to stem pollution effects of paper mill effluents in England have taken two courses : conventional treatment and water reuse. Since paper mills must pay for water and water must be conserved like any other resource, a system of recirculating water within a plant has been instituted. This has reduced the loading on treatment plants thereby reducing treatment costs. Water reuse has also alleviated the sewage fungus problems in rivers downstream from paper mill outfalls. New machines have been designed to accept reused water and show great promise in increasing benefits from this concept. Effluent purification is expensive and gives no return on capital. In-plant recovery of water results in substantial savings and provides for a better effluent.

Resource scarcity, environmental constraints and economic factors were noted as the principal reasons for water reuse in the Australian pulp and paper industry. These reasons were examined and water reuse practices were described. Equipment and processes utilized to prepare the water for various recycling processes were shown to vary with quality and environmental requirements. Examples of water reuse systems utilized by Australian Paper Manufacturers Ltd. mills were included and some problems associated with water reuse were discussed. The future of water reuse in the industry was considered.

The concept of waste-free technology in the pulp and paper industry, as defined by the Commission on Economics of the European Common Market, was discussed by Tipisev et.al. (114) and measures already introduced toward this goal at Russian mills were indicated. Measures aimed at reducing consumption of fresh water include dry barking, diffusion washing of pulp, screening and beating at high consistency, manufacture of paper by the dry process and purification and recycling of fibre-containing effluents. The proposed conversion of the Seoenga pulp and board mill, located near Lake Baikal (USSR), to entirely effluent free operation was discussed.

Environmental protection of waterways from paper mill discharges can be achieved by closing the white water circuit of papermachines (115). Swedish experience with a closed-system newsprint machine has indicated that at least part of the normally discharged pollutants can be recycled and included in paper products without detriment to their quality. Some properties, such as optical and mechanical characteristics, can actually be improved. Moreover, savings in fibre and heat consumption can result. Operating conditions of papermachines must, however, be carefully adjusted and monitored.

In order to limit environmental pollution, many paper mills in West Germany are adopting the closed-water system of production using recycled water (116). The closed-system offers savings in water and energy. Its use with the alkaline hydrolysis process allows recovery of valuable by-products such as pentoses and hexoses.

Results of a survey of environmental protection being used by pulp and paper mills in Austria have been presented (117). Emphasis has been placed on reduction of air and water pollution by technological improvements, closed-cycle processes and other measures which permit partial recovery of chemicals rather than on the treatment of effluents.

Wernquist (118) discussed recent technology developments by the Swedish pulp and paper industry in preventing water and air pollution. Closed-circuit pulp screening and purification of condensate, along with dry barking and an improved pulp washing method, has resulted in a nearly completely closed-system in a modern mill up to the bleaching stage. Presently, bleaching is responsible for nearly 70% of mill-caused pollution and efforts are being made to develop suitable processes for purification of bleach plant effluents.

Coats (119) reported on water conservation measures in the design of new paper mills. It was determined that specific reuse was essential. Typical demands and methods of economy were described for mill water system, including reuse of cooling water, gland seal water, vacuum pump seal water and press felt cleaning water. A closed white water system was deemed essential to water economy. Examples were given of typical white water chest designs for efficient system purge and maximum white water reuse.

Springer (120) reported a study program devoted to the development of information which would be useful to mills in implementing programs of more extensive water reuse in high quality paper manufacture.

Increased reuse of papermachine wastewaters seems desirable both from economic and ecological viewpoints (121). Three continuous trial runs were conducted on the 30 inch wide Fourdrinier machine at Western Michigan University with 72% to over 97 % reuse of white water. Increasing system closure from 72 to 97 % water reuse did not seriously affect the quality of manufactured paper. After several minor changes in equipment and operating procedure, the paper differed only negligible in strength properties, dirt content and printability.

Due to rising energy costs and environmental constraints, efficient reuse and recycling of wastewater streams at pulp mills can be advantageous because it can reduce overall water consumption, minimize effluent volumes to be treated and optimize low level heat recovery, thereby decreasing steam usage (122). Quantitative and qualitative methods used to design an efficient water reuse system were analyzed and examples were given of alternate modes of unit process operations and how they can affect the overall water, steam and effluent streams.

One possible way to reduce discharge of water pollution from Kraft mill bleaching is to recycle effluent streams from the bleaching plant to the recovery system (123) ; however, this raises questions concerning effects of increased chloride levels in the liquor cycle and removal of chlorides from the recovery system. These workers conducted mill trials to determine the distribution of chlorides between the smelt and gas phase in the recovery furnace and correlated the distribution with a theoretical chemical process model. Implications of these studies on operating conditions of the recovery furnace were discussed.

Recycling bleach plant effluent to the recovery system reduces the amount of water pollution from a bleached Kraft pulp mill (124). It was reported that several methods of removing chlorides from a mill with a closed bleachery were under development. Extended delignification in the cook, oxygen bleaching and the use of a high proportion of chlorine dioxide during bleaching will help keep chloride levels low.

Haynes (125) reported on the evaluation of a number of processes for water recycling possibilities in the pulp and paper industry. Systems were evaluated on the basis of incentives for process installation. This analysis was carried out on departmental and mill wide scales. The latest water recycling values were probably low, thus, a new mill installation with the emphasis on practical recycling schemes shows a reuse factor of up to 1 600% for a bleaching Kraft pulp mill. The all industry recycling value last reported was 290%.

Water and air pollution in the Kraft pulping industry were discussed by Miller (126). A Kraft mill uses 15 000 to 60 000 additional gallons for bleaching pulp. Sedimentation, aerated basins and activated sludge are the main external effluent treatment methods; however, particulars of water-reuse system vary from the mill to mill.

Hammer and Rydholm (127) outlined papermaking operation of Kraft or sulfate process pulp mills and evaluated them with regard to their water pollution aspects. Among recent technological developments holding considerable promise of abating pollution are the trend toward high yield pulping processes, especially semi-chemical processing; improved pulpwood digestors combined with counter-current pulp washers for increased recovery of black liquors; bleaching with oxygen resulting in low BOD bleach plant effluents; and water recirculation for fibre recovery and attendent reduction of suspended solids. Chemical recovery from black liquor via dissolved smelt was also addressed.

All aqueous effluents from bleached Kraft pulp mills can be eliminated by recovering and reusing all water and chemical required for bleaching (128). None of the process changes that would be involved would be radical departures from existing technology and none of the equipment needs are novel. The design and development status of effluent free Kraft mills is discussed.

Narum and Moeller (129) described a four part program initiated by Simpson Paper Company to improve wastewater treatment at its integrated bleached Kraft pulp and paper mill near Anderson, Califonia. The program included greater internal reuse of process water, upgrading existing primary treatment facilities, a new low rate aerated stabilization basin as a secondary waste treatment system and use of the secondary effluent for irrigation of grain crops.

Developments in pulp bleaching are strongly influenced by the need to utilize existing equipment and to minimize water and energy use in old mills and to reduce capital and energy expenditures in new facilities (130). Counter-current reuse of wash liquors can reduce effluent volumes perhaps as much as from 20 000 to 4 000 gallons per ton of pulp. Diffusion bleaching promises to reduce this further to about 2 600 gallons per ton with simultaneous reductions in steam consumption and pumping energy. The effluent free bleached Kraft mill concept promises to find realization in the Rapson-Reeve system currently undergoing practical trials.

