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ADVANCED CERAMICS IN THE CANADIAN PULP AND PAPER INDUSTRY

A Survey of Present and Future Applications

Final Report

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by

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and

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THIS REPORT IS DEDICATED TO THE MEMORY OF ROMAN KUMAR

"Yours was the world and all that was in it.........."

Kipling

d. 24 June 1990 aged 24 years.

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by

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EXECUTIVE SUMMARY

The Pulp and Paper Research Institute of Canada (PAPRICAN) and the Canadian University-Industry Council on Advanced Ceramics (CUICAC) were contracted by Industry, Science and Technology Canada and Investment Canada to undertake a survey on the applications of advanced ceramic materials in the Canadian pulp and paper industry. The survey consisted of site visits to mills of various kinds, to pulp and paper machinery manufacturers in Canada, and to suppliers of ceramic materials and components. The team visiting the plants consisted of scientists from both PAPRICAN and CUICAC as well as a management team from CUICAC and Investment Canada.

The survey found that advanced ceramics are already well-established in the pulp and paper industry for specific applications. Generally, however, mill engineering staff were not familiar with either the ceramics being used in their mill or the properties available from advanced ceramic materials. The industry is thus almost totally reliant on suppliers for expertise in the use of advanced ceramics. The survey also found significant areas of opportunity in the industry for either the new application of existing ceramics technology, or for innovative research and development. Generally, there appear to be more applications for ceramic coatings than for monolithic ceramics. The most fruitful area at present for development of new applications is the paper machine.

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INTRODUCTION

This report presents the results of a survey of applications for advanced ceramics in the Canadian pulp and paper industry. The survey was conducted by the Pulp and Paper Research Institute of Canada (Paprican), in association with the Canadian University-Industry Council on Advanced Ceramics (CUICAC).

Specialist expertise in ceramics science and engineering was provided for the survey by the Alberta Research Council, who are members of CUICAC. Major funding for the survey came from Industry Science and Technology Canada, through its TOP-AIM programme. Additional funding for the work was provided by Investment Canada.

The survey consisted of site visits to six pulp and paper mills across Canada and three original equipment manufacturers. The six mills were selected to be typical of the Canadian pulp and paper industry. For this reason, emphasis was placed on mills producing kraft pulp or newsprint; these commodities together represent about 80% of the industry annual export production. Other grades produced at the survey mills included tissue, fine and coated papers, sulphite pulp and paperboard. The geographical location of the mills visited is as follows:

Mill A	Kraft pulp, newsprint	West Coast
Mill B	Tissue	" "
Mill C	Sulphite pulp, newsprint	East Coast
Mill D	Kraft pulp	" "
Mill E	Paperboard	Central
Mill F	Newsprint, coated and fine papers	"

A seventh mill, producing newsprint from recycled paper, was originally scheduled to be included in the survey. Unfortunately, this was not possible due to a labour dispute at the mill. This mill was therefore replaced in the survey by mill F in the above list.

The original equipment manufacturers (OEM's) visited during the survey were:

OEM A	Medium and high-consistency pulping equipment
OEM B	Paper and board machines
OEM C	Paper machine fabrics, felts and drainage elements

In addition, telephone interviews were conducted with several other companies, to gain as wide an experience as possible.

These manufacturers were selected on the basis of their being a) established equipment suppliers to the Canadian industry and b) either current or potential users of advanced ceramic materials.

The survey team consisted of four individuals:

Dr. Parvez Kumar	CUICAC
Dr. Debabrata Ghosh	ARC
Mr. Richard Lovatt	Investment Canada
Dr. Christian Thompson	Paprican

This report has been co-authored by Drs. Kumar, Ghosh and Thompson.

The report is in two main parts.

Part I gives a general description of each site visit and lists, without prioritizing, the possible advanced ceramics applications that came out of each visit.

Part II contains a technical appraisal of these various potential ceramics applications. In this section, the possible applications given in Part I are discussed in terms of both their technical and economic feasibility.

Part II also contains the conclusions and recommendations of the report. Applications are classified as requiring either short, medium or long-term research and/or development to bring them to fruition.

Three appendices are included in the report.

Appendix One gives reference sources listing the various machine suppliers, repairers and installers dealing with the Canadian pulp and paper industry.

Appendix Two gives a guide to the various pulp and papermaking processes represented in the report. This appendix is designed to help the non-specialist better understand the nature and operation of the industry and its equipment.

Appendix Three lists the names and addresses of Canadian pulp and paper companies, and provides an overview of the industry's significance to the national economy.

PART ONE
SITE VISITS - GENERAL OBSERVATIONS

VISITS TO THE WEST COAST MILLS (MILLS A AND B)

Introduction

Mills A and B were visited in October 1990. Mill A is a large, integrated pulp and paper mill, producing semi-bleached kraft pulp, newsprint and groundwood specialties. Mill B is a tissue mill producing tissue and related grades.

Mill A: Kraft pulp, newsprint, groundwood specialties

Figure 1-1 shows the general layout of mill A.

The following areas of the mill were visited:

- stone groundwood.
- CTMP refiners.
- paper machines.
- kraft mill.
- woodroom (wood preparation).

Stone Groundwood: The conveyors carrying the cut logs to the groundwood room had significant wear on their teeth. The teeth used to propel the logs into the grinder magazines also showed signs of wear. **Figure 1-2** shows a typical cross-section through a pulpstone.

The grindstones were typical of those used in stone groundwood operations across the country. The stones are composed of abrasive segments bolted onto a reinforced core, as shown in Figure 1-2. The complete stone is about 1.5 m diameter. The segments in use at this mill were said to be vitreously-bonded silicon carbide particles. Vitreously-bonded alumina segments are also available; other materials may also have been tried in the past, as this technology is well-established. Norton Inc. and Carborundum Inc. are the major suppliers of pulpwood grindstones in this country. To maintain pulp quality, the segments are sharpened or dressed at regular intervals using patterned steel burrs.

CTMP Refiners: The disc refiners at this mill were typical of high-consistency refiner operations in many mills. As this mill is a coastal operation, however, chloride-related corrosion problems may be of more concern than would be the case in inland refiner mills. This mill was making refiner pulp using the chemi-thermomechanical pulping (CTMP) process. The refiner plates being used were in cast white iron; cast stainless steel versions are also available from manufacturers. A typical refiner plate is shown in Figure 1-3. Pulping and fibre development occur between opposing (gap < 1 mm) sets of refiner plates. The plates operate at peak temperatures of about 160°C; large amounts of steam are produced between the plates during operation. The plates at this mill were changed every 1200-1900 hours, depending on which refining stage they were in.

Paper machines

Mill A had six paper machines. Ceramic drainage elements (i.e. foils, suction box covers) were being used on the machines. The principal supplier of these items was stated to be Wilbanks Inc., Hillsboro, Oregon, USA. Mill staff were uncertain as to the exact type(s) of ceramic being used. As far as could be determined by visual examination with the machines on the run, alumina was the predominant ceramic.

As with all mills, centrifugal cleaners were used for separating grit and other solid contaminants from the pulp. Figure 1-4 shows a typical unit. For economic reasons, Mill A had decided to use plastic, rather than ceramic, replaceable tips in their cleaners.

The Kraft Mill

Kraft mills use a lot of chemicals in order to extract the wood fibres from the chips. They also have to recycle much of the chemicals used and, at the same time, recover as much energy as possible through the recovery boilers. As such, environmental and pollution concerns are high.

The cooking, bleaching, recovery and recausticization areas of the mill were visited. Glazed ceramic tiles were being used to line bleach towers and stock chests. No obvious applications for advanced ceramics were seen in the cooking and bleaching sectors. The main materials problems in these areas were corrosion-related, and were being controlled by the use of highly-alloyed metallic materials, and fibre-reinforced plastics. Refractory wear in the recaust lime kiln was an on-going maintenance item, as it is for all kraft mills to ensure the operation of the kiln. From discussion with the mill staff, it appears that existing refractories give satisfactory performance. Lime mud pumps in the recausticization plant are subject to erosive wear.

Typical of the situation in many kraft mills, corrosion was an on-going problem in the recovery boiler-precipitator-stack system. Because of the crucial importance of the recovery boiler to the operation of the kraft mill, boiler maintenance has high priority. Any use of new materials that could compromise the operation of the boiler in the event of component failure would not be accepted. Corrosion problems inside the boiler were said to be in the generating banks and on the waterwall tubes of the lower furnace. Thinning of the water-cooled smelt spouts was also a concern. For both the waterwall tubes and the spouts, perforation can cause water-smelt mixing, with the risk of explosion. Corrosion in the precipitator was an additional problem at this mill.

Woodroom:

The jack-ladder, which picked up logs from the mill pond and transported them to the debarking area, showed signs of wear on its teeth and chains. Apparently the teeth and chains have to be replaced every 2 years. The main problem, apart from the wear and tear of moving heavy logs, is the combination of salt-water corrosion and metal-on-metal wear that occurs between links. Circular saws, to cut the logs to size, also suffered wear. Stellite tips were welded onto these saw teeth to get better life out of them. It took some 8 hours to tip a circular saw blade. Untipped steel blades wore out in 4 hours.

The debarking procedure at this plant was to use a 9.6 MPa water jet whilst rotating the logs on toothed rollers. Note that this is an unusual debarking technique; most mills in Canada use drum debarkers. Belt saws were used to cut the logs into lumber and panels manageable by the chipper. These laser aligned saws had a life of around 4 hours but changeout took only five minutes. The belt saws were made by Simons.

The chipper was operating, so it could not be examined closely. The chipper knives were reground daily. Use of ceramic knives would be a possible application.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

A list of all the potential applications of ceramics in the areas visited by the team follows. This is not in any order of priority:

- spike roller teeth in the log-moving operation
- stone groundwood magazine charging roller teeth
- liners for the 1 m diameter CTMP cyclones
- finger bars in the grindstone chamber
- improved grindstones
- paper machine sensor applications
- replacement of granite press rolls
- process feedback time constants and the possibility of reducing these through the use of ceramic transducers
- mud pump impellers
- uncooled smelt spouts
- protective ceramic coatings for the lower furnace tubes in the recovery boiler
- ceramic-coated chipper blades

Mill B: tissue and related grades

At the briefing session prior to the plant visit the team met with the ventures manager, the chief engineer, the electrical engineer and a research projects engineer. The basic process through the plant was discussed. Stone-ground wood pulp with some kraft reinforcing was the principal furnish. Products included tissues and towelling.

Paper Machines

The machines used for these processes were old, the original having been installed in 1922 (subsequently rebuilt). Number 2 and 3 machines were supplied by Beloit in 1947 and 1952 respectively. The fourth machine came from KMW. The company was already using ceramics in certain areas of operations. A ceramic pick-up bar 2.5 cm diameter and 370 cm long made of zirconium oxide by a German company, (IBS being the US agents) for transferring the paper from the forming section to the dryer had been installed in 1989 and still showed no signs of wear. The 10 cm diameter centri-cleaners already had ceramic inserts. Ceramic foils (5 cm wide and 325 cm long) had been installed on the wet box covers some 5 years ago. They still showed no signs of wear. Prior to this the mill had tried plastic (i.e. high-density polyethylene) foils with limited success. The main operating problem with ceramics was changing the foils on the run, due to the possibility of cracking some of the ceramic elements.

Yankee Dryers

Three of the tissue machines were equipped with Yankee dryers. These are large, steam heated, cast iron dryer cylinders. The steam pressure in Yankee dryers is typically about 1 MPa. Other working stresses in a Yankee shell arise from both thermal cycling and rotational forces. Heat transfer is a critical factor to allow efficient high-speed tissue drying. At the same time, the need for heavy doctoring to remove the tissue from the dryer causes wear of the Yankee's working surface. To maintain the pressure rating of the Yankee dryer, it is now common practice to rebuild the drying surface with a thermal sprayed molybdenum-nickel alloy. This coating technique is done by Bender Machine Inc., and CWS Inc. The Yankees at Mill B had been rebuilt by this method in the past. One Yankee is scheduled to be rebuilt during 1991.

The doctor blades used to crepe tissue off Yankee dryers are heavily loaded and wear out rapidly (Figure 1-5). At this mill the blades were 10 cm wide and 3.75 m long and wore out regularly, typically anywhere between 10 minutes and 24 hours depending upon operating conditions, in this case 1700 m/min, with a bearing pressure of 70 kN/m. The application of ceramic coatings was being looked at. Lodding & Scott in the US were said to be doing R&D in this area.

Tissue testing

It was also noted that any advances in non-destructive evaluation and testing of the tissue on the run would help considerably in cutting back the delay time (currently 20 minutes) for feedback. The company has installed a computerised system for real time property measurements, namely; basis weight, bulk, brightness, and moisture. Some Foxboro ceramic sensors were being used. There was an O_2 sensor in the exhaust of the boilers. Microwave sensors were used to detect the presence of polymers as well as the grit and dust from the operations.

Converting operations

In the converting operations i.e. making the tissue and paper into consumer products with wrappings, there seemed to be little need for ceramic materials, with tool steel blades and saws giving acceptable performance. The printing presses were using ceramic anilox rollers.

The Woodroom

This was a small woodroom compared to that observed at Mill A. Billets were handled manually for loading into the grinder magazine. The grinders themselves had been installed in 1947 and 1952 and had silicon carbide segments on the grindstones. Each grinder processed some 110 tons/day of pulp. This pulp was then formed into 0.5 cms thick sheets on a pulp machine and transported to the tissue-producing area. The company bought its kraft pulp from outside sources.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

Possible areas of ceramic applications not already implemented by the company included the following:

- ceramic coatings on the doctor blade. Note that the possibility of using a super-plastic bulk ceramic here should also be looked at.
- application of a ceramic anti-wear coating to the Yankee dryers.
- use of ceramic transducers to measure tissue parameters on the run.
- ceramic blades for the chipper.

VISITS TO THE EAST COAST MILLS (MILLS C AND D)

Introduction

Mills C and D were visited in November 1990. Mill C produces sulphite pulp and newsprint. Mill D produces fully-bleached kraft pulp. Although the processes and procedures were often much the same as for the mills on the west coast there were, nevertheless, certain new areas of applications for advanced ceramic materials which had hitherto not been identified. For completeness, all the areas of concern raised at the mills have been recorded below.

__Mill C: Sulphite pulp and newsprint__

A flow diagram of mill C is given in Figure 1-6. Prior to visiting the plant, discussions were held with mill engineers regarding various applications where wear and corrosion were a problem, or where ceramics were already being used. Areas discussed and later observed during the mill tour included:

- all the woodyard conveyors had heavy wear.
- chipper knives were removed and reground every 48 hours. The chippers themselves were approximately 6' in diameter with 12 segments, having four knives/segment made out of tool steel. The possibility of using tungsten carbide cermets was discussed. Occasional passage of rock through the chipper is a problem.
- hog hammers - used to break-down bark into smaller pieces for use as hog fuel in the boilers. The hammers wore out frequently. The hammers were rebuilt by welding-on new steel heads.
- shredder knives also needed frequent changeout
- the debarking drums (manufactured by Rauma - Repola and some 50' long and 18' in diameter) had significant wear and corrosion occurring on their inner surfaces. The heavy impact forces present in these drums, however, precluded any use of ceramics.
- in general terms, the engineers present stated that anything giving them a higher throughput in either wood preparation or groundwood pulping would be very welcome.
- the hot (100°C) sodium chlorate holding tanks were a perennial corrosion problem; FRP was inadequate.
- the chips were currently being conveyed through a pneumatic chip delivery system with a large consumption of energy. Moreover, the chips caused wear at elbows in the system. This system is scheduled to be replaced by conveyors.
- siphon nozzles in the paper-machine dryers were made of stainless steel, and were subject to fatigue cracking. The possibility of ceramic coatings on the syphons was discussed. A paper machine typically has 30 dryers.
- chip cyclones (3.5 m dia x 5.5 m long x 0.5 m dia) were fully lined with ceramic tiles.
- the hog-fuel boiler screw conveyors had a protective coating of ceramic beads embedded in epoxy on the hot-end flights.
- centrifugal cleaner tips were already ceramic, but blockages at these tips caused wear further up the cone. The cones were 200 mm dia x 1 m long x 50 mm dia. with a 250 mm long tip. This is an area of short-term application for slip-cast ceramic cones.
- newsprint drainage elements (suction box covers, and some foils) had been changed from polymeric to ceramic in the last 2 or 3 years. Performance to-date was said to be

satisfactory. It was not known exactly which type of ceramic was being used. Visual inspection suggested it was alumina.

- corrosion of digester valve internals was a handicap to precise pulping control.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

The list below covers the main potential applications for ceramic materials noted at the mill:

- chipper knives
- hog hammers
- any means of increasing groundwood production (note that this could possibly be a longer-term application when higher performance ceramics can be introduced into the grindstones)
- dryer siphon nozzles
- centrifugal cleaner tips
- digester control valve internals
- chip cyclones. Large or single-piece castings to replace tiles.

<u>Mill D: Kraft pulp</u>

A flow-chart of the main mill processes is given in Figure 1-7(a) and (b). The complete mill system is shown in Figure 1-7(c).

<u>The visit</u>

In addition to some wear and corrosion problems seen in the previous mills, i.e. chipper blades,centrifugal cleaners, drainage elements, etc. the engineers stated that one area of heavy abrasion in the plant was the grate blocks at the bottom of the hog fuel boilers. In this particular design of boiler, the ash was raked out manually and parts of the grate floor, made of steel or cast iron blocks, wore out every 6-8 weeks due to the abrasive action of steam-blown fly ash (the steam jets are used to blow the ash towards the manual cleaning ports). Replacement of the grate blocks took 24 hours. Examples of worn cast iron blocks were seen. Use of ceramics in this region would be an improvement over the present high chromium white cast iron blocks.

A discussion was held on the possible use of advanced ceramics for environmental control applications. Possibilities include filtration units or molecular sieves. No immediate opportunities were evident. A major problem is in the volume of effluent that would have to be treated.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

By far the most immediate, and realistic, application of ceramic materials was in the replacement of the cast iron grate blocks in the power boiler. Use of individual ceramic blocks, or large slip-cast ceramic segments would be a short-term application.

VISITS TO THE CENTRAL MILLS (MILLS E AND F)

Introduction

Mills E and F were visited in December 1990. Mill E produces paperboard from recycled fibre. Mill F produces newsprint, coated and fine papers.

Mill E: Paperboard

This mill uses 100% recycled furnish, comprising beer cases, computer paper and other printed paper (but not newspaper). Separating the broken glass, staples, metal bands etc. was a major first step. The re-pulper uses an impeller, rotating at the base of a tank (**Figure 1-8**). Abrasive wear occurs on and around the impeller and its associated screen plates.

The pulp was then cleaned and screened. Cleaning used three stages of centrifugal cleaners, high, medium and low density. The high-density cleaners were of three-piece ceramic construction, the top-most section being about 30 cm diameter. The mill had three of these cleaners; they were said to be about $20,000 each. The eight medium density cleaners also had ceramic cones. The numerous (i.e. >50) low-density cleaners were plastic.

Paper properties such as profile, humidity and caliper, were measured on the run, whilst mechanical properties including ply-bond, porosity, waterproofness etc. were done off-line in a laboratory. The mill had tried using infra-red for drying the paper board, but had abandoned this method due to "wet edge" formation.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

All stock pumps experienced severe wear on their casings and impellers. The bottom of the pulper tank also experienced heavy wear, and was a candidate for lining with ceramic plates.

Mill F: Newsprint, coated and fine papers

This is one of the biggest mills in Canada with 10 paper machines of various kinds in operation. It produces between 1150-1200 tonnes of paper per day, of which some 400 tonnes are coated papers. The main reason for visiting this mill was to inspect the coated paper machines and the supercalenders, neither of which had been represented at the other survey mills. The mill produces TMP and stone-groundwood pulps. Kraft pulp is purchased from outside sources. The highest speed machine is currently 945 m/min.

Paper machines

Engineers at the mill stated that they had implemented the use of ceramics wherever possible. In particular, they were using zirconia foils on one of their machines at the dry end of the Fourdrinier section. Alumina foils were used at the wet end. The suction box covers were supplied by JWI Ltd. and used 2.5 cm wide ceramic inserts. It is to be noted that the original alumina foils used on the machines came from Italy (Carborini) and cost in the region of $7,000 each. The zirconia foils, from the US, and having roughly the same shape and dimensions, cost about US$4,000. Ceramics were also used in the Uhle box covers.

OTHER APPLICATION AREAS

Other areas included:

- the induced-draft fan casing in the power boiler
- elbows of the pneumatic chip handling system. The mill has recently installed ceramic liners in these areas; typical dimensions are 0.3 m x 0.3 m x 12 mm for the sides and 0.3 m x 0.3 m x 25 mm for the elbow.
- the infra-red radiant heaters for drying the coated paper used ceramic mantles which were heated by natural gas burners. These were supplied by Krieger (Germany) and Solaronics (France?)

Super Calenders

No opportunities for ceramics were evident on these machines.

VISITS TO CORPORATE ENGINEERING OFFICES

Two corporate engineering offices were visited for the survey, one on the west coast (kraft, newsprint, groundwood specialties) and one in central Canada (newsprint, groundwood specialties).

A paper machine engineering specialist and a corrosion/materials engineer were interviewed. From the perspective of the paper machine engineer, any new machine running faster than 1000 m/min would be fitted with ceramic stationary drainage elements. The higher cost of ceramic elements relative to polymerics was not necessarily an important factor, particularly for the purchase of a new machine. Lifetime and machine performance considerations were more important than cost alone. Mechanical damage of ceramic drainage elements (e.g. operator abuse, hard objects passing through the machine) was a significant concern, so that repair-ability of damaged elements is important. Any operating problems with ceramics would be dealt with through the paper machine builder, rarely with the ceramics supplier directly.

From the perspective of the corrosion/materials engineer, there had been no significant involvement in materials selection or component failure analysis for ceramics in over fifteen years of the group's existence. This was in complete contrast to the situation for metallic materials. A request to the corrosion coordinators at each of the company's mills for operational experience with ceramics, circulated prior to the meeting, had brought no response. Advanced ceramics thus have little visibility in the industry in respect of corrosion control.

VISITS TO ORIGINAL EQUIPMENT MANUFACTURERS

Manufacturer A (Medium and High Consistency Pulping Equipment)

This manufacturer designs and builds process machinery and high-yield pulping systems for the pulp and paper industry. The team met with a number of the company's design and operations engineers. Areas of high wear and/or ceramic usage were identified as the following:

- centrifugal cleaners
- rotary valves used for feeding chips into pressure vessels.
- refiner plate gap sensor. The ceramic material was used as a shield for the gap sensor mounted behind it. The possibility of using a ceramic sensor itself was discussed. Tolerance required was 1.25 mm +/- 125 μm. The refiner plates themselves lasted 1,000 hours and, in some cases, could be reground once before being discarded.
- the possibilities of using hard ceramic coatings on refiner plates were also discussed with the engineers present. However, the coatings were thought to be unsuitable for refiner plates, which can contact each other with high impact during operation.
- use of ceramic membranes as filters was discussed briefly.
- plug screw feeders. Made from cast stainless steel, hardfaced on the flights to maintain profile and feedability.
- because of the complex geometry of much pulp and paper equipment, it was suggested that there are probably more applications for ceramic coatings in the industry than there are for monolithic ceramics.

AREAS OF POTENTIAL CERAMIC APPLICATIONS AND/OR R&D

- use of a ceramic plate-gap detector for the refiners.
- coating the leading edges of the chip feed screws with ceramic material.
- use of ceramics (monolithic or coatings) to extend the life of chip refiner plates. Plate clashing (i.e. hitting together during operations) is a significant barrier to full exploitation of ceramics in this area.

Manufacturer B (Paper Machines)

On 13 December 1990, the opportunity was taken to visit a major manufacturer of paper machines, located in Montreal. A significant number of these machines are used in Canadian mills, and the company has an extensive R&D effort in Europe.

The company gave a short overview of the types of paper machines they manufacture, and the areas in which they use ceramics. A full range of paper machines is available, including paperboard, multi-ply, coated and newsprint machines. In all cases, use of ceramics is confined to the wet-end and press sections (i.e. drainage elements, Uhle box covers). Ceramic components are bought-in from either German or American sources. Board and multi-ply machines are the largest users of ceramic foils; on a board machine, for example, ceramics may account for about 20% of the total machine cost.

Current Issues and Problems

A number of actual or potential concerns relating to ceramics usage were discussed. They included:

- lack of cooling or lubricating water on ceramic drainage elements was a perennial problem, with the risk of overheating and cracking. Thermal shock problems could also occur. Machine start-up conditions could be tough. Zirconia was seen as one solution.
- machine speeds will increase in the future, particularly in the case of newsprint. Recycled furnish will become widespread, and associated use of coatings and fillers will most probably increase significantly. Together, these trends will cause harsher working environments for ceramic elements on paper machines.
- replacement of granite press rolls by other materials continues to be of interest and concern. Similar views were expressed at some of the mills visited during the survey. The possibility of cooperative research involving the paper machine company and Canadian partners was discussed

<u>**Manufacturer C**</u> (Felts and Fabrics)

A major Canadian manufacturer of paper machine clothing and drainage elements was visited during October 1990. The company is a large user of ceramics, importing to the level of $4-5 million annually from Japan (Kyocera). The company has an active in-house research capability; their research and development in ceramics is directed mainly at quality assurance and evaluation of alternative materials.

Prime requirements for stationary drainage elements are "gentleness" to the fabrics or felts moving over them, and high wear resistance. These needs led naturally to an interest in the use of hard materials. Early use of both solid and coated tungsten carbide was abandoned because of corrosion problems. Alumina has been successful; it can be mounted in either polymeric or stainless steel supports,depending on its function and position in the machine. Foils are typically constructed by inserting 5 cm long segments into high-density polyethylene strips (8-10 m long, 7-8 cm wide) extending the full width of the paper machine. There must be less than 25 μm variation in height from segment to segment. The segments are usually finish-ground by the Japanese manufacturer. Once installed on the paper machine, a typical lifetime for a ceramic foil was said to be in excess of 10 years.

Other ceramic materials including zirconia and silicon nitride are either being introduced onto the market by the company, or are under consideration. The main reasons for looking at alternative ceramics for foils and suction box covers are improved fabric life and higher mechanical strength (i.e. better ease of handling). Improved thermal shock resistance was a factor. Future concerns as far as ceramics are concerned were said to include the change to alkaline papermaking, and recycling, both of which may increase the usage of calcium carbonate fillers; the concern is how a particular ceramic-filler combination will affect fabric life.

<u>**Additional Manufacturers' Comments**</u>
(Manufacturers D and E)

To get as wide a range of experience as possible, two other paper machine manufacturers were interviewed by telephone. As with manufacturer B, neither of these two companies manufactured ceramic drainage elements themselves, buying-in instead from offshore companies. Manufacturer D stated that their customer chooses whether to use ceramic or polymeric drainage elements. By contrast, manufacturer E makes the decision themselves, and preferred UHMWPE elements during start-up of new fourdrinier machines. Both companies would use ceramics for twin-wire applications. The relatively high cost of ceramic drainage elements was not seen to be a major problem, though both thought there may be market interest in alternative, cheaper, ceramic coated or plastic elements.