Rapson and Reeve (131) outlined the required processes and process changes necessary to make bleached Kraft pulp mills free of liquid effluents by recovering and reusing all water and chemicals used for pulping and bleaching.

The Continental Can Company of Hodge, Louisiana, initiated a modernization and expansion program for better water pollution control at an unbleached Kraft and semi-chemical pulp and paper mill (132). A large scale colour removal system was designed from criteria established in laboratory and pilot plant facilities. New standards for unbleached Kraft waste effluent treatment were also developed. Water consumption was reduced by 30 % through recycling and utilization of the colour removal system to further reduce BOD in the waste effluent. The total investment necessary was determined to be less than two-thirds the cost of constructing a new plant of equal capacity.

An outstanding example of the use of advanced techniques for the control of air and water pollution is exemplified at the American Can Company plant for the manufacture of Kraft pulp, paper and tissue products (133). Processes were selected for incorporation in the extensively automated plant that minimized odour production and which facilitated the use of recycled water. The wastewater treatment system consists of a primary clarifier, two aerated ponds, secondary clarifier and chlorination basin.

A description of the wastewater treatment system installed at the Bridgeview, Illinois, container plant of St. Regis Paper Company was given (134). Pollutants are precipitated with chemicals, filtered from the water and disposed of in a sanitary landfill. Treated water is decolourized in an activated carbon column and either reused in the container plant or discharged to the municipal treatment system.

Timpe et.al. (135) presented a survey of the literature and other sources on the handling and treatment of pulp and paper mill effluents, with particular emphasis on the Kraft process and the use of activated carbon and lime treatment advanced methods of treatment. The survey was made as a first step of a development program aimed at maximum water reuse in Kraft pulp and paper mills based on effluent treatment using activated carbon. Results of the survey includes information on activated carbon and its application in treatment of pulp and paper mill effluents. Information is presented on lime treatment of Kraft mill effluents and other advanced methods. The subject of in-plant water reuse is also covered.

Ishii (136) described anti-pollution features at Oji Paper Company's Kraft pulp and paper mill in Japan. Papermachine white water is filtered or passed through save-alls for recovery of suspended fibres, clay filler and other solids and then into in a 24 meter diameter clarifier. The supernatent is recycled as condenser cooling water. Installation and operating costs of all pollution control facilities are listed.

An environmental improvement program has been completed to supplement existing treatment facilities at the integrated Kraft pulp and paper mill and converting plant of Thilmany Pulp and Paper Company, Kaukauna, Wisconson (137). The installation comprised both external and internal treatment measures. Internal water conservation measures include an extended white water collection system, high-pressure machine cleaning showers, reuse of decontaminated evaporator condenser water and fibre-recovery save-alls. External treatment involves a clarifier basin, centrifugal sludge dewatering system and two biological oxidation lagoons. A flow chart of the entire system including auxillary equipment is included.

Renovation programs in two existing kaft mills have demonstrated that increased water reuse and recycle within conventional bleach plant can reduce steam and fresh water consumption and effluent volume. The design for new Kraft bleach plants incorporated not only chlorination filtrate recycle and complete counter-current washing, but many other steam and water saving features. All the bleach plant filtrate can be recovered and the last major source of water pollution from bleached Kraft pulp mills eliminated (138).

Warnquist (139) discussed reduction and control of pulp room effluents and sulfur dioxide emission from the recovery furnace in bleached or unbleached Kraft mills by system closure and by external measures. In-plant solutions for reducing the large factor of organic compounds in the screen room effluent including extensive brown stocks washing, recycling the decker effluent to the screen room, screening at high pulp consistency and in-line refining with minimum or no screening. A Norwegian integrated mill was described which produces Kraft pulp for bag paper and lineboard with in-line refining without screening. A proposal to close the system suggests that the drum filter effluent be reused counter-currently in the high-heat washer and that a radial washer be installed after the refiner to increase chemical recovery.

Nicholls (140) discussed development of closed-process technologies for Kraft mill multi-stage bleach plants. Alternative in-plant treatments comprise reductions in bleach plant volume and two engineering approaches to oxygen bleaching: recirculation of bleach effluent in the pulp mill system and oxidative pulping bleaching. If bleaching plant effluents are to be recycled, their volume must be reduced, perhaps by reverse osmosis concentration and their chloride content must be eliminated.

The large effluent volumes from a conventional brown stock screen room on a Kraft mill can be reduced by recycling the decker effluent, by screening at high pulp consistency and by in-line refining with minimum or no screening (141). Closed handling and treatment of coarse screen rejects can be accomplished by recooking or refining and recycling of rejects. Cost comparisons were made for in-plant measures to reduce effluent volumes versus external treatment and for the options for closed rejects handling.

Burkart (142) conducted experiments in which the wastewater from the alkaline extraction stage of a pulp bleach plant was recycled in order to study the effects of recycling on the quality of bleached pulp and on the colour or ease of decolourization of the resulting, more concentrated effluents. Results indicated the pulp required no increased consumption of bleach to achieve the desired brightness and that lignin in the recycled alkali extraction water is readily precipitated, leaving an amber coloured supernatent that can be further decoloured with activated charcoal or bleach, if necessary.

Black liquor evaporator condensates, raw mill effluents and chemically or biologically pretreated aqueous waste of the Baikal Kraft pulp mill (USSR) were subjected to reverse osmosis in comparison with ultrafiltration, using Soviet made cellulose acetate membranes (143). Both methods of effluent treatment recovered water of sufficient purity for recycling as pulp mill process water. Ultrafiltration was found to operate more efficiently at relatively low pressures; whereas, reverse osmosis was superior in removing dissolved mineral compounds.

Engelhoffer (144) indicated technological and economical advantages of white water clarification by flotation for treatment of recyclable waste and final effluent and noted the successful experience at four paper mills. Scharsmied and Slanina (145) discussed the need for and problems associated with, recycling white water and effluents in the pulp and paper industry, particularly the complex nature of deposit and corrosion problems.

Berger and Wilson (146) reviewed the status and possibilities of wastewater reclamation and reuse in the Kraft pulping industry. Ranhagen (147) presented models for closed-water systems integrated with an air emmission control system for a Kraft pulp and paper mill. He concluded that a closed-system is a realistic possibility.

Ranhagen (148) discussed present and future ways and means for closing integrated paper mills for air and water pollution control. Paticular aspects covered included changes in pulp washing, chemical balance control, treatment of contaminated condensates and integration of mill operations to reuse water. Diagrams of a closed Kraft and groundwood mill and theoretical aspects of washing systems were presented.

Counter-current washing for pulp from the bleach stage of Kraft mills is one proposed system for pollution abatement (149, 150, 151). Laboratory work on this method has indicated the effectiveness of this system. Effluents from the acidic and alkaline sewers of a bleachery using the D(C)EDED sequence to bleach can be reduced approximately 10 fold by extensive chlorination, filtrate recycling and counter-current washing. The system may not be used as a separate bleach plant effluent treatment or for bleach chemical recovery.