Both manufacturers had experienced operating problems with ceramic drainage elements. Manufacturer D reported instances of rough surfaces on the elements removing hairs from the press felts. Some customers were reluctant to use ceramic Uhle box covers for this reason. Ceramic forming boards on twin-wire tissue machines could get red-hot when stock was shut-off during operation and crack when the stock came back-on again. In agreement with the machine clothing/drainage element OEM reported earlier, manufacturer D felt that the most important item was the surface smoothness of the drainage elements, being critical to the operating life of fabrics and felts.

Manufacturer E also found the surface smoothness of drainage elements to be an important concern. Increased wear and roughening of ceramic elements may well increase as more use is being made of fillers.

Concerns

A major concern in the implementation of any of the recommendations or proposed projects is the question of product liability. Some of the engineers encountered during the mill visits were reluctant to try out any test-bed experimentation which might compromise the product liability currently carried by the manufacturer of the machinery in question. According to them it would be better if the manufacturer of the machinery did the experimentation prior to implementing it in service. Other engineers met with did not appear to have this concern, and were prepared to do some minimal experimentation on their installed machinery provided that it did not interfere with their production operations nor have any major effects should there be a failure. It looks, therefore, that each recommendation will have to be reviewed on a case by case basis.

Another concern is that, if the testing has to be done at a manufacturer's pilot plant or facility, then there will tend to be a technology transfer out of Canada, since many manufacturers of pulp and paper machinery used in Canada are from either the US or Europe. Formal joint collaborative projects will have to be proposed between the various parties and these, unfortunately, could take a long while in their implementation. However, it is possible that Investment Canada could promote foreign manufacturers to set up test-bed facilities in Canada which, in cooperation with PAPRICAN, could add significantly to the pulp and paper R&D infrastructure existing in Canada.

The question of funding for such applied research and/or applications needs to be addressed. While it is recognised that members of PAPRICAN already fund research to some $26 million per annum, most of these funds are allocated well into the future. Thus sources of new funds will have to be identified. Individual paper companies would not, in general, have sufficient research funds available to do the necessary development work by themselves. However, some manufacturers and pulp and paper companies do have in-house research capabilities and may be prepared to enter into some shared-cost agreements for appropriate research and development in ceramics. It is this latter approach which is proposed, on the understanding that Canadian sources of funding will match any funding put up by the overseas manufacturers and/or their governments. It is understood that the Canadian funds will be used in Canada.

Recycling

Legislative and consumer pressures in the US and elsewhere are having a profound effect on the Canadian newsprint industry. Many publishers now require at least 40% of recycled fibre in their newsprint. Major technical challenges facing Canadian paper companies include the effect of recycling on product quality and deinking.

Use of ceramic materials in the recycling and deinking processes needs to be investigated. It was not possible to visit the only Canadian newsprint mill having such equipment, due to a labour dispute. This mill should be visited in a later phase of this project.

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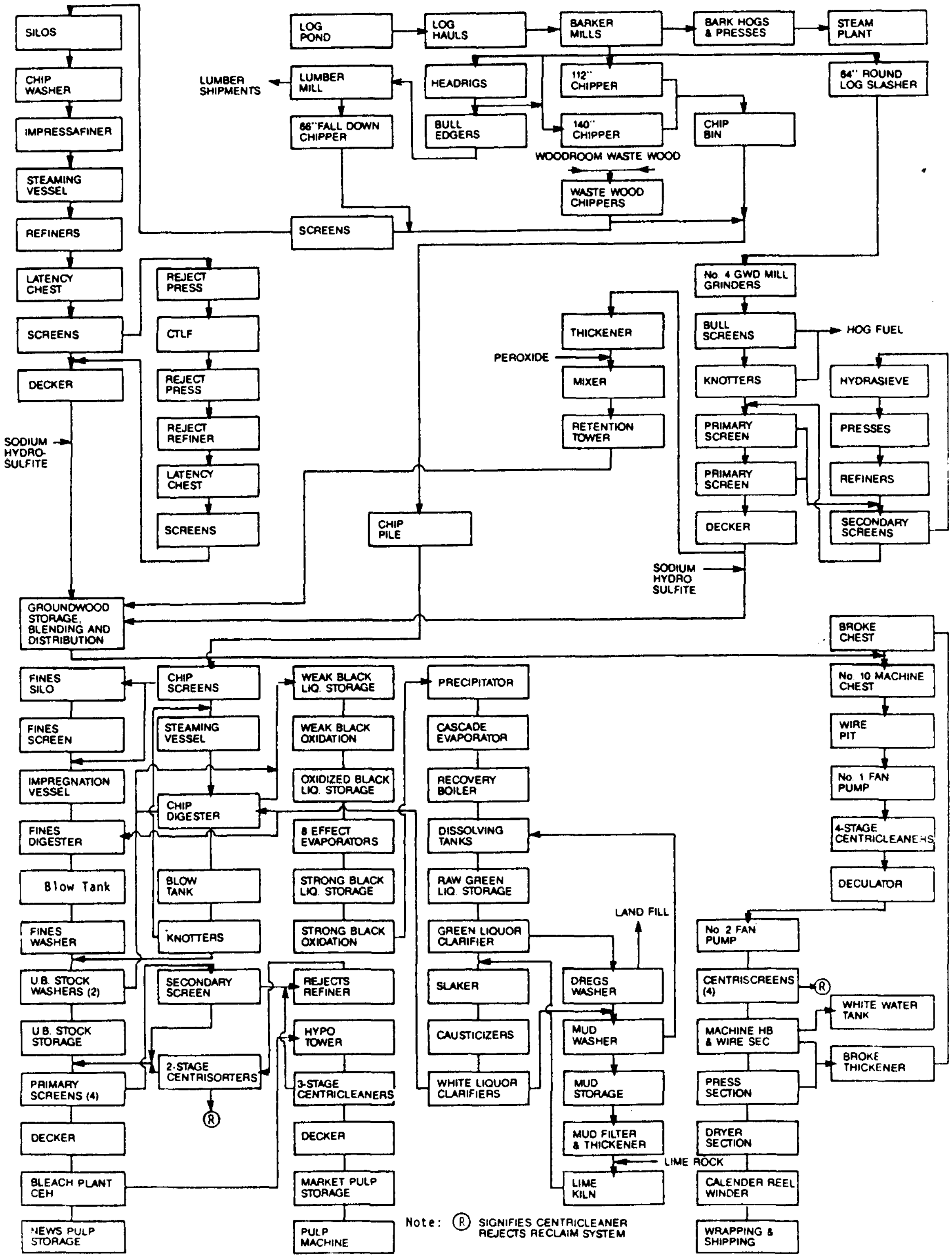

Figure 1-1 The general layout of mill A.
(Reproduced by permission of Pulp and Paper Canada)

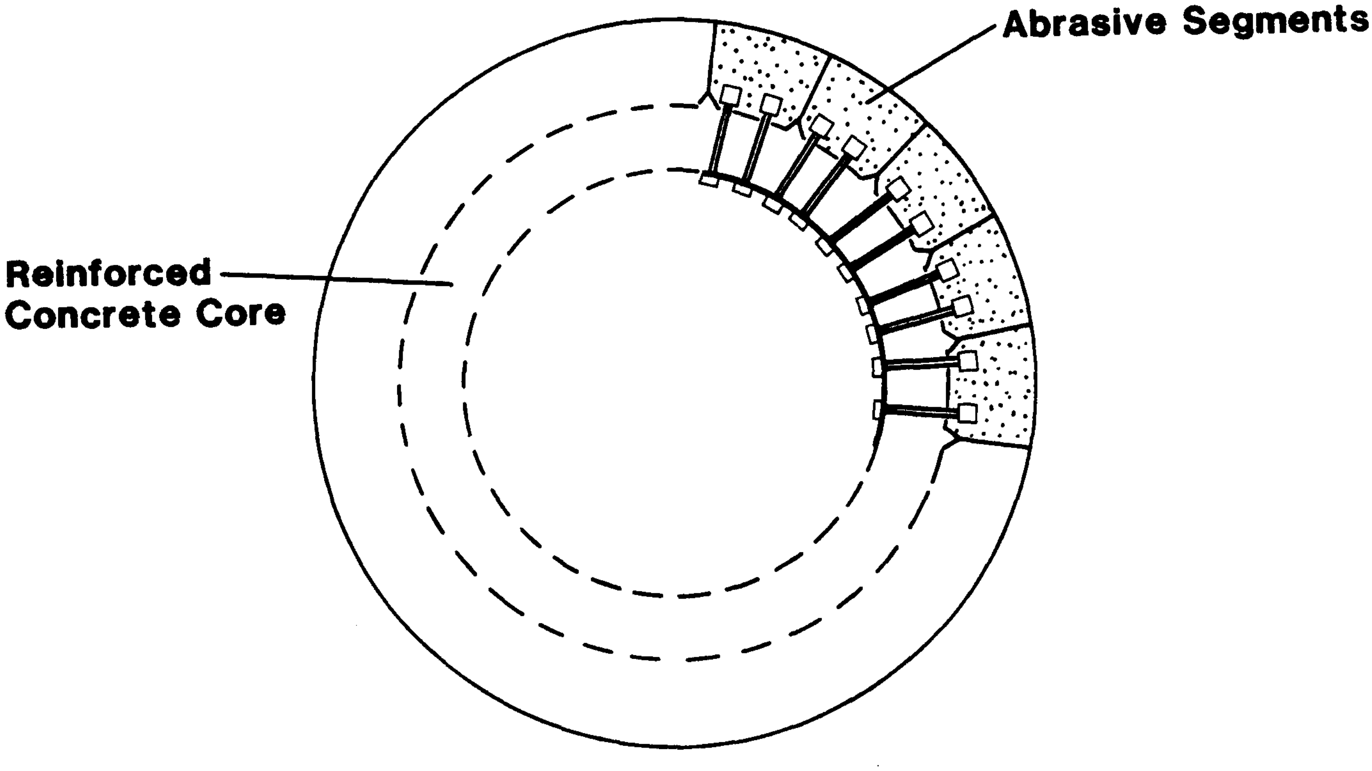

Figure 1-2 Schematic cross-section of a pulp grindstone, showing the individual segments bolted onto a reinforced concrete core.

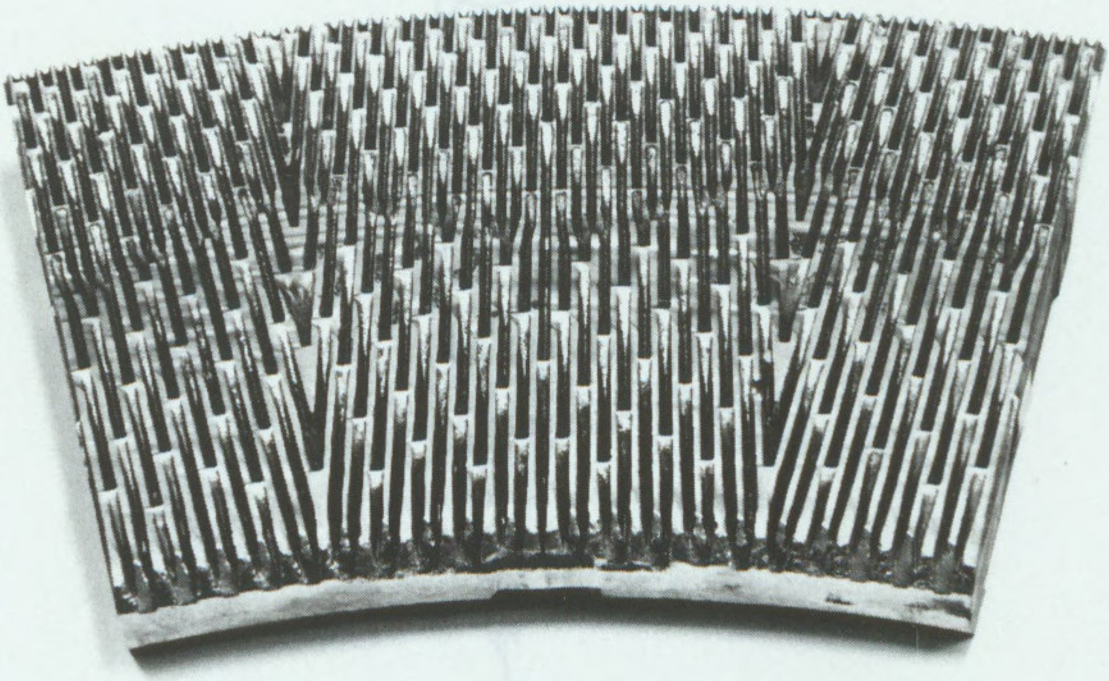

Figure 1-3
A typical refiner plate, showing the different bar widths.

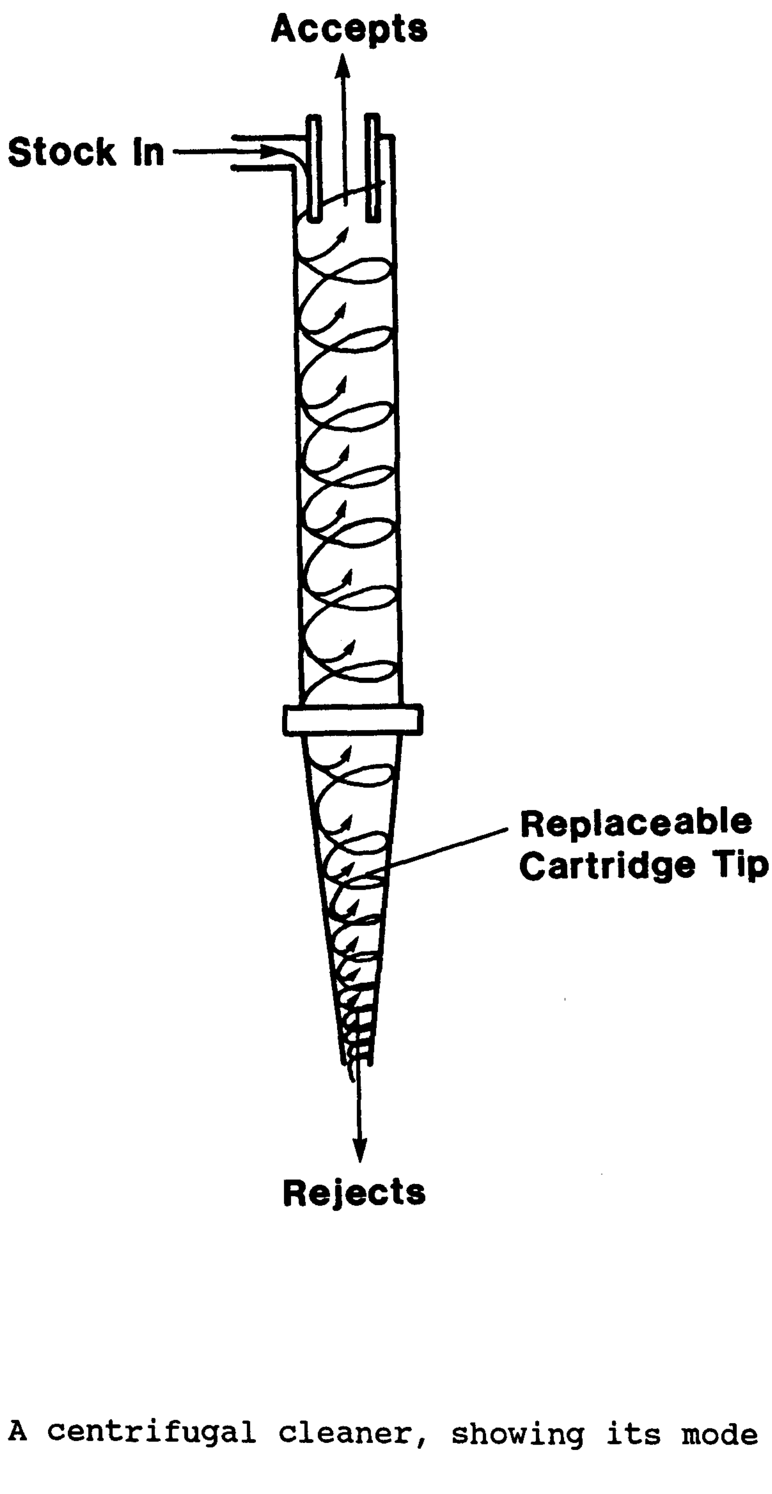

Figure 1-4 A centrifugal cleaner, showing its mode of operation.

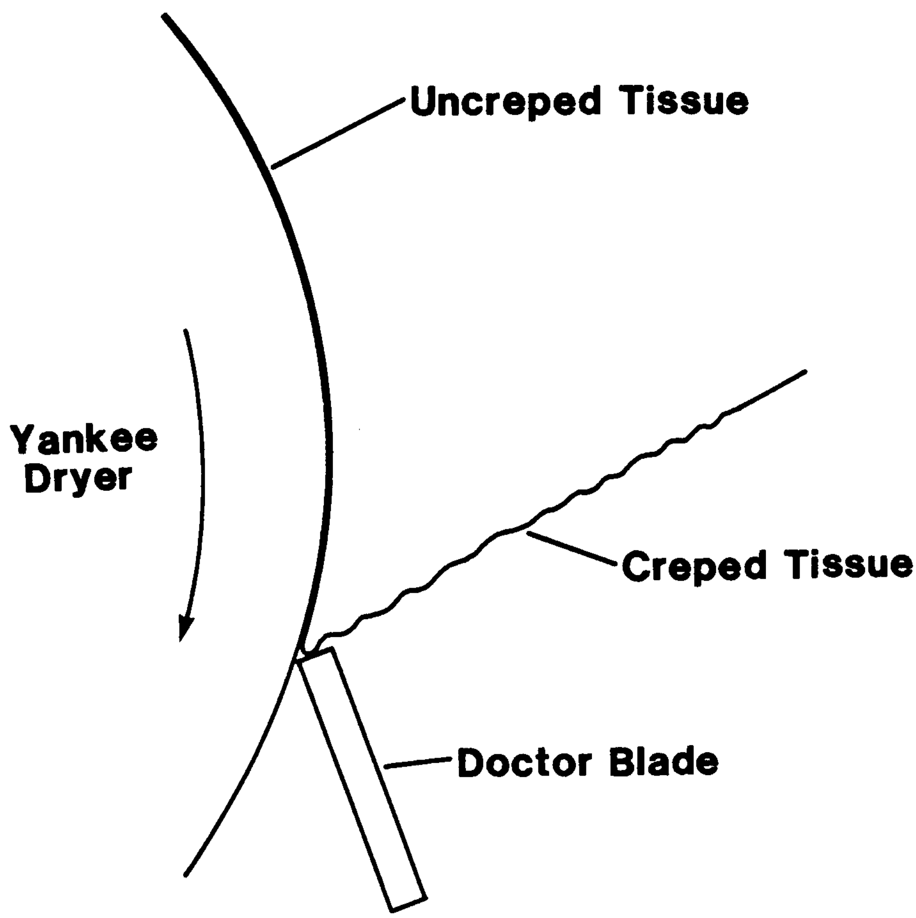

Figure 1-5 A heavily-loaded doctor blade is used to crepe tissue off the surface of the Yankee dryer. Wear occurs on both the doctor and on the dryer surface.

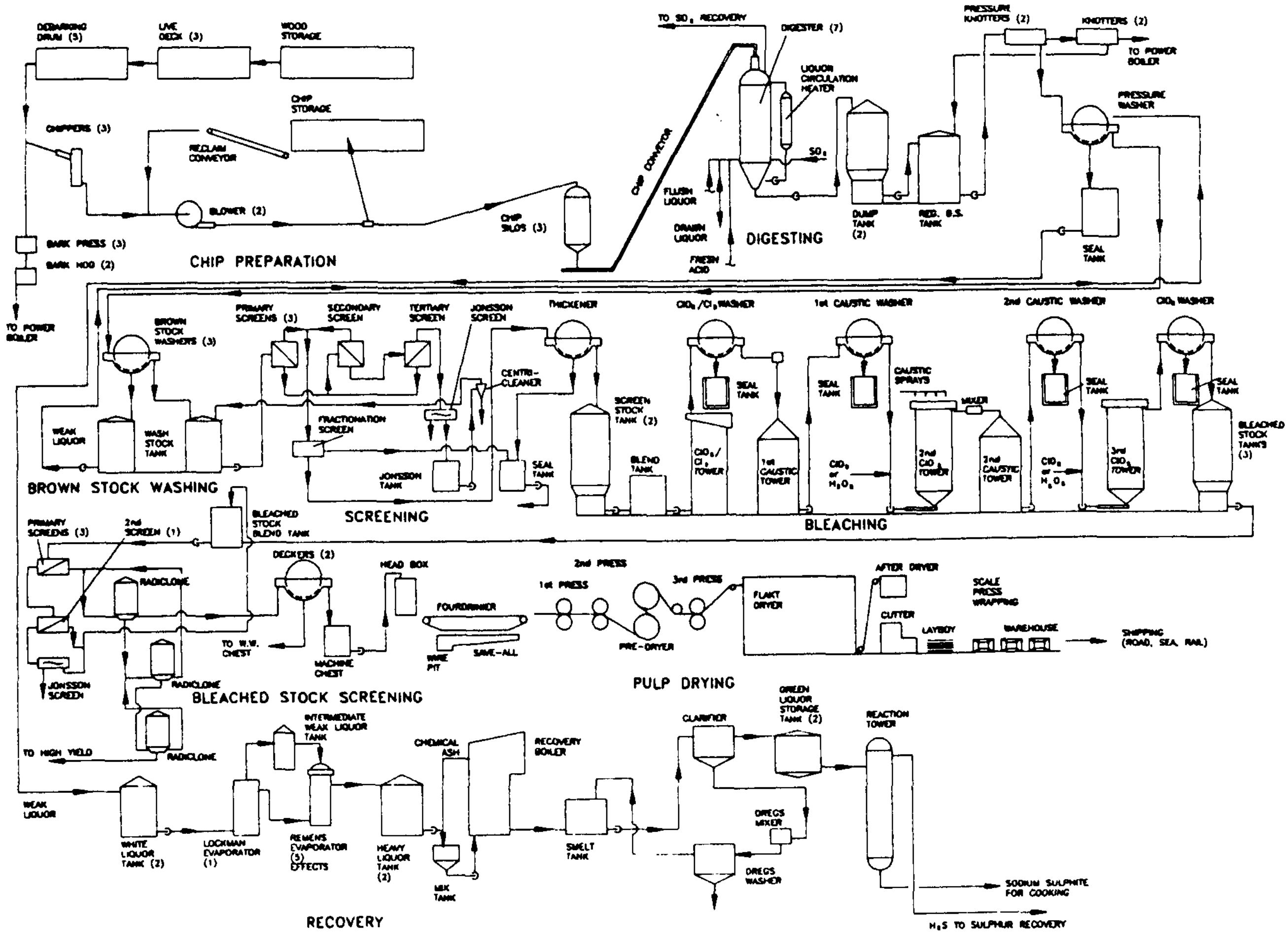

Figure 1-6 The general layout of mill C.
(Reproduced by permission of Pulp and Paper Canada)

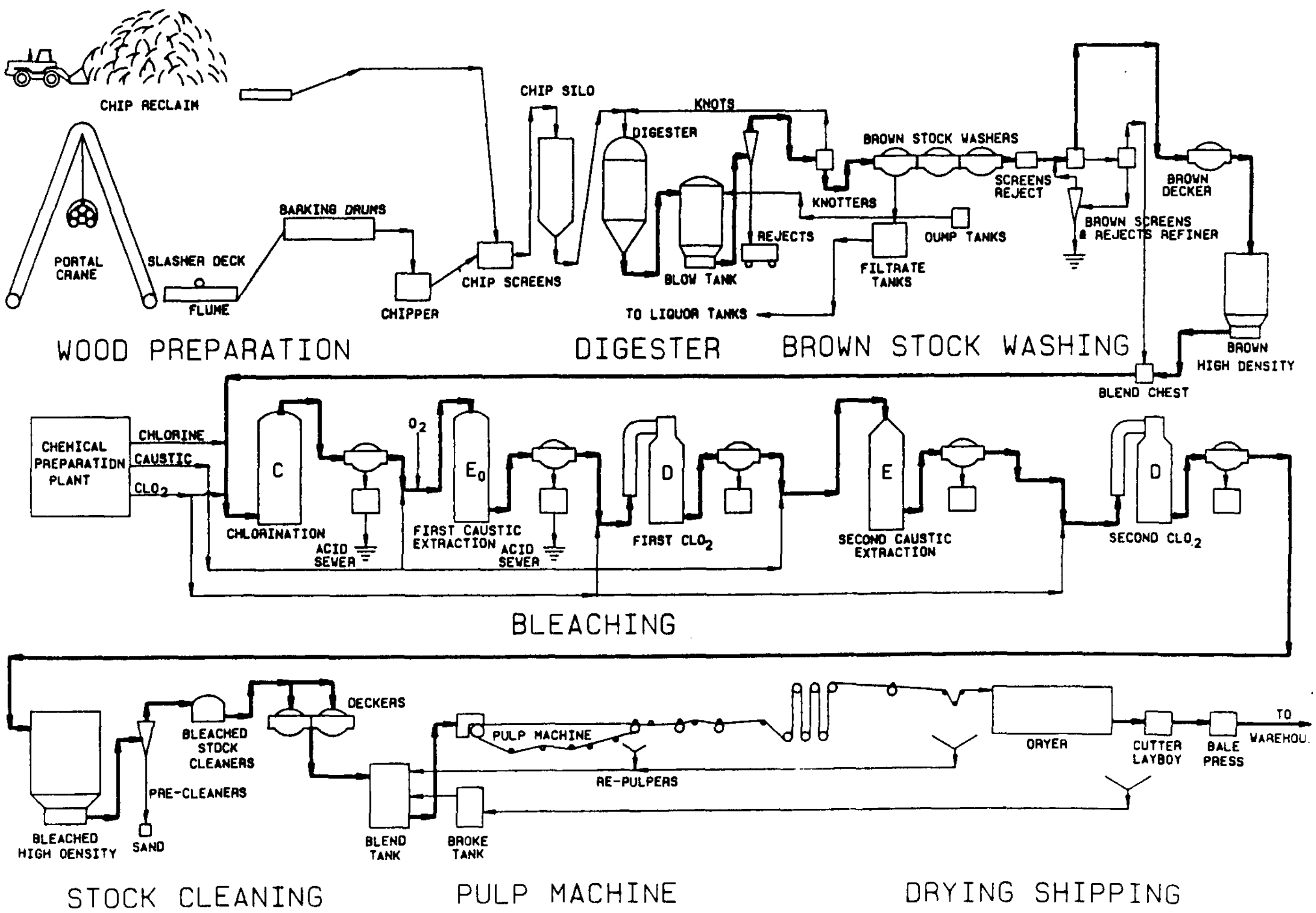

Figure 1-7 (a). The general layout of mill D.