Histed (152) reviewed counter-current pulp washing practices of 20 Canadian and U.S. Kraft mills. Details, including the flow charts, were presented with emphasis on water needs and recirculation problems. Cornell (153) described a closed-cycle bleached Kraft pulp mill using a salt recovery process. Complete counter-current washing in the bleach plant reduced water usage by 8%.

Armstrong (154) discussed the $10 million energy and environmental improvement program at the Abitibi bleach Kraft pulp and stud mill in Smooth Rockfalls, Ontario. Effluent from the pulp mills screening operation plus fines from the bark screen room are processed by an Eimco Envirotech effluent clarifier. Recycling water from the clarifier and counter-current washing in the bleach plant have cut water consumption to 44 000 gallons/ton of pulp.

Stevens (155) described a white water recirculation system for a papermachine producing various grades and colours of Kraft specially papers. The system uses a disk filter to clarify the white water with recirculation of the filtrate to the machine showers and the filter showers.

With presently available equipment and other methods, complete recycle of condensate in a Kraft mill can be achieved while reducing BOD by 75% (156). Capital and operating costs of such a system and methods for reducing operating costs were presented.

Lowe (157) described the effluent treatment system at the Gulf States Paper Corporation 100 ton/day Kraft mill in Tuscaloosa, Alabama. Combined effluent from the pulp and paper mills is clarified in a primary clarifier, treated in 4 stage UNOX activated sludge plant, decoloured by reacting with alum mud and finally clarified and discharged to a holding lagoon. Gulf States eventually plans to reuse most of the purified effluents.

A decription was given of the 700 ton/day bleached Kraft pulp mill of Great Lakes Paper Company, Thunder Bay, Ontario (158). The closed-cycle process consists essentially of recycling bleach plant effluent through the standard black liquor recovery cycle and from the resulting white liquor separating out the salt which becomes the basic raw material for manufacture of chlorine dioxide. Flow sheets of the closed-cycle recovery system, salt recovery process and pulp screening, cleaning and bleaching operations were included. Benefits of the closed-cycle mill were noted. Savings in operating costs for the mill were detailed.

The closed-cycle bleached market Kraft pulp mill of Great Lake Paper Company, Thunder Bay, Ontario is the first practical installation utilizing the Envirotech salt recovery process (159, 160). Savings are expected to occur from heat savings, fibre and chemical savings, water savings, reduced effluent treatment costs and yield increases. Within 2 to 3 years, these economics are expected to pay for the greater capital investment compared to a conventional new Kraft mill. Only 4 000 gallons of water are used per ton of pulp, about 85% less than in conventional Kraft mills. Counter-current reuse of filtrates plus other modification reduce steam demands in the bleaching to about 10 to 15% of those normally required. Clean clear cooling water is the only liquid discharge from the mill.

Stevens (161) discussed installation of the Rapson-Reeve salt recovery process at the 700 ton per day bleach Kraft mill of the Great Lake Paper Company at Thunder Bay, Ontario. The process will remove sodium chloride from the recovery cycle, thus limiting its equilibrium concentration to a tolerable level. The process and operating equipment were briefly described. All streams containing BOD, suspended solids, colour and toxicity can be reused within the process, so that only clear water used for cooling will be discharged.

Weyerhaeuser Company at Miquon, Pennsylvania, installed a primary clarifier and storage lagoon to treat white water from five papermachines (162). The need for further water conservation prompted the start up of a pressure filter to treat and recycle a portion of the clarifier effluent. Although the full-scale plant operated less efficiently than the pre-investigated pilot unit, freshwater needs were expected to be cut by 50%.

Brown et.al. (163) described a reverse osmosis system for concentrating white water from a papermachine, the white water having been previously freed of its fibre content through treatment in a filter or decanter. The RO unit separates fibre-free white water into a concentrate of pulp additives and a permeate. Both the concentrate and the permeate can be recycled in the papermaking process, making it possible to operate a mill on a closed-water system basis.

The Mayak Revolyutsil paper mill (USSR) was to install a new effluent treatment system in 1978, in which the machine white water will flow into a storage tank and be reused in the pulpers (164). The system will increase the degree of fibre and filler recovery from 78% to 94 to 96% and reduce the solids content in purified water from 150 to 46 mg/l. Recovered fibres are used in making high quality papers. Other advantages are reduced power consumption and operating costs.

Luzina (165) described a Soviet process for manufacture of highyield unbleached Kraft pulp with efficient recycling of treated effluent water.

The process is said to reduce fresh water consumption from 29,7 to 9,8 cubic meters and effluent volumes from 36,1 to 15 cubic meters per ton of pulp produced. The process features four double chamber pulp washing filters; a two-stage recovery of black liquor entrained with digester relief; surface condensers in lieu of barometric condensers; partial reuse of purified effluents in various mill department; automatic water quality control for cooling of bearing and other hydraulic functions; and monitoring of water consumption and effluent discharges in all mill departments.

Fremont et al (166) examined ultrafiltration (UF) as a means of reducing colour in Kraft mill effluents more efficiently and/or more economically than the presently available method. A 10 000 gpd pilot-plant was operated for six months at the Champion Paper Company pulp and paper mill, Canton, North Carolina. Four experimental aspects of the process were evaluated : feed pretreatment, UF, concentrate disposal and water reuse potential. Process colour removal efficiency was satisfactory. For all influent studied, typical results were 90% colour removal ; with 98,5 to 99% water recovery. Total operating costs were estimated.

Internal process control measures for controlling pulp mill pollution and reducing materials wastage include increased pulp washing, closing the brown stock screening system, new bleaching process, improved condensate handling and spill collection (167). These measures are exemplified in recent a Scandanavian installation. Overall treatment costs to meet various discharge limits in a bleached Kraft mill are examined for different combination of internal and external control measures.

Lyons et.al (168) developed a generalized mathematical model for use in determining the optimum quality of water recovery and reuse. The model and associated methodology were applied to the water management system of a medium size bleached Kraft pulp mill. Through optimization of this problem, the reuse of water reclaimed from industrial wastewater was accomplished by utilizing the model. The cost solution considered effects of variations in production process water quality requirements, cost and quality of fresh water and reclaimed water and cost of effluent treatment. Application of the model to the pulp and paper mill indicated that high levels of recycle could be economically justified if stringent colour standards for wastewater effluent required a high degree of biological treatment. The key to the process of reclaiming usable water from the pulp and paper mill was colour removal.

An invention relating to a pulping and bleaching system in which the bleaching and extraction stages yield an aqueous alkaline filtrate and provides procedures for recycling these filtrates has been patented (169). Part of the acid filtrate is neutralized with fresh aqueous sodium hydroxide and used in washing digested pulp in a washing stage immediately prior to passing the washed pulp to the bleaching system. The remainder of the acid filtrate is introduced as an aqueous medium into the spent pulping liquor recovery cycle at a point after burning of the spent liquor. Part of the alkaline filtrate is used as wash water for washing pulp in the earlier stages of the washing system, before the stage using acid filtrate. The remainder of the alkaline filtrate is used in diluting regenerated pulping liquor to the desired concentration.