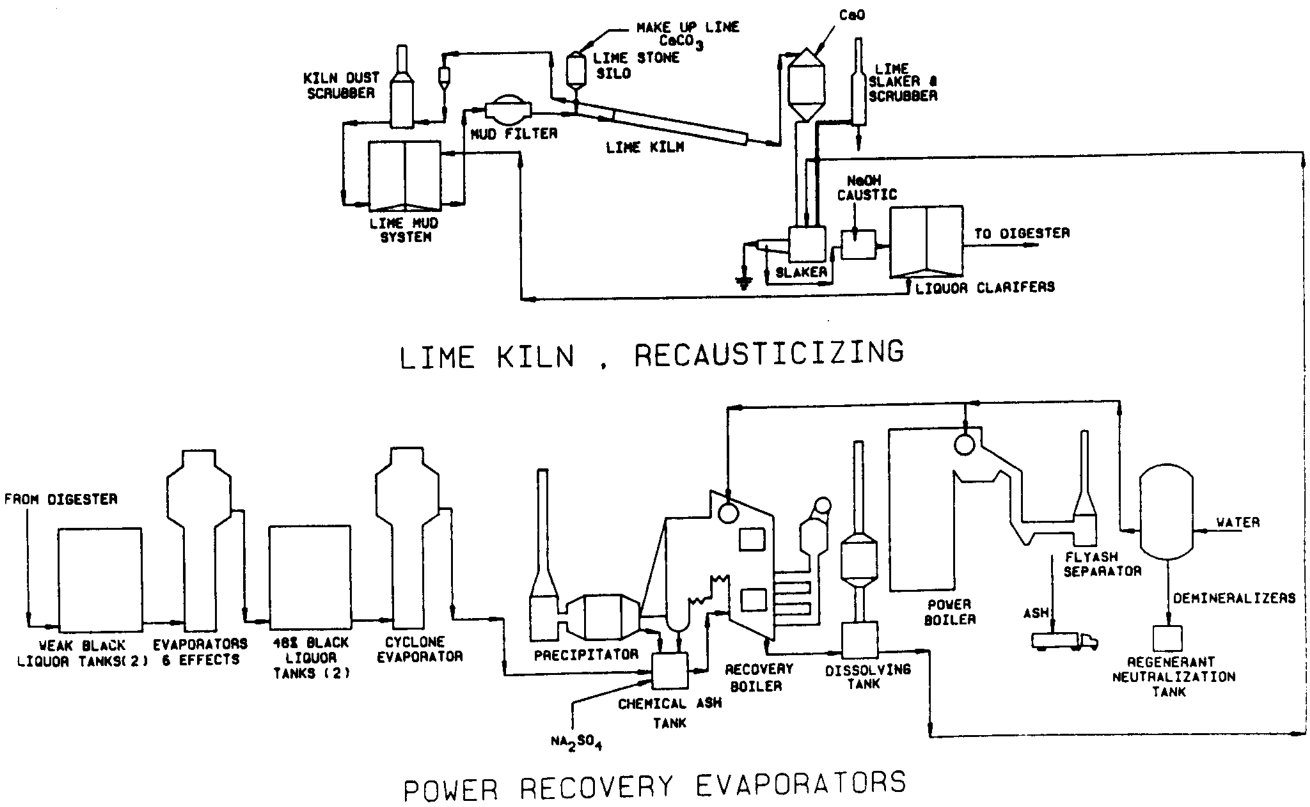

Figure 1-7 (b). The general layout of mill D.

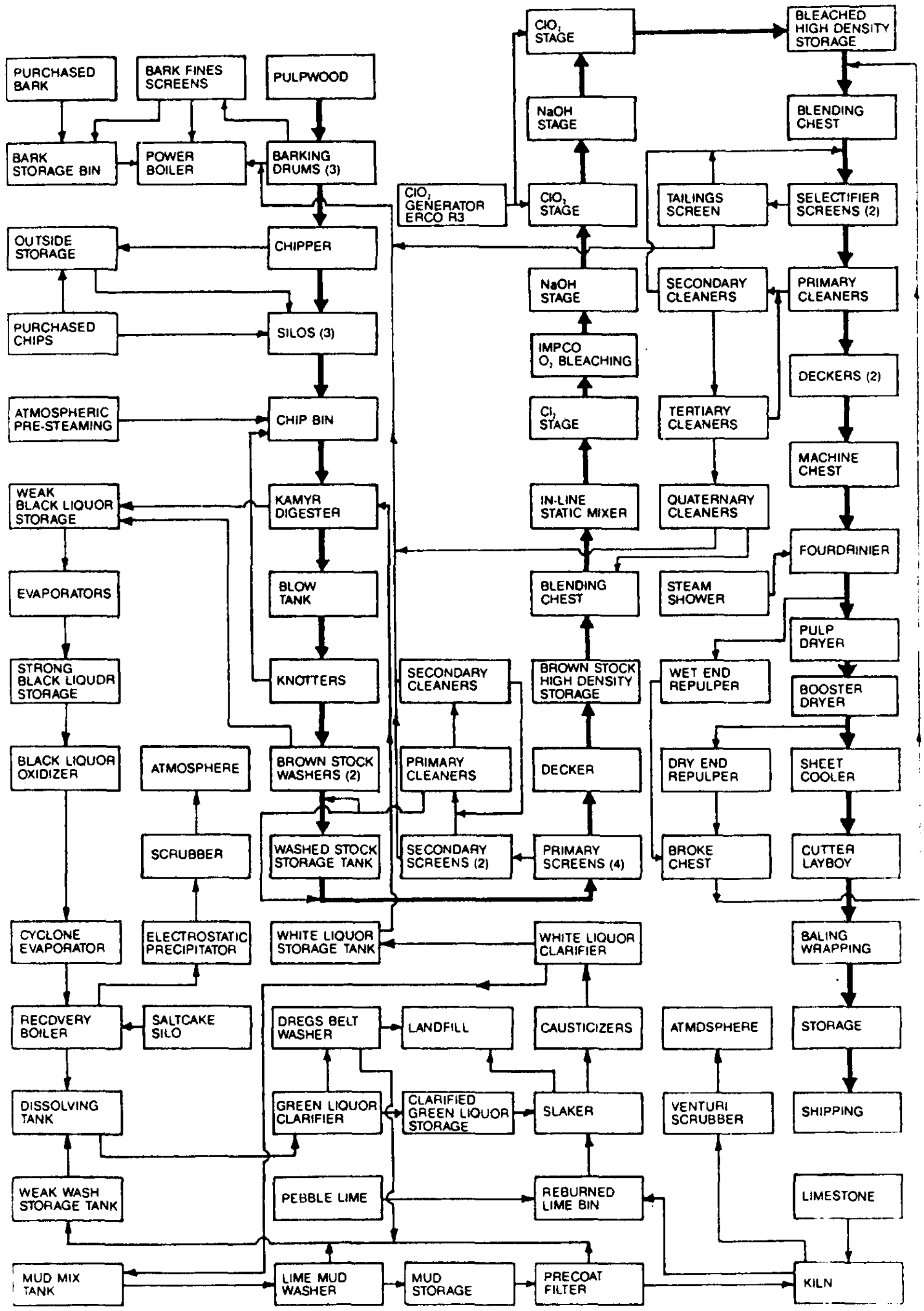

Figure 1-7 (c). A more detailed flow-chart of the mill. (Reproduced by permission of Pulp and Paper Canada)

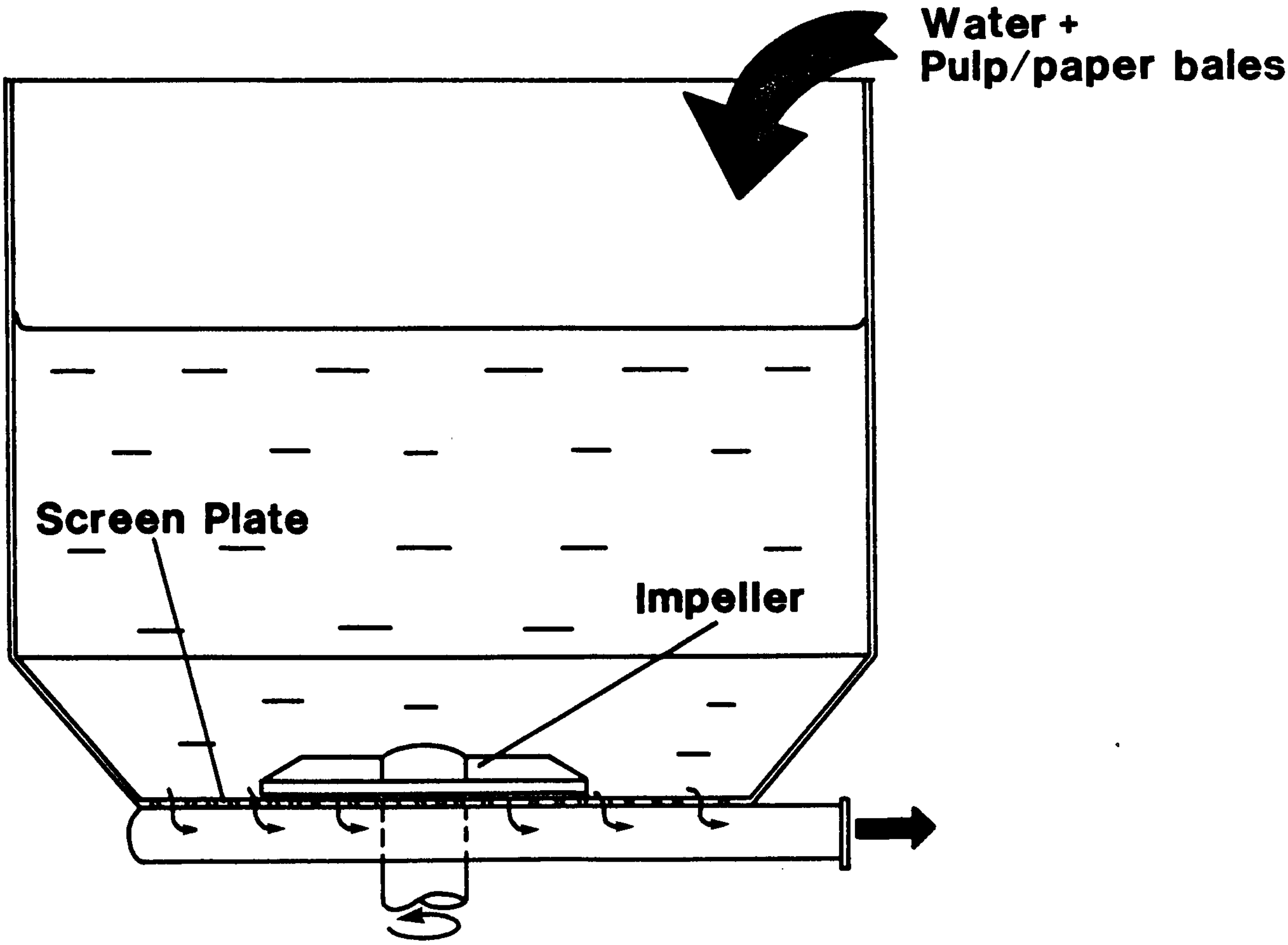

Figure 1-8 A schematic cross-section of a repulper, showing the impeller and the screen plates.

PART TWO

TECHNICAL APPRAISAL OF OPPORTUNITIES FOR ADVANCED CERAMICS

CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

TABLE OF CONTENTS FOR PART TWO

INTRODUCTION

The Alberta Research Council was subcontracted by PAPRICAN/ CUICAC to contribute advanced ceramic expertise to the survey project. This part of the report, submitted by the Alberta Research Council, summarizes the present use of advanced ceramic materials in the industry and discusses potential applications where they could be used. This appraisal is based on the site visits reported in Part One.

The pulp and paper industry is already a substantial user of ceramic materials. This is hardly surprising considering the industry operates under some harsh physical and chemical environments and restraints. The chemical pulping and bleaching process, for example, is highly corrosive, requiring ceramic tile-lined reaction vessels. Ceramic components were first introduced onto paper machines in the early 1960's, and have played an important role in the development of faster, more reliable machines.

The first section of Part Two describes applications where "advanced" ceramics are presently being used in the mills. By "advanced" is meant ceramic materials where property development and/or processing technology have been specifically designed to meet a particular applications requirement. Traditional ceramic tiles and refractories are extensively used to line process vessels and kilns. They are not usually considered to be advanced materials, however, and will not be described further here.

Part Two then goes on to a short description of applicable ceramic materials and, finally, to consider new applications of advanced ceramics or ceramic coatings. In each area, there is a short description of possible opportunities available to advanced ceramic manufacturers and pulp and paper companies. To derive the maximum benefit, it is crucial that these two groups work closely together.

PRESENT USES OF ADVANCED CERAMICS IN THE PULP & PAPER INDUSTRY

This section reviews the ceramic components presently being used in the pulp and paper industry. Other than silicon carbide pulpstones, the majority of applications to-date involve high alumina ceramics. High performance ceramic materials, such as zirconia, silicon carbide, silicon nitride, zirconia-toughened alumina and some ceramic matrix composites (CMC's), such as SiC-bonded TiB_2 etc., are being slowly introduced for particularly demanding applications.

Pulp Grindstones

General

The stone groundwood process is a mechanical method of obtaining papermaking fibre from wood. It is a highly efficient process, with yields as high as 95%, compared to about 50% yield for chemical pulping. The heart of the process is the pulp grindstone.

Natural sandstone grindstones were used exclusively until the 1920's but, as production demands and grinder powers increased, artificial stones became much more important. Artificial sandstones, made from quartz or silicon carbide grits bonded with cement, were first introduced in Europe. However, they are not suited to modern high-speed, high-horsepower grinder systems and have been replaced by the modern ceramic-bonded segmental pulpstone.

The Grindstone Design

The grindstones are made from wedge-shaped segments that are jointed together and connected by metal bolts to a reinforced concrete core, as shown in Figure 2-1. The spaces between the segments, required for thermal expansion, are filled with special grouting material. This design has evolved over the years as a compromise between manufacturability, maintenance and operating requirements. Modern ceramics technology may permit the construction of single-piece grindstones, e.g. by slip-casting. While a single-piece stone may be convenient to manufacture, however, it has the following drawbacks :

- **Possibility of catastrophic failure.** A crack initiated in one area would rapidly propagate through the whole structure. In the case of the segmented design, the failure is restricted to one segment.

- **Ease of maintenance:** It would be difficult to repair monolithic stones.

- **Differential thermal expansion:** As the grindstone gets hot during operation, considerable thermal stresses occur between the ceramic and the rest of the structure, which could lead to failure.

Manufacture

Grindstone segments are available with two different grit materials - alumina (Al_2O_3) or silicon carbide (SiC). The silicon carbide grits are harder, more angular & brittle, and present sharper particles to the pulp wood. The alumina grits are more blocky, less friable, but tougher under impact.

Segments are typically made by: 1) mixing grit of the proper size distribution with a vitrified bonding agent consisting of clay, feldspar and other materials, 2) cold pressing in a mould, and 3) firing at high temperatures to form the vitrified bond. The two major manufacturers in North America are Norton and Carborundum.

Specifications

The following must be specified when purchasing grindstones: type of abrasive, grain or grit size, hardness, density, and type of bonding agent. The most important factors are grit size, ratio of grit to bonding agent and the hardness of the bonding agent. A coarse grit (20 to 24) is used for board stock; a medium size grit (50 to 60) is used for newsprint; and a fine grit (80 to 100) is used for printing papers.

Surface Preparation

Grindstones must be dressed with a burr before being used. This produces a definite cutting pattern as shown in Figure 2-2. The grindstone must be dressed at regular intervals to optimize production rate, specific energy and pulp quality factors, such as burst and tensile strength.

Opportunities

It must be realized that the stone groundwood process is a very mature area. Grindstone technology has been developed over the last 60 years by optimizing a variety of conflicting requirements based on pulp quality, productivity, safety, cost etc. While it may be possible to improve the durability of the vitreous bonding phase, the gains will be marginal. Similarly, significant improvement in grit performance is not considered likely. There is a steep learning curve required for a new company before it can make a contribution in this area. The introduction of pressurized stone groundwood may necessitate some materials development for the grindstone. However, pressurized groundwood is not yet used extensively in Canada.

Centrifugal Cleaners and Cyclones

General

Centrifugal cleaners are extensively used in the pulp and paper industry to clean out bark, sand, metal or other heavy contaminants from the pulp. Figure 2-3 shows schematically how the cleaners operate. Due to centrifugal force, the rejects containing bark, sand, etc. are thrown towards the wall and exit at the apex of the cone. Hard grits in the pulp cause a rapid erosion of the walls, especially near the apex where the velocity of the grits is highest. This has led to the "duplex" design for small cleaners where the low erosion areas at the top are made from stainless steel (or plastic), and the high erosion area, the apex, is made as a replaceable cartridge from either ceramic or plastic. The choice of apex material is economic, based on the severity of erosion in a given situation. Use of bleaching chemicals such as peroxide may cause degradation of plastic cleaner cones.

Cyclones are larger than centrifugal cleaners, typically being at least 1-2 m in diameter. They are often used to separate chips or pulp from steam.

Manufacture

The replaceable ceramic cartridge for a cleaner is generally made from high alumina (Al_2O_3) material. Ceramic powder of proper composition is first shaped in a mould by cold isostatic pressing or by a slip casting technique. The dried "green body" is then fired at high temperature to give the final "sintered" product. Cyclones are made from either stainless steel or steel lined with alumina tiles.

Paperboard Cleaners

In paperboard plants, where recycled beer cartons, etc., are used, the wear of high and medium density cleaners is particularly severe, due to the presence of grit, broken glass, staples, bottle caps, etc. The high density cleaners, which are 25 to 30 cm in diameter, are lined with ceramic, usually high alumina material. The lining is normally produced in three sections and costs more than $20,000. The top section, which has a lot of detail, costs about $12,000. The medium density cleaners are smaller, around 10 cm in diameter, and are usually made in one or two sections.

Opportunities

This application does provide considerable opportunities for both pulp & paper and ceramic manufacturers. Most pulp and paper plants have a large number of centrifugal cleaners operating, and they are a significant replacement item. So, it is worthwhile for the two groups to work together to optimize the material and design of the various cleaners. Similar development may also be possible for cyclones.

As mentioned above, ceramic materials are ideally suited for this application. High alumina linings and apex cartridges are already available from ceramic manufacturers such as Wilbanks. High alumina (85% to 96% Al_2O_3) is a relatively inexpensive material with reasonably good wear resistance, and hence has been the material of choice up to now. However, recent advances in ceramic materials and processing techniques may result in better wearing products at an equivalent cost. For example, addition of 5 to 15%

by volume of zirconia to alumina can substantially improve its toughness and, hence, can lead to better performance.

Silicon carbide, with its higher hardness, has better abrasive wear resistance than the high alumina materials. Sintered silicon carbide, which requires a high temperature controlled-atmosphere furnace for its firing, is not cost competitive with alumina. However, there has recently been an interesting development of an alumina bonded silicon carbide material which can be slip cast into shape and fired in normal air furnaces. This could lead to a material with an improved cost/performance ratio compared to high alumina.

Converting the "duplex" cleaners into fully-lined ceramic cleaners will greatly improve their reliability. One common problem with this design of cleaner is that when there is a blockage of the reject exit(which does occur quite often), accelerated erosion is observed higher up the cone. This results in perforation of the stainless steel cone and the whole unit has to be replaced. To avoid this problem it is suggested that the entire unit be made from ceramic.

For large cyclones, a standard technique is to line the inside with shaped alumina tiles, but this is labour intensive and costly. One solution may be thixotropic slip casting technology, which has been developed to cast large intricate parts. The same technology could also be used to cast single-piece linings for the centricleaners.

Paper Machines

General

The efficiency of paper machine operations has improved considerably during the last 30 years. Modern newsprint paper machines with widths up to 10 m can now run at speeds of about 1300-1400 m/min. Tissue machines typically run at >1830 m/min. The use of advanced ceramics has made a significant contribution to the attainment of these higher speeds.

The most important application area for ceramics on paper machines is in the wet-end, i.e. the part of the machine where the sheet is formed from the pulp-water slurry being fed out of the headbox. In addition, some use of ceramics is also made in the press section of the machine. Ceramics in the wet-end are primarily used for construction of the stationary drainage elements that dewater the sheet; fabric turning bars, palm guides and pick-up shoes are other applications. Sheet dewatering is a critical step in paper machine operations. Dewatering has to be both efficient (to permit high machine speeds) and uniform across the sheet (to prevent wet streaks and minimize sheet breaks).

Efficient, reliable drainage elements are thus of importance to both paper machine operators and builders.

Why Ceramic Dewatering Elements?

Hardwoods, polymers, cermets and ceramics have all been used for stationary drainage elements. Polymers (e.g. ultra-high molecular weight polyethylene) and ceramics are the most common materials in use today. As discussed with Manufacturer C, (Part One), two important factors for selecting drainage elements materials are that they do not damage the forming fabrics and that they have good wear resistance. Polymeric materials have given acceptable service in many situations, and have an economic advantage over ceramics. Factors such as higher machine speeds, increased use of fillers and the presence in the white-water of oxidizing chemicals such as peroxide, however, favour the increased use of ceramics.

The important characteristics of advanced ceramics for use as drainage elements are :

Long Life. Because of their remarkable wear resistance, ceramics offer both the dimensional accuracy as well as sufficient dimensional stability required of the dewatering elements, even under the influence of abrasive filler components such as titanium dioxide and calcium carbonate. It is not unusual for ceramic elements to last over 15 years where polyethylene would last 6 months. Ceramic elements often fracture or chip due to mishandling before they wear out.

Improved Fabric Life. The lifetime of the forming fabric can be increased significantly due to the hard, smooth, and compact surface of the ceramic, typically having an average roughness of less than 0.1 μm. No abrasive particles can stick to this hard poreless surface, and hence wear of the fabric is substantially reduced.

Low Friction. The surface characteristics of ceramics result in a decrease in friction and, hence, in a reduction of the electrical power consumption of up to 45%. The following is the coefficient of friction for three materials as reported by a ceramics manufacturer.

Polyethylene	0.25-0.27
Alumina	0.06
Zirconia	0.04

The following components of paper machines contain ceramics:

Forming Boards

The function of the forming board (Fig. 2-4) is to retard drainage of the pulp suspension to prevent fabric blinding, and to support the fabric. Precise leading edges and flat, smooth surfaces are of the utmost importance. By adjustment of the forming board, both the longitudinal and transverse flow of the paper suspension can be controlled. In this manner, the preconditions of a uniform sheet formation are established.

Fourdrinier and Twin-Wire Drainage Elements

a) Fourdrinier Drainage Elements

Nowadays the most common dewatering and sheet formation elements are foils that skim the water with their front edge from the bottom side of the fabric. The foil angle between foil blade and wire creates a negative pressure pulse, causing a dewatering effect (see Fig. 2-5). By a suitable arrangement of either wide single foils or narrow multifoils, the dewatering efficiency can be adjusted and controlled. Due to the dimensional stability of ceramic foil edges and the constancy of the adjusted foil angle, increased drainage, improved sheet formation and better filler distribution can be obtained.

b) Twin-Wire Drainage Elements

Some designs of twin-wire machines use a forming shoe immediately after the headbox. The forming shoe has two functions; to support the fabric and to assist dewatering by means of the stationary drainage elements built into the surface of the shoe. The forming shoe drainage elements are called blades, and differ from foils in that the blade tips are deliberately held against the fabric in order to cause dewatering.

Turning Bars

Ceramic turning bars have replaced the large diameter forming and breast rolls on some roll-former twin-wire machines. This has allowed the headbox to be kept close to the forming section, helping to improve formation.

Wet Suction Box

Wet suction boxes (Fig. 2-6) use a combination of foils plus vacuum pumping to get higher drainage rates than with foils alone. The dimensional stability of the wear resistant ceramic leading edges is essential to the efficiency of the process. Wet suction boxes are usually installed towards the end of the forming zone.

Dry Suction Box, or Flat Box

Flat suction boxes (Fig. 2-7) are placed just before the couch roll. They have either drilled, slotted or herringbone covers. As these boxes constitute a significant portion of the total fabric/ stationary element contact zone, they represent an important factor in fabric wear.

Felt Suction Box

With increasing machine speeds, the cleaning and conditioning of the felts becomes more problematic. Residual impurities such as silicates, aluminates, and carbonates can cause cover wear, leading to damage of the felt. Ceramics are therefore popular materials for this area.

Anti-Blow Cover, Anti-Flutter Cover

These covers are being used in faster-running press sections to control sheet movement. The anti-blow cover prevents the sheet from blowing against the press roll. Curved ceramic anti-blow covers have been used to replace a suction press roll in this function, thus helping to simplify press section operation. Anti-flutter covers are used on unsupported felt runs to prevent fluttering of the sheet before it enters the press roll nip.

Pick - Up Bars

On tissue machines, a stationary pick-up bar or cover is often used to aid transfer of the sheet from the forming fabric to the dryer felt. Like all paper machine stationary elements, it is a high wear area, where ceramics offer significant advantages over other materials.

Wire & Felt Guides

To keep fabrics and felts in position, guides are placed at various locations on the paper machine. Some ceramic manufacturers claim that ceramic guides have over 10 times the life of stainless steel guides, especially for filled sheets.

Conclusions

In conclusion, the exceptional hardness and wear resistance of ceramics offer three main advantages to papermakers:

1) Improved productivity by contributing to higher machine speeds and reduced down-time.

2) Reduced production costs by helping increase the lifetime of machine fabrics and felts.

3) Maintaining paper quality, due to durable surface finish and profiles of the drainage elements.

Opportunities

As can be deduced from the above discussion, this area presents significant opportunities for both ceramic- and paper-manufacturers. The majority of applications of ceramics on the paper machine have traditionally involved high-alumina materials, containing 85 to 96% aluminum oxide (Al_2O_3). While high-alumina ceramics perform well in many applications, substantial benefits may be realized from newer high performance ceramics, such as zirconia, silicon carbide, composites, etc., in more demanding applications. Zirconia, in particular, is already finding acceptance in the industry. A recent patent describes the use of ceramic foam to support the forming fabric and provide drainage. Advantages claimed include no shadow marking of the paper, and reduced fibre disorientation [1].

Material selection depends mainly on the cost/performance ratio, and the nature of wear taking place. The cost of some of the advanced ceramic materials described in later sections are substantially higher than the high-alumina ceramics. Transformation-toughened zirconia containing MgO is about 50% more expensive than alumina, while zirconia containing other modifiers such as yttria and ceria is even more expensive. Further, sintered silicon carbide is substantially higher, being about 250% more expensive than alumina. Thus, the performance factors must be equal or better than the cost ratios in order for the newer materials to replace alumina. The use of ceramic coatings offers an alternative, potentially cheaper manufacturing route; silicon carbide-coated graphite suction box covers are already commercially available, though market penetration appears limited to-date.

At the start of the paper machine forming section, where water is present to act as both a coolant and a lubricant, high-alumina ceramics perform well. They typically last for years, with breakage often occurring from mechanical abuse or mishandling before any substantial wear takes place. Further down the forming section, however, where it is dryer, the heat generated by friction between the fabrics and the ceramic components in a high speed modern machine can be sufficient to cause failure by thermal shock for materials like alumina. Due to their higher strength and toughness, zirconia-toughened alumina and partially-stabilized zirconia give better performance in these areas. Silicon carbide (monolithic or coated) has also been used in these dryer, hotter applications.

Slitter Blades and Anvils

Finishing operations in a paper mill consist of slitting and rewinding the mill roll into the widths and diameters desired by the end-user. Two principal types of slitters in use are the shear-cutter and the score-cutter. Shear-cutters consist of a pair of driven overlapping sharpened blades rotating against each other. In the score-cut method, a single rotating blade is held by pressure against a hard anvil drum located underneath the paper web. Both blades and anvils ("bottom bands") are commonly made from hardened tool steels, and require periodic sharpening by grinding. Metallic or cermet hardfacings have also been used to enhance wear resistance of the anvils.