Skarsgiris and Skoupskas (170) described wastewater treatment equipment for a paper mill producing high quality printing papers from bleached pulp. Eqiupment consisted of six conical save-alls receiving dirty water from wet presses, felt conditioning, overflows and water used for general mill cleaning. Effluent from the clean water treatment system is recycled for process water makeup and recovered solids are sent to the hydropulpers. Effluent from the dirty water system is discharged.

The AES 3 600 gravity strainer, developed in Finland, can be used to treat water for use and reuse in the pulp and paper mill (171). The filter resembles a large vertical drum with effluent flowing toward the center at about the top perimeter of the tank. The effluent flows through a distributor plate and a metal or plastic screen into a tank over which the filter is mounted. A rotating shower beneath the screen lifts, rejects and floats them toward the centre reject outlet. Three applications in the United States are illustrated.

Norton (172) discussed water reuse in non-integrated paper and board mills and the associated problems. Examples were given of closing the water system on a multiply board machine and of water conservation on a fine papermachine.

Gibson et.al. (173) described the wastewater treatment system which furnishes water for reuse at the Ponderosa Paper Products Inc. plant in Flagstaff, Arizona. Plant wastewater is collected at a central point and treated in a dissolved air flotation unit. Clarified water is then put into a 3 section lagoon. From the lagoon storage basin, the effluent is polished in two automatic granular-media filters. The filtered effluent is pumped into a water tower for reuse in the mill. Operating problems and plans for improving the wastewater treatment system was discussed. Fresh water consumption at the mill has been reduced from 50 000 to 30 000 gallons per day.

A test program performed at a paper mill in Aberdenshire area of Scotland demonstrated the ability of the Mecatec effluent treatment system to recover fibre. The Mecatec system is a multi-purpose low cost modular unit developed in the United Kingdom (174). It has been successfully used for general and industrial wastewater treatment. The system has no moving parts and combines features if inertial and blanket filtration for effective removal of particles. The trial run showed impressive separation of thick and thin fractions. The clarified overflow was used as shower water. The thickened underflow was returned to a save-all unit achieving 400% increase in save-all drum efficiency. The recycled water resulted in a 50% reduction in main intake. Fibre recovery should pay for the cost of the system in several months.

A patent has been issued for a closed-circuit paper mill effluent treatment process (175). The total effluent is collected in separate closed-circuits. Parts of the untreated effluent is used for pulp heating and dilution. The remainder is collected in at least one other closed-circuit, regenerated by addition of chemicals, conditioned and then supplied to the paper making process in place of fresh water. Advantages of the system include : smaller consumption of fresh water; almost complete elimination of waste disposal; no buildup up of salts; and use of a smaller quantity of expensive chemicals.

Mattison and Bier (176) described a proprietary system for recovering usable fibre from process elements. Data were cited which show that fibre recovery can reduce waste treatment cost by reducing waste treatment equipment requirements, reduce fresh water requirements by permitting water that would be sewered to be reused, reduce plant maintenance requirements and return useful fibres to process or for sale to produce income.

Akerhagen (177) described equipment for removing fibre for reuse. Fibre is separated from fines by impinging white water on a screen. Water containing the fine fraction can be reused. The device was said to be best applied in combination with flotation. Jacobson (178) described a fractionation to classify white water for various points of reuse and exemplified its use in the production of various grades of paper and for removing solids from barker water.

One technique of recycling wastewater becoming widely adopted in the U.S. pulp and paper industry utilizes the SWECO, Inc, Centrifugal Wastewater Concentrator to remove fine particles and fibre from mill effluents (179). Operation of the equipment and a number of important pulp and paper applications were discussed. The experience of the Horner Waldorf, St. Paul, Minnesota boxboard mill was quoted and the cost savings achieved by resultant water recycling, energy conservation and fibre reuse mentioned.

A patent has been issued for a straining apparatus that separates fibres from backwater coming from a paper making machine so that the water can be reused as spray water. The apparatus consists of a funnel shaped vessel with an outlet (180). A first strainer forms one wall of the vessel and a second strainer covers the outlet of the vessel.

Folchetti (181) described the design of a paper mill waste treatment system that is integrated with the existing process water system to provide for closed loop operation to reclaim the total effluent or for operation in conventional open mode. The system consists of chemical coagulation and solids flocculation and separation in a clariflocculator, with underflow being dewatered for disposal and overflow going to the process water system.

Follea (182) described the wastewater treatment system developed for a 320 ton per day paper mill with two papermachines and one cooler. The system centres around a flocculator/clarifier and was specially designed for recycling of clarified water to the mill process water.

Slightly polluted spray water from papermaking machines and ventanip presses can be cleaned by the use of Ronnigan - Petter filters, arranged in units of two or more, for continuous operation in a closed water cycle (183). In addition sealing water in vacuum pumps can be purified by means of Ronningan - Petter filters for recycle in heat exchangers. The use of these filters with backflush and snap fit gives easy mounting.

The Ukrainian State Institute for planning of pulp and paper and hydrolysis industry plants has developed several closed-water cycle systems for pulp and paper mills. Many of these systems are already in operation or are being introduced. Dubitskaya (184) described and illustrated water recycling systems operating in an electrical insulation board mill, a pulp and filter paper mill, a fine paper mill, a boxboard and corrugating medium mill and a board mill. All systems considerably reduced fresh water consumption and effluent volume.

Effluent quality leaving the process of an integrated paper mill in Vancouver, British Columbia was upgraded by internal reclamation and recycle of suspended solids from various streams including press tray water and wire return roll shower water (185). Save-all clarified water is used for low level makeup to the seal pit and the rich white water tank. Paper quality problems relating to the closed-system have not been encountered.

McCourt (186) reviewed the use, role and importance of post save-all devices in providing a uniform quality water, hence enhancing the possibility for continuity of operation and more extensive water reuse in the paper making process. Reported experience with post save-all solids devices was described. It was concluded that more detailed knowledge of capability of these devices to perform the solids separation function under variable flow and feed quality is needed to enhance the potential for more extensive water reuse.

Stevens (187) discussed and compared save-all types and designs, white water characteristics, objectives of a good white water system and factors affecting save-all design. Types of save-alls described included drum, flotation and disc filters.

Brooks (188) discussed types and technology, application, fibre and water recovery and operational data relative to save-alls. Principles of operation of the various units were presented as were operational problems. White water systems and characteristics were enumerated. The importance of water reuse was pointed out and the effects of closing a white water system were listed.

Smith and Berger (189) proposed an overall treatment scheme for pulp and paper mill waste which handles the wastewater stepwise to produce a reusable process water. A four stage process utilizing lime dosing, biological treatment, activated carbon filtration and demineralization was used on bleached and unbleached total Kraft mill effluent. A three stage system without biological treatment also was tested. Cost comparisons showed that reusable water would cost approximately twice as much from the three stage system.

A sequential treatment consisting of activated sludge treatment, lime treatment and activated carbon absorption treatment was tested on unbleached Kraft pulp mill washing wasterwater in a pilot-plant system (190). Activated carbon treatment of this pretreated effluent produced a colourless, extremely low COD water suitable for reuse.