Opportunities

Ceramic inserts, made from zirconia, have been introduced for slitter blades (Japan) and anvils (USA). The manufacturer of zirconia anvil inserts claims that, in addition to increasing the time between regrinds, the quality of the cut is improved and dust formation is reduced. Thus, this area presents opportunities for further development of hard coatings and solid ceramic components, which will lead to substantial cost savings for paper production.

Steam Joints

Rotary pressure seals are used on paper machine dryer cylinders. Steam, at pressures up to 450 kPa, is introduced through the seals into the cylinders to dry the paper passing over the outside at high speeds. This is a substantial maintenance item and a silicon carbide seal in this joint has already been introduced to reduce downtime. Again, this presents a reasonable opportunity for a ceramic manufacturer, as there are a large number of these seals on a paper machine and they are a consumable item.

Linings for Pneumatic Chip Lines

Some mills use pneumatic blow lines instead of belt conveyors to transport chips from the wood-room to pulp-making operations. The advantage of a pneumatic system is that it is fully enclosed, thus reducing dust and wind losses. However, disadvantages include heavy wear on the piping system and higher blower-fan power consumption. Ceramic linings installed as panels or tiles greatly reduce wear on pipe elbows, valves, silos, etc. One manufacturer claims that a high alumina ceramic lining outlasts steel alloys by a factor of 5 to 20 times.

This may be an opportunity for a ceramic manufacturer that can compete with sintered high alumina shapes. For example, a 1.3 cm thick alumina-lined 40 cm diameter 90 degree elbow with 200 cm radius costs about $5500, including stainless steel exterior. Slip casting or other near net shape processing of large sections may be cost competitive compared to the present practice of installing tiles or panels. However, the total market may not be very large and is probably shrinking as more mills choose belt conveyor over pneumatic systems.

Radiant (Infra-Red) Heater

On coated paper machines, infra-red radiant heaters are commonly used to achieve rapid drying of the applied coating. Natural gas or propane is burnt within ceramic radiant tubes to achieve surface temperatures up to 1200°C. The requirements for radiant tubes are high temperature stability, thermal shock resistance and gas impermeability. Some ceramic materials, such as cordierite ($2MgO.2Al_2O_3.5SiO_2$) and silicon carbide(SiC), have been shown to be good radiant tube materials that can operate up to 1500°C. This may be a good short-term development opportunity for a ceramic manufacturer, although the market size may not be substantial.

Sensors

The pulp and paper industry is highly automated, with on-line real-time process control based on monitoring of process variables [2]. A wide variety of sensors is used for these purposes. The area of sensor development presents a general opportunity for ceramic based sensors. Opportunities are available everywhere in pulp and paper plants, from wood rooms to paper machines. Part I of this report describes some of the sensors presently being used for on-line measurements on the paper machine and other processes. A later section of Part II suggests a possible use of a lead zirconia titanate piezoelectric sensor for refiner plate gap measurement.

ADVANCED CERAMIC MATERIALS

General

This section presents a short description of a few advanced structural ceramics that are either being used, or can potentially be used, in the pulp and paper industry. It is not intended to be a comprehensive compilation of properties and processing information, but rather a brief overview for the non-specialist. Functional ceramics, including sensors, are not described here.

Tables 1 and 2 list the common structural ceramic materials, their properties, components and fabrication methods. A short description of each of these materials follows, concluding with a general section on factors determining the wear resistance of ceramics.

Alumina and Alumina Composites

The majority of ceramics applications in the pulp and paper industry have traditionally involved high alumina materials. High alumina ceramics, containing 85 to 96% aluminum oxide (Al_2O_3), have been the mainstay of wear resistant structural ceramics for a long time. These materials are reasonably hard and strong, and can be economically manufactured with standard ceramic production equipment. As shown in Table 1, they contain varying amounts of MgO, SiO_2, and CaO. In general, the strength of high alumina materials is largely dependent on composition (alumina content), porosity, grain size and finishing conditions. Figure 2-8 shows the relation between alumina content and strength. Over the years, the purity and microstructure of alumina have been improved, resulting in higher strengths and hardnesses. However, their brittleness (low toughness) and low reliability have prevented more widespread use under plant operating conditions.

Over the last 15 years, there have been considerable worldwide efforts to improve both the toughness and reliability of ceramic materials through microstructure engineering. Substantial improvements in toughness (and strength) of alumina have been obtained by the addition of 5 to 30 vol.% zirconia (see Figure 2-9). Zirconia undergoes a martensitic transformation from the tetragonal phase to the monoclinic phase at about 1100°C with a large volume change (3-5%). This results in toughening of the alumina, with a corresponding increase in strength and reliability. Although there is a slight reduction in hardness with addition of zirconia (see Table 2), wear resistance is improved by the increase in toughness.

Zirconia

Transformation toughening results in high toughness (K_{IC} = 6 - 20MPa.$m^{1/2}$) and wear resistance for partially-stabilized zirconia (PSZ). Stabilization of the transformable high-temperature tetragonal phase can be achieved by addition of various oxides, such as CaO, MgO, Y_2O_3, CeO_2, etc(see Table 2). The properties of the various zirconia materials vary with composition and microstructure, but these materials are the toughest and strongest ceramic materials available. They also have very low coefficients of friction, which is of interest for paper machine applications.

Silicon Nitride and SIALON

Silicon nitride (Si_3N_4) ceramics, including SIALON, were developed during the last 20 years, mainly for automotive engine applications. SIALON is an Si - Al - O - N solid solution with a silicon nitride structure. Tables 3 and 4 give typical properties of silicon nitrides and beta-SIALON, respectively. In addition to good hardness, toughness and strength properties, these materials also have low friction properties.

Silicon Carbide and Silicon Carbide Composites

Although silicon carbide is relatively brittle (K_{IC} = 2 - 3 MPa.$m^{1/2}$), its excellent hardness (26 - 28 GPa, see Table 2) leads to good wear resistance in abrasion. Table 5 shows some properties of SiC manufactured by various processes - reaction sintering, pressureless sintering and hot pressing. Under impact wear conditions, performance is not as good due to low toughness. Recently, there have been attempts to improve the toughness of silicon carbide by the addition of second phase materials such as titanium diboride (see Table 2). The Table also shows properties of titanium diboride, which is one of the hardest ceramic materials available (27-32 GPa).

Cemented Carbide (Cermet)

Cemented carbide is not a true ceramic material, but is a cermet. It consists of tungsten carbide (WC) particles bonded together by a cobalt (Co) or nickel (Ni) matrix. The hardness, toughness, strength and other properties of WC - Co cermets depend on the composition or WC/Co ratio. With increasing metal content, toughness and strength increase with a corresponding decrease in hardness. Thus, a variety of alloys is available for various applications. Because of the metallic matrix of these materials, corrosion resistance has to be considered. Other cermets such as TiC-Fe-C have been introduced recently but, as yet, have not found wide acceptance in the industry.

Wear Resistance of Ceramic Materials

Wear of ceramics is a complex phenomenon. It depends on the fracture properties of the materials, surface conditions and the nature of the surface interactions. Therefore wear of ceramic materials cannot be simply correlated to any one physical property such as hardness, toughness, strength, etc. A number of empirical correlations between wear resistance and properties such as hardness (H) and fracture toughness (K_{IC}) have been published. They have the general form

$$\text{WRP} \;\alpha\; (K_{IC})^x . (x)^y . H$$

where WRP is a wear resistance parameter. The coefficients x and y depend on the type of wear - abrasion, impact, etc. Figure 2-10 shows the relation between wear resistance, K_{IC} and hardness for a variety of ceramics. In general, wear resistance improves with increasing hardness and toughness, but their relative importance depends on the type of wear taking place. Therefore, for selection of material for a wear application, the above relationship can only be taken as a general guide and the actual wear mechanism must be determined.

POSSIBLE NEW USES OF ADVANCED CERAMICS AND CERAMIC COATINGS IN THE PULP AND PAPER INDUSTRY

An attempt has been made in this section to list possible new applications of advanced ceramics or coatings in the pulp and paper industry. A number of these ideas arose during discussions with personnel in the plants visited. These are initial thoughts and require careful scrutiny from machine designers, maintenance engineers and production staff. The suggested materials, in particular, must be taken as tentative. All of the applications listed require research and development effort to varying degrees for successful implementation. They are not listed in any order of importance or stage of development.

Granite Press Rolls

There has always been interest in finding a replacement material for granite press rolls; granite of acceptable quality for large rolls is available from only two quarries in the world. Research efforts were intensified in the late eighties after two catastrophic granite roll failures. The fundamental surface properties required for an effective press roll (and which granite fulfils) are still a matter of dispute. Commercially-available granite substitutes include several rubber-based materials and one plasma-sprayed ceramic material ("XG" roll, Yamauchi Corp. Japan)

Ceramic components for mud pumps: The wear from abrasive slurry in recaust mud pumping systems can probably be reduced by the use of ceramic components, such as seals, impellers, valves, etc. Depending on the application and operating conditions, a number of materials could be considered, e.g. toughened alumina, partially-stabilized zirconia, silicon carbide, etc.

Grate blocks for hog fuel boiler: Stationary-grate furnaces for hog fuel boilers are typically cleaned of ash with steam. This leads to heavy wear which could be reduced by the use of ceramic blocks. In addition to wear resistance, good thermal shock resistance is also a requirement for this application; hence, silicon carbide may be the material of choice.

Rotating syphons on dryer rolls: The tips of rotating syphons used to collect condensate from inside dryer rolls wear out and become inefficient as the wall-syphon gap increases. A ceramic syphon may reduce this maintenance problem. Silicon carbide may be useful in this application due to its good wear and thermal shock characteristics.

Ceramic Membrane Filters for Effluent Treatment: Ceramic membrane filters are now commercially available with pore sizes around 0.2-0.8 μm (micro-filtration) and 5-50 nm (ultra- filtration). These have been shown to be extremely efficient in the treatment of produced water from oil wells and for cleaning soluble machining oils (coolants) for reuse. Ultrafiltration is also widely used in the food industry. Ceramic membrane filters may have use for removal of organic pollutants from pulp mill effluent. Note that polymeric ultrafiltration membranes are already being used (Sweden, Japan) to treat kraft mill bleach plant effluent. Figure 2-11 shows schematically how a ceramic membrane filter functions. It is an asymmetric system, with a thin membrane layer being deposited within a supporting porous ceramic body. The filter works on a cross-flow mode, thus operating continuously and avoiding problems with membrane fouling. Ceramic membranes made from alumina are most common, although zirconia and titania membranes have recently become available. Performance of the latter two membranes are greater than alumina under certain conditions. The polymeric membranes referred-to above are reportedly susceptible to shock pressure loadings. Use of ceramic membranes may be advantageous in this respect.

Smelt Spouts on Recovery Boilers: The recovery boiler is a crucial part of the kraft process, where black liquor from the digester is burnt under controlled conditions to recover energy and inorganic cooking chemicals. In the reducing zone of the boiler, organic and inorganic sodium compounds are reduced to a molten sodium sulphide-carbonate smelt, which flows by gravity through water-cooled metal spouts into a dissolving tank (see Figure 2-12).

The spouts corrode/wear due to the action of smelt, and are replaced at frequent intervals to avoid the possibility of cooling water coming into contact with the molten smelt. The possibility exists of redesigning the spouts to use ceramic construction, and thus avoid the necessity for water cooling. This would be a particularly demanding application, however, for the following reasons:

a) the spout is subject to heavy mechanical abuse - frozen smelt blocking the exit is often removed by rodding.

b) a "hot" ceramic spout would be subject to wear and corrosion from the molten smelt flow. Sodium sulphide is corrosive, especially in the presence of air. At air/molten smelt/ceramic interfaces, the corrosion could be accelerated due to formation of Na_2O by oxidation of the smelt.

Silicon carbide or zirconia could be tested in this application.

Recovery Boiler Waterwall Coating: Carbon steel waterwall tubing corrodes by the action of a) sulphur-containing hot gases (e.g. H_2S, CH_3SH, CO_2 etc.) and b) contact with the sodium sulphide-sodium carbonate smelt. This corrosion may be preventable by using a protective ceramic coating. To permit good heat transfer, the coating must either have high thermal conductivity or be thin. Although there is not sufficient corrosion data available for ceramic materials under these conditions, silicon carbide coatings would be a possible candidate materials.

Refiner Plates: This is a severe application. In a refiner, closely-spaced circular sets of ridged plates rotate at 1200 or 1800 rpm, with a gap of about 0.75 mm. Considerable power, (nominally 3 to 14 MW), is concentrated in this small gap in order to mechanically pulp wood chips. Typical conditions of operation are 150-180°C temperature and 690 kPa pressure. The plates are made from cast stainless steels or cast white irons and have limited life, typically between 1000-2000 hours. Considerable research effort has gone into improving the wear resistance of the plates. Due to the severe mechanical and thermal stresses involved, solid ceramic refiner plates have not been accepted by the industry; however, wear resistant ceramic or cermet coatings could be beneficial. Titanium diboride/NiCr cermet coatings could be candidate materials.

Refiner Plate Gap Sensor: From the above, it is clear that maintaining a minimum plate gap is important; otherwise severe damage of the plates can occur. In at least one design, the plate gap is measured by an eddy current sensor with a ceramic protective cover, usually made from alumina or zirconia. The eddy current sensor probably can be replaced by an all-ceramic lead zirconia titanate piezoelectric sensor, with resulting improvement of reliability.

Chip and Pulp Handling Equipment: Chip and pulp handling equipment, such as chip feeders, pulp feeders, screw presses, etc., are subject to considerable wear. Typically, they are made from stainless steel and need to be replaced or rebuilt every 12 to 18 months. The coefficient of friction between the material of construction and the feed needs to be low. Again, ceramic/cermet coatings or, in some instances, solid ceramic inserts may improve the life of these components. Zirconia or silicon nitride are good candidates, due to their low friction characteristics.