A Kraft plant owned and operated by La Cellulose D' Aquitaine, located at St. Gardens, France, employs a pure oxygen bleaching unit that will completely recycle its own effluent to the Kraft recovery cycle (191). The unit has a bleaching capacity that completely matches the capacity of the Kraft pulping unit it serves.

Koleskinov (192) diagrammed a closed-system for recycling white water in the manufacture of sized papers. Fresh water makeup to the system is 1,6 cubic metres per ton. A demineralization process is included in the system. Czappa (193) described a fine paper mill operation that achieved 40% reduction in wastewater flow through reuse of white water and recycle of vacuum pump seal water.

Leker and Parsons (194) discussed wastewater treatment measures taken at the Masonite Corporation pulp and paper mill in Laurel, Mississippi. Wash water from stream processed pulp, containing 90% of the BOD but amounting to less than 15% of the total wastewater flow, is concentrated in a quintuple effect evaporator. Residual solids are converted into a marketable product. Two other effluent streams containing process water plus cooling, sealing and housekeeping water are handled separately in primary clarifiers from which 90% of treated water is recycled to the mill. The remainder is treated in a biological contact stabilization system. Overflows pass to an aerated lagoon for polishing before reuse or discharge.

Holmes (195) discussed the recycling of white water at the Powell River Division of MacMillan Bloedel, Ltd, in British Columbia. Although effluent toxicity did not increase when white water was passed through the direct contact heat recovery unit of the thermo-mechanical pulp (TMP) plant, recycling did cause unexpected changes in pH, conductivity and BOD. Recycled pulp mill white water is about twice as rich in environmentally deleterious material as in excess papermachine white water. Chemical pretreatment of pulpwood chips and other TMP process variations could cause greater differences.

Closing of water systems in integrated mills is impossible as long as slush pulp enters the system at a water content higher than the web enters the dryers (196). A press capable of high tonnage and high discharge consistencies was described. This press provided an additional washing stage and allows a final assault on the objective of a totally closed-water system. An arrangement of closed-system was diagrammed.

Decker and Louise (197) described an anti pollution system and equipment installed at the Intercontinental Pulp Company mill in British Columbia. In-plant measures include equipment for maximum reuse of process waters and fibre and chemical reclamation system. It is emphasised that systems such as these will not produce the desired results unless they are operated properly.

Operations and equipment of a German paper mill were described (198). The mill produces 315 000 tons of newsprint annually on four Voith papermachines. Discharged papermachine white waters are treated in four scraper filters with the effluent purified chemical-mechanically in a passavant coagulator and partly recycled.

Foul condensates are collected from digester flue gases, turpentine recovery operation and black liquor evaporators at the Nekoosa Paper Inc. Kraft mill at Nakoosa, Wisconsin. After stripping, the condensate is used to heat the incoming feed and then as wastewater in the brown stock area (199). Condensates are pumped to a distillation column. The distillation column is integrated between the first and second effects of the old multiple effect evaporators.

Method of treating aqueous effluents from paper and board mills have been reviewed, including recycling of papermachine wastewater, primary treatment to remove suspended solids, secondary or biological treatments to reduce biochemical oxygen demand, premixing of waste and treatment of condensates (200).

Model (201) described conversion of a paper and board mill to a closed-water system. Effluents are treated by sedimentation and filtration. The system has resulted in elimination of a proposed treatment plant, decrease in water consumption and recovery of solids. Disadvantages, particularly corrosion problems, were discussed.

The integrated groundwood Kraft pulp and coated paper mill of Biose Cascade Corporation, Rumford, Maine, instituted in-plant water recycling and reuse systems to reduce flow, suspended solids and BOD to the effluent treatment plant (202). A comprehensive in-plant sewer sampling and reporting program provided management with the data needed to minimize losses and to document the effect of the recycle and reuse systems. Feed to the effluent treatment plant was reduced from 45 mgd in 1972 to 23,71 mgd in September, 1977, which is 5% below plant design capacity.

Morgeli (203) reviewed closed-water cycles in paper and board mills in Switzerland and discussed problems associated with high salt concentrations and biological activity in the recirculated water. Possibilities for controlling these problems were outlined. On the basis of theoretical considerations, test results and mill experience, three of the processes are unable in recycling water : flocculation, filtration and adsorption. Suitably combined with biological processes, these offer a solution to the water pollution problems.

A rational basis for water reuse in paper manufacturing has been developed and applied to combination paperboard manufacture (204). The central idea of the approach is to determine the lowest quality water which can be successfully used in a given application. A water quality guideline is determined for a given water use based on that limited water quality. Water quality guidelines for a given application are obtained from actual plant data. Visits were made to 13 plants which were exhibiting good water reuse practices. These mills served as the data base for water quality guidelines for 22 water uses. A steady state water flow model for combination paperboard manufacture was developed and used to illustrate techniques the mills employed in reuse and conservation of water.

An extensive mechanical effluent purification system was put into operation at the Stupino Board Mill, USSR (205). Effluents from the board mill and auxilliary plants first pass through sand traps and then to radial sedimentation tanks. Clarified effluents than undergo a second purification stage in contact clarifiers filled with gravels and layers of quartz sand of different granular composition. About 70% of the purified effluents are recycled to the mill as replacement for fresh process water.

Dubitskaya and Galenko (206) provided a schematic description of a water recycling and reuse system for a paperboard mill to be added to an existing integrated pulp and paper mill at Zhidachev, USSR and a similar system to be installed at a board mill in Rostok. Effluent from the board machine will be treated with chlorine for colour removal, coagulated with alum and polyacrylamide and passed to contact clarifiers. Clarified water will be recycled and substituted for 40 cubic meters of the 70 cubuic meters of fresh water needs per ton of board produced.

The Ukrainian Board Mill in Lovov was faced with the necessity of introducing a closed-water cycle because of a shortage of process water (207). The first step in this direction was an improvement in the wastewater system to increase its degree of purification. The system was described and illustrated with a diagram. Partially clarified white water goes to two vertical sedimentation tanks where aluminum sulfate and polyacrylamide are added. Purified white water can be recycled. It can be used for washing belts and cylinder mode wires.

Svitel'skii and Litvinova (208) reported on a study of water reuse at a paper and board mill processing waste paper. The study, conducted by the Ukrainian Research Institute of the Pulp and Paper Industry, showed that water reuse averaged 70% and at some mills reaches 85%. Consumption of fresh water ranges from 34 to 80 cubic meters per ton. A purification system is described which will reduce fresh water consumption to 20 to 24 cubic meters per ton, reduce the pollution load by 15% and allow the reuse of over 75% of the purified water. The system consists of separating reusable fibres on an OV-02 fractionator and treatment of the effluent with aluminum sulfate and polyacrylamide, followed by dewatering the sediment by centrifugation.

Abitibe Corporation has reactivated at 125 ton per day board mill in Blountstown, Florida. Pulping and stock refining systems were designed specifically to accommodate the relatively dry raw material and to attain zero discharge are outlined (209). In general, the closed-water system is comprised of a series of semi-closed loops within the system. Substantial operating cost reductions as well as compliance with water pollution control standards have been achieved with the system.

Wastewater purification procedures for two integrated board producing/ converting mills and one board converting operation in West Germany were outlined by Morch (210). Following sedimentation, biological purification and chemical treatment, thick stock material from the wastewater treatment plant is returned to the mixed waste paper pulper for one of the board manufacturing lines, while another uses chemical-mechanical reclarification plus biological treatment. The influence of recycled solids on board quality and production was also considered.

Superior Fibre Products, Inc. undertook a project to eliminate any discharge of process water from their wet process hardboard manufacturing plant through a program of water reuse (211). All but wash-up water and some pump seal leak water discharges were eliminated. Water absorption and linear expansion of the board increased after close-up. Close-up of the process reduced chemical usage. Board strength problems were eliminated through control of the white water temperature. Some remaining drawbacks to the system are a darker board colour and overall reduced cleanliness of the mill.

Starkweather and Frost (212) discussed various philosophies of achieving low or zero discharge via water recycle in paperboard manufacture and outlined operational problems encountered in several mills. Gran (213) discussed the effects of complete or partial closing of the water circuit on the volume and concentration of contaminants in a paperboard mill. Various method for treating and disposing of highly pollute effluents were considered.

Successful conversion to closed-circuit operation of a wet process fibre board mill was first achieved in France (214). A brief description of what was done and some environmental and cost factors of recycling process water for pollution control in a wet process building board mill were presented. Efforts to reduce pollution and recycle wastewater at a French paper mill were discussed by Vandewoestyne and Maric (215). A fibreboard factory was described that completely recovers and recycles process water with recovery of all solids in suspension.

The effluent treatment plant at the St. Anne Board Mill, Ltd. plant in Bristol, England was decribed (216). The treatment system consists of two clariflocculators, a sludge thickener, aerated lagoon and sludge filter. Provisions has been made for recycling some of the clarified effluent to the mill. Up to 200 000 gph of clarified effluent can be returned to the water treatment plant to be chlorinated and then returned to the mill water system.

Jacobsen (217) described the change to a closed-water system in a coated board mill. The system is based on recycling of process water through a sedimentation save-all. In addition to reduction in the fresh water requirement, energy requirements were reduced, production was increased and fibre filler recovery was increased. Data on chemical costs, water consumption, fibre recovery, energy costs and total costs were presented.

Panak (218) reported that water from the manufacture of wood fibreboard and from the dewatering system was partially recycled. Acceptable levels of suspended solids were maintained by vacuum filtration and the recycle ratio was controlled so that dissolved organic matter was kept below 3%.

Forming wire wash water was clarified and recycled separately. Only 1,7 cubic meters of makeup water per ton of product was used.

Godin (219) noted that water use and total suspended solid losses at a board mill were substantially reduced by installation of a float wash fractionator to allow recycle of board machine white water to cyclinder and felt showers. Hammon (220) described a system for total wastewater reuse in a box board mill. Mill water went to a clarifier, then to sedimentation basins and into surge tank from which it was reduced or sent to the process water treatment plant.

Simon (221) reported the recovery of primary and secondary clarifier underflow for reuse in filler finish in a 60 ton/day board mill with no effect on product quality. A portion of the treated effluent is also recycled to the mill.

Pilot-plant reverse osmosis units were operated on weak wastewaters from a pulp and paperboard mill to obtain further data on RO as an integal part of a closed-water system within the mill (222). Of the many equipment types tested, the one selected was capable of concentrating a steam containing 1% dissolved solids to 99% less volume containing 10% dissolved solids. Product water thus separated was of high quality, suitable for use for stock dilution, pump shaft seal lubrication, etc.

Trent Valley Paperboard Mills on Ontario planned to partially close water circuits for two six-vat cylinder board machines by passing the white water through SWECO concentrators, the filtered water to be reused in felt cleaning showers. Initial trial runs indicated that reusablility of the white water was governed not so much by the quantity of suspended particles as by their size and shape (223). No significant felt plugging or picking was observed with screened white water compared to river water.

Flocculants, such as aluminium sulfate and coagulants, such as polyacrylamide, make it possible to clarify and reuse papermachine white waters and, ultimately, to close the water circuits of paper and board mills, especially those producing coarser grades of paper and paperboards (224).

Guss (225) examined the use of totally closed-water systems in board and tissue mills using secondary fibre as furnish and found that closed systems can be attached with existing equipment and techniques. Problems include corrosion, chemical and water balances and motivating personnel to adopt new methods. Benefits include material, heat and chemical savings; elimination of fresh water and wastewater treatment costs and long range freedom from further pollution control restrictions. Problems and benefits were discussed. Examples of operating closed systems in various board and tissue mill were presented.

Selected, long clean saleable fibre may be recovered by the action of a DSM system for paper mills (226). The operating device is a screen comprising a series of bars with a wedge shaped cross section. A highly detailed study was made at a large tissue mill in Pennsylvania. The full flow of the mill sewer is run through DSM units to thicken the stock after cyclone cleaning. This stock is returned to the bleach system. Cleaner rejects are added to the clarifier sludge for centrifual dewatering and disposal. The DSM system recovers 39% of the sewered fibre at 5% consistency. Additional savings result from reuse of some of the sewered water and from reduced maintenance requirements at the flotation clarifiers.

Hubble and Bowers (227) summarised trends in white water reuse toward closed system operation in 30 European paper mills and found the degree of reuse to be greatest in groundwood and board mills. Very few mills were operating fully closed systems. Effects of white water reuse on corrosion were examined in particular and conditions in the mills were tabulated. Bowers (228) reviewed the literature relative to corrosion of papermaking equipment in closed systems. Corrosion problems encountered as a result of white water recycling were reported. Bowers (229) examined corrosivity of recycled white water in closed systems and showed effects of pH, temperature and chloride content.

The effluent treatment plant at the Bowater - Scott disposal products plant at Northfleet in Kent, United Kingdom, was described (230). Effluent from the mill is segregated into two streams : "clean" stream, containing fibre from the papermaking machine and a "dirty" stream from floor drains and overflows. Each stream is fed into a contact flocculator. Alum and an anionic polymer are used as coagulants in the clean water flocculator. Water from the clean water flocculator is fed to a reusable water tank and the dirty water is discharged to the river.

The Absorbent Products Division of Brown Company, Eau Clarie, Wisconsin, recycle up to 9 million gallons per day of deinking wastewater treated in a primary stage consisting of the addition of 120 to 150 ppm of alum at pH 6,0 to 6,5 and an unidentified anionic polymer (231). Flocculation was improved by the addition of 10 to 15 ppm of activated silica. Treatment removed 94 to 95% suspended solids and 50 to 60% BOD.

Brown Company produces 150 tons per day of absorbent tissue products. About 85% of its mill process water is recycled (232). Sulphuric acid, aluminium sulfate, an unidentified anionic polymer and activated silica are added to the process water prior to treatment in a primary clarifier. Recycling treated water raised the in-mill dissolved solids level by a factor of three.

Springer (233) reported results of a study of process water characteristics and water reuse practices employed in the manufacture of tissue products. A large number of such mills were surveyed. Benefits and deficits of various save-all systems were made. Problems in water conservation efforts included corrosion, plugging, slime, colour, scale and foam.

Johansson (234) described closed white water systems at a Kraft mill and a tissue mill showing up to 84% reductions in water use. Costs savings are related to fibre recovery and reduced effluent loads. Gropp and Montgomery (235) described a tissue mill effluent treatment systems designed for a minimum recycle rate of 80%. The process uses disk filters, polishing basins and percolating beds.

Wisconsin Tissue Mills in Manasha, Wisconsin, installed a new effluent system in 1973 (236, 237). An EIMCO reactor clarifier achieves primary treatment followed by a two-stage activated sludge process patterned after the Zurn-Attisholz process developed in Switzerland. Clarified overflow from the secondary systems is reused in the deinking mill or in the paper mill.

The Kimberely Clark of Canada Ltd. tissue mill in Huntville, Ontario controls pollution by a water reclamation system which recycles about 87% of the process water to a high speed tissue papermachine at rates up to 2,5 mgd while reducing the effluent to about 0,12 mgd (238). The multi-stage water and effluent treatment involves essentially retention in a polishing basin, aeration and filtration through twin one acre percollation beds.

A tissue mill at Huntsville, Ontario, has been designed to meet stringent effluent quality regulations (239). A high proportion of the white water is treated in a large disk type save-all, using magnesium hydroxide as primary flocculant and is then recycled to the tissue paper manufacturing process. A flowchart of the water treatment cycle was given, along with a chemical description of the Kimberly Clark patented lime process for precipitation of magnesium hydroxide.

Hartley (240, 241) reported that products recovery from wastewaters and wstewater reuse was essential in holding down costs at the Building Products Ltd. Edmonton, Canada plant. Wastewater treated in a circular clarifier and a detention lagoon is reused to the maximum extent possible.

White water from the grinder room of a groundwood mill in Mexico was purified in a clarifier basin with addition of flocculants (242). The treated water was found suitable for reuse as process water in the mill without requiring microbicidal or algaecidal additions for slime control.

Thompson (243) reviewed wastewater generation, disposal and recycle in veneer and plywood plants in the British Columbia. He reported that the wastewater can be totally recycled for extended periods of time. Frost (244) obtained a patent for an improved process for manufacture of roofing felts which involves incorporation of separated sludge into the felt and reuse of clarified water in a closed-cycle operation.

Roscoe (245) considered the economics of water reuse at an integrated printing paper mill in order to meet effluent limitations and compared several alternatives. Experiments were reported concerning treatment for effluents from the pulping of straw with lime (246). Improvements in effluent quality to a level permitting reuse in the manufacturing process was achieved by flocculation of wastewater solids with phosphoric acid.

Teer and Russel (247) described a prototype wastewater treatment system and design criteria for wood preserving plants of the Osmose Company of Griffin, Georgia. Treated wastewater is reused in makeup water supplies for mixing the wood treating chemicals.

Recirculated water is increasingly being used to reduce water consumption in the paper industry. Some of its aspects were discussed by Lutz (248). A diagram was given of the Attisholz process for the water treatment system of sulphite pulp mills and a sketch was included of the Ruthner rapid purifier for purifying effluents. Some statistics on costs of different purification processes for effluents of various types of paper mills were presented.

A significant development has been made toward solving the problem of pollution and costs by recovering sodium-base spent sulphite liquors (SSL) and marketing products produced from them (249). The spent liquor is acidified and the organic acids extracted. The residual liquor can be sold as a salt cake substitute. A flow diagram explains the many steps of the process. Basic chemistry and required equipment are also detailed. Significant results of the system are that a major portion of the chemicals required in the pulping process are reusable ; no significant odors are generated from the pulping or recovery processes ; recovery of sodium-base sulphite pulping liquor has been tested on a plant scale ; and the process is economically competitive. This system should be applicable to any independent sodium base neutral sulphite semi-chemical pulp mill and for sodium base sulphite pulp mills practicing full chemical cooking.

The largest consumers of water in Finland and the ones who pollute it most are sulphite pulp mills (250). A successful solution for water protection is represented by the 3-stage pulping method with soluble sodium base, employed by Rauma Repola Osakeyhtio, who mainly produces rayon pulp.

The method enables 95 to 98% recovery of the waste liquor and the regeneration of chemicals.

In-plant measures taken to reduce air and water pollution at a Swedish sulphite pulp mill were described by Brannland et.al. (251). A flow diagram was presented of the Stora chemical recovery process used at the sodium base sulphite pulp mill. The condensate is reused in the cooking liquor and for final pulp wash time in the bleach plant. Changing the bleaching sequence from CEHD allows the extraction effluent to be returned to the recovery furnace via the screen room and unbleached pulp washing plant.

A study of fresh water usage potential at the Ventrni integrated pulp and paper factory in Czechoslovakia showed that it would be advantageous to reduce the newsprint machine effluent, after mechanical treatment, in the sulphite pulp mill (252). The only problem might be contamination of the sulphite pulp mill system, mainly the spent liquor evaporators, with sulphite ions originated in the paper mill. Results from computer simulation of the proposed recycle showed that the sulphite ion concentration would not reach a dangerous level when the newsprint paper mill effluent is used in the separation section of the sulphite pulp mill.

Properties related to combustion, chemical recovery and reuse of recovered chemicals and relief liquors from waste liquors in magnesium-based semi-chemical pulp production were investigated by Chou et.al. (253). Production methods assessed were the vapour phase magnetite, magnetite, slurry, two component and high O-yield sulphite processes. Reuse of recovered chemicals presented no problems, except for the relief liquor of the vapour phase magnetite method. Results indicated that the vapour phase magnetite and liquor phase magnetite methods were more beneficial than the others. Because the former has the additional disadvantages of longer cooking time, the latter may be the best method available.

In many Scandinavian sulphite mills, SSL evaporation condensates are recycled either to the cooking liquor preparation or to the pulp washing stage (254). Two possibilities for internal reuse were proposed : 1) untreated condensates might be reused in the bleach plant; or 2) partial purification by anion exchange would reduce the BOD by 50 to 60% and the

COD by 70 to 75%, so that treated condensates could be used in lieu of fresh water for pulping and pulp washing without adverse effects on pulp quality.

Nelson et.al. (255) described the pulp and papermaking operation at the Green Bay, Wisconsin, neutral sulphite semi-chemical mill. Generation and distribution of solubles in the process and excess waters of the mill were also discussed. The operation consists of mill sewers, recycled water flow, spill surge flow and internal monitoring control system. Wastewater handling with proposed reverse osmosis operation was detailed.

Green Bay Packaging Company operates a tightly closed neutral sulphite semi-chemical corrugating medium mill at Green Bay, Wisconsin (256). An essentially closed white water system and full-scale reverse osmosis unit are integrated in such a way that steady operation is expected to result in less than 5 pounds of BOD per ton of pulp in the mill discharge. Some difficulties with the membrane support structure have been experienced.

The rational and methodology of the in-plant waste control system at the Green Bay Packaging, Inc semi-chemical pulp and paperboard mill in Green Bay, Wisconsin were presented by Morris et.al. (257). The system includes a RO plant to maintain volumetric control of reuse process water. The RO plant design and operating performance were described. The effort to reliably maximize the reuse of excess water and to define the capability of RO as a tool for controlling reuse volume were the goals of this project (258).

Kunzler (259) described pollution abatement measures instituted at a sulphite paper mill to reduce effluent load and application of clarification to the effluent with recycling of some of the clarified effluent. Akim and Bystrova (260) described a process of manufacture of sulphite dissolving pulp in which cooking liquor is prepared from spent liquor of oxygen alkali refining and other liquors are reused resulting in drastically reduced effluent volumes.

A theoretical calculation was made of the effects to be expected in sulphite pulp mills in which spent sulphite liquor is neutralized and recycled to the wood digester along with recovered evaporator condensates obtained at different liquor pH and with varying degrees of condensate reuse (261). Complete closing of the liquor cycle was found to be impossible because the volume of condensates exceeds the water demand of the acid making system. Excess condensates may conceivable be reused as wash water in a sectional spent liquor recovery system with a major portion being introduced into the dilute liquor while a minor portion would accompany the washed pulp and be lost down the screen room sewer.

Process modification made at the ITT Rayonier pulp mill, Fernandia, Florida, to reduce wastewater discharge from the sulphite pulping process were discussed (262). Conversion of the pulp bleaching process from an ammonia-based cooking cycle to a soda-based cycle allowed for direct recovery of many digester wastes as solids rather than liquids, with the result that they can be incinerated for full value. The process change resulted in a decrease of BOD in the plant raw water loadings of about 90%. Overall costs of the modifications were quoted as $38 million in 1972 dollars.

A reverse osmosis pilot unit at the Institute of Paper Chemistry was used to concentrate dilute pulp wash water obtained from a nearby pulp mill where a high yield sodium sulphite semi-chemical pulp had been dewatered in a screw press (263). At elevated temperatures (about 45°C), the problem of membrane fouling was alleviated. Continuous operation of the RO unit in conjunction with the screw press, gave 90% or better recoveries of dissolved liquor solids. Clear water obtained was of sufficiently high quality to be recycled to the process stream of the pulp mill.

Claussen (264) described ultrafiltration and reverse osmosis modules developed by a Danish company for treatment of pulp and paper mill effluent. Purification of SSL by UF and RO treatment of dilute SSL and wash waters were discussed. A RO plant has been operating at a Norwegian sulphite mill since September, 1976. The plant processes 14 cubic meters per hour of dilute SSL. The permeate is reused in the bleaching plant for neutralization after the hypochlorite stage. Suggestions were offered for using membrane filtration equipment as parts of larger integrated systems for treatment of pulp mill effluents. Data were presented showing the mass balance concentration data capacity and cost of UF and RO treatment of SSL using coarse and dense filtration membranes.

A waste treatment process which involves contacting a waste effluent with a metal salt reagent, preferably alum mud, has been patented (265). Effluent is oxidized and a substantial portion of the organic content is precipited. The decolourized effluent is bio-oxidized in a multi-stage sequence and subsequently is sufficiently pure for recycle purposes. The purified effluent may also be bleached prior to recycle.

Laboratory evaluations of twenty resins and seven carbons showed that resins were equal to carbon for decolourizing the combined waste from a 4-stage Kraft bleach plant (266). With few exceptions, resins were unsuited for decolourizing wastes from each stage seperately. Single stage ion exchange produced water adequate for unbleached pulping. Any of the continuous counter-current ion exchange processes are probaly adequate for producing water for bleached pulping.

Davis et.al. (267) reported that sand and gravel pressure filtration improved the quality of primary clarifier effluent to the extent that the filtrate could be used as process water in the manufacture of printing and other fine paper. The filtered water is further improved by adding an amylase enzyme to destroy the dispersant power of cationic starch present in the white water and be treated with chlorine to prevent slime deposits.

Reeve (268) presented a review of the literature on sodium chloride (NaCl) in alkaline pulping and chemical recovery. The history of NaCl control and accumulation in recovery system and methods available for NaCl control and removal were reviewed.

Mulford and Cooke (269) reported and evaluated 16 methods of reusing vacuum pump seal water. These were grouped into three categories in order of preference : a) fresh water supply with reuse after the vacuum pumps ; b) reuse of previously used water ; and c) recirculation of seal water.

Dickbauer (270) examined effluent problems in the corrugated board industry and pointed out the advantages of wastewater recycling. In the case of cooling water, a substantial reduction in fresh water consumption results. With starch containing effluent, the most important aspect of consumption can be reduced by 80 to 90% by conversion to an oil lubricating system operating via compressed air. Finally, recycling can eliminate the need for building and operating a biological clarifier.

Widmer and Widmer (271) described a completely closed circulation system for paper and board machines. The system is based on treatment of white water in flotation save-alls with addition of a non-toxic slime control additive. Experience with the system in two fourdrinier and two combined fourdrinier/cylinder machine for production of corrugating media, coated and uncoated paperboards and packaging paper showed it to permit machine operation with a minimum of fresh water intake and practically no effluent discharge. In addition, there were no adverse effects on product quality and production rate.

A chemical treatment system for corrugated box factory wastewater has been developed in Japan (272). Effluent containing corrugated starch paste and flexographic printing ink waste are combined and then flocculated and precipitated with ferric chloride, calcium or sodium hydroxide and/or organic coagulant aids. Clarified wastewater is recycled and reused for preparation of more starch paste and a wash-up water for the flexographic printing presses. Some cost data were given, along with an outline description of the process.

Brief descriptions were given of the clearator, expunger, flexo-o-kleer and colour tamer system for clarifying flexographic press wastewater from corrugated box plants (273). Chemicals are added to the effluent to flocculate and precipitate residual ink and other substances so that they can be separated from the water by filtration and/or sedimentation. Reuse of press wash water in preparation of corrugating adhesive was also discussed.

A German paper mill which manufactures corrugating medium, packaging paper and similar coarse and low grade paper utilizes two fourdrinier machines with completely closed-water circuits with essentially no effluent during normal operation (274). The manufacturing scheme was described, including diagrams of the pulp stocks and water circulation system. Although closure of the water system has increased concentrations of solids in the white water with attendant corrosion and water and slime deposit problems, these difficulties are amenable to technological solutions. No adverse effect on either the quality or quantity of paper products has been noted.

Unqualified success with reuse schemes is not always achieved. Morris (275) reported that when inhouse recycle was started at a pulp paperboard mill, it had an adverse effect on some aspects of plant operation. Recycle raised the processing water temperature which produced higher humidity, thus reducing some material service life.

Milner (276) identified factors that have limited the extent to which water reuse has been practiced in bleaching operations. The evaluation was based on a literature survey and information gained through a series of visits with both successes and problems associated with further reuse. Activities where water reuse practices create operating problems, such as temperature increase and corrosion, were identified and steps taken to reduce them were noted. Where material of construction permit, extensive or alternative bleaching water recycle practices were also identified.

Although the pulp and paper industry has made considerable progress in reducing its water consumption, much more can be achieved by using modernized methods and equipment (277). Reuse of water for washing, general cleaning, felt conditioning, wire showers and lubrication of shaft packing boxes was discussed. Careful attention to detail of mill design, including proper selection of auxiliary equipment, provisions for greater reuse of water and machine operation, can contribute to further reductions in specific water consumption to manufacture a ton of paper.

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