Pulper Components: Repulper screen plates and impellers are subjected to heavy wear from tramp materials such as broken glass, steel wire, bottle caps, staples and similar debris. These repulper components are typically made from stainless steel, which is sometimes hardfaced to reduce wear. Ceramic plates, inserts or coatings may provide extended service life. Possible candidate materials are toughened alumina, zirconia and silicon carbide.

Wood Room Machinery: A lot of wear in log and chip handling machinery occurs from metal-to-metal or metal-to-wood sliding abrasion. This wear may be reduced by coating with low friction materials such as silicon nitride or zirconia.

Yankee Dryer and Doctor Blade: As described in Part One, worn Yankee dryers are rebuilt by thermal spraying a molybdenum-nickel alloy. Due to heavy mechanical and thermal cycling at the surface of the dryer, it would be very difficult to replace this metallic coating with a ceramic. A cermet coating, such as titanium diboride/nickel-chromium matrix may, however, be applicable. The doctor blade may be more amenable to the use of advanced ceramics. A zirconia or silicon nitride coating on the blade could reduce friction and wear on both the dryer and doctor surfaces.

Impulse Dryer Cylinders: There is considerable interest at present in the development of impulse dryer technology, for newsprint and other paper grades. To obtain the high dryer roll surface temperatures needed for this technology, electrical induction heating systems are being used. In some designs, an electrically-conductive ceramic coating on the roll is used to achieve and control the resistive heating effect [7].

REFERENCES (For Part Two)

1. US Patent 4985-121, Papermaking Machine Having Web Support of Ceramic Foam.

2. McGill, F.J., Measurement and Control in Papermaking, Adam Hilger Ltd., Bristol, England (1980).

3. Morrell, R., in Engineering Applications for Ceramic Materials - Source Book, M. Schwartz, Editor, ASM International, Metals Park, Ohio (1985).

4, Fine Ceramics, S. Saito, Editor, Elsevier Sequoia Ltd., (1985).

5. Ghosh, D. et al., Development of Tough Ceramics, The Electrofuel Manufacturing Co., report to CANMET, Energy Mines and Resources Canada, Ottawa (1988).

6. Baldoni, J.G. et al, in Tailoring Multiphase and Composite Ceramics, R.E. Tressler et al., Editors, Plenum Press (1986).

7. US Patent 4,948,466, Method for Heating a Cylinder or Roll with an Electrically Conductive Ceramic Outer Layer.

Table 1: Characteristics of Advanced Ceramics [3]

Ceramic Type	Fabrication Method	Addition (%)	Typical Strength ($MN\ m^{-2}$)	
Al_2O_3	Sinter	~0.05 MgO	200-400	Refractory, high-purity
		0-2 MgO, 0-4 SiO_2	200-250	Acid-resistant
		0-3 CaO, 0-10 SiO_2	200-300	General-purpose
		10-20 ZrO_2	200-500	Transformation-toughened
	Hot press	20-40 TiC	200-500	High-strength
ZrO_2	Sinter	4-8 CaO, MgO, Y_2O_3	200	Stabilized, refractory, not strong or thermal shock resistant
	Sinter + aging	2-4 CaO, MgO, Y_2O_3	500	Partially stabilised, transformation-toughened
	Sinter	1-2 Y_2O_3	1000	Transformation-toughened, not refractory
SiC	Reaction-bond	8-20 Si	400	Hard, wear-resistant, thermal shock resistant, acid-resistant
	Hot-press	1-2 Al_2O_3	500	Stronger
	Sinter	~1 B	300	Acid- and alkali-resistant
Si_3N_4	Reaction-bond	-	200	Thermal shock resistant, moderate strength, porous
	Hot press	1-5 MgO, Y_2O_3	800	Harder, impermeable
	Sinter	5-15 MgO, Y_2O_3	600	High strength, more shape flexibility
Sialons	Sinter	5-15 MgO, Y_2O_3	600	Strong, hard, wear-resistant
B_4C	Hot-press	~1 B	400	Very hard and wear-resistant

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Table 2: Properties of Some Structural Ceramic Materials

Material	Hardness (HV) GPa	Flexural Strength MPa	Toughness K_{IC} $MPa.m^{½}$	Density g/cm^3
Alumina (85-95%)	15-18	300-400	3-4	3.75
Alumina (>99%)	18-20	500-600	3-4	3.85
Zirconia Toughened Alumina (ZTA)	16-18	600-800	5-8	3.9-4.2
Partially Stabilized Zirconia (Y-PSZ) (ZrO_2)	10-13	1200-2000	6-20	6.0
Silicon Nitride/ Sialon	14-18	800-1200	5-7	3.2
Silicon Carbide (SiC)	26-28	350-500	2-3	3.1
Titanium Diboride (TiB_2)	27-32	400-700	4-5	4.5
SiC/TiB_2 Composite	27-29	400-600	4-5	3.3
Carbide	13-20	1500-3000	8-20	13-15.5

Table 3. Properties of Hot-Pressed and Sintered Silicon Nitrides

Property	Hot Pressed	Pressureless Sintered
Density (g/cm^3)	3.1-3.26	3.0-3.2
Thermal conductivity (W/m.K)	25-35	15-25
Flexural strength (MPa)	1000-1250	800-1000
Compressive strength (GPa)	4.4-4.8	3.8-4.2
Thermal expansion (X 10^{-6}/°C)	3.2	3.4
K_{IC} ($MNm^{3/2}$)	6-9	5-9

Table 4. Properties of SIALONS

Property	Typical Value
Flexural strength (MPa)	800-1000
Hardness (GPa)	15-18
Fracture toughness ($MNm^{3/2}$)	5-10
Thermal expansion (x10^{-6}/°C	3.2
Thermal conductivity (W/m.K)	20-30

Table 5. Variation of SiC Properties with Fabrication Method

Property	Reaction Sintered	Pressureless Sintered	Hot Pressed
Density (g/cm^3)	3.1	3.1	3.2
Bend strength (MPa)	450-600	500-850	400-500
Coeff. of thermal expansion (10^{-6} $^oC^{-1}$)	4	4.5	4.5
Thermal conductivity (W/m.K)	160-180	60-80	100-160

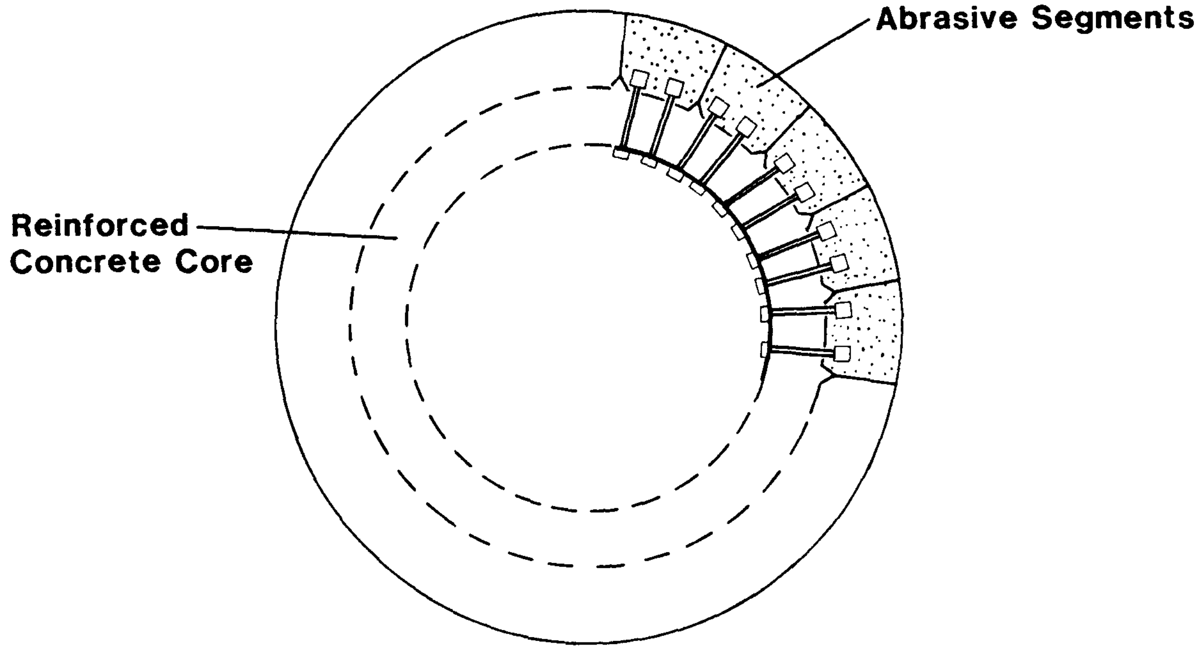

Figure 2-1
A schematic cross-section of a pulp grindstone, showing the individual segments bolted onto a reinforced concrete core.

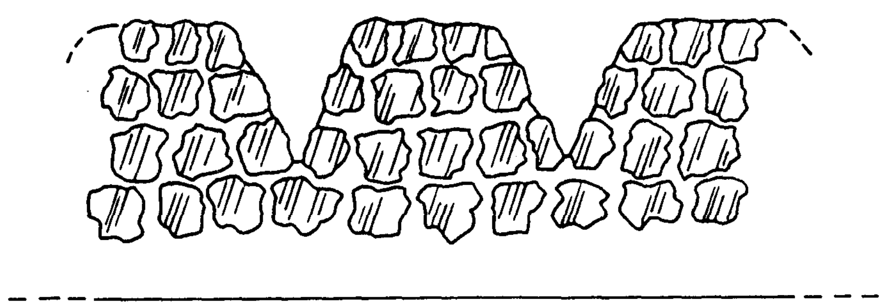

Figure 2-2 A grindstone surface is dressed before use, giving a deliberate surface pattern. The figure shows a typical pattern in cross-section. After dressing, the stone has to be run-in, or conditioned, for a few hours before producing good quality pulp.

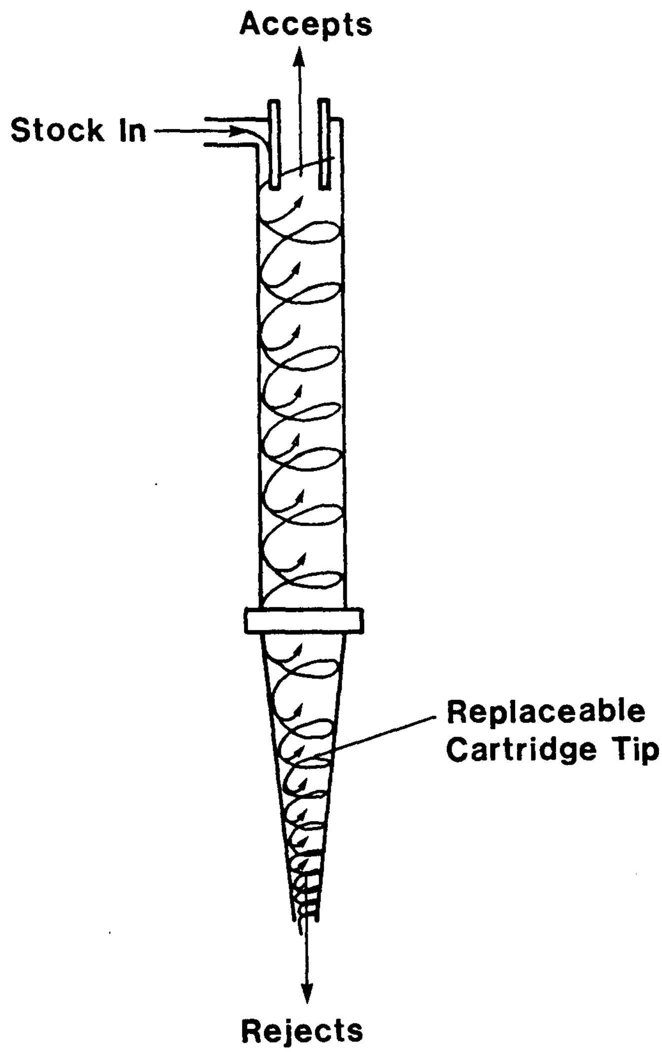

Figure 2-3 A centrifugal cleaner, showing its mode of operation.

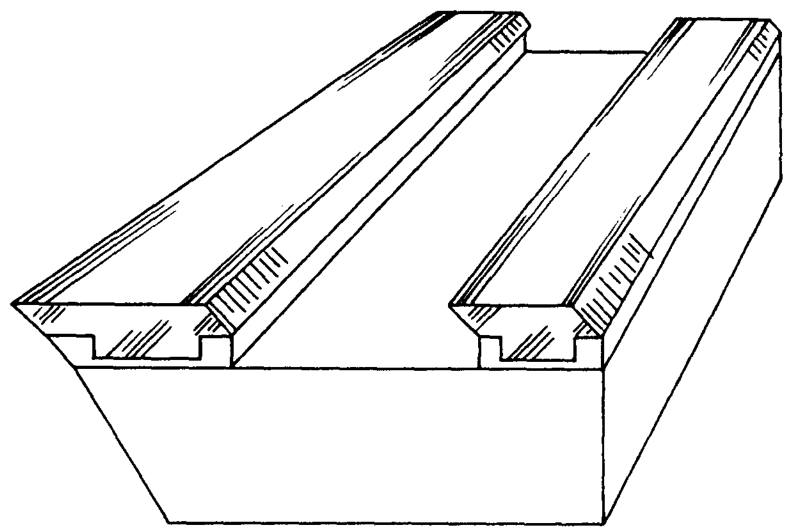

Figure 2-4 A schematic of a forming board. Flat, smooth surfaces are important.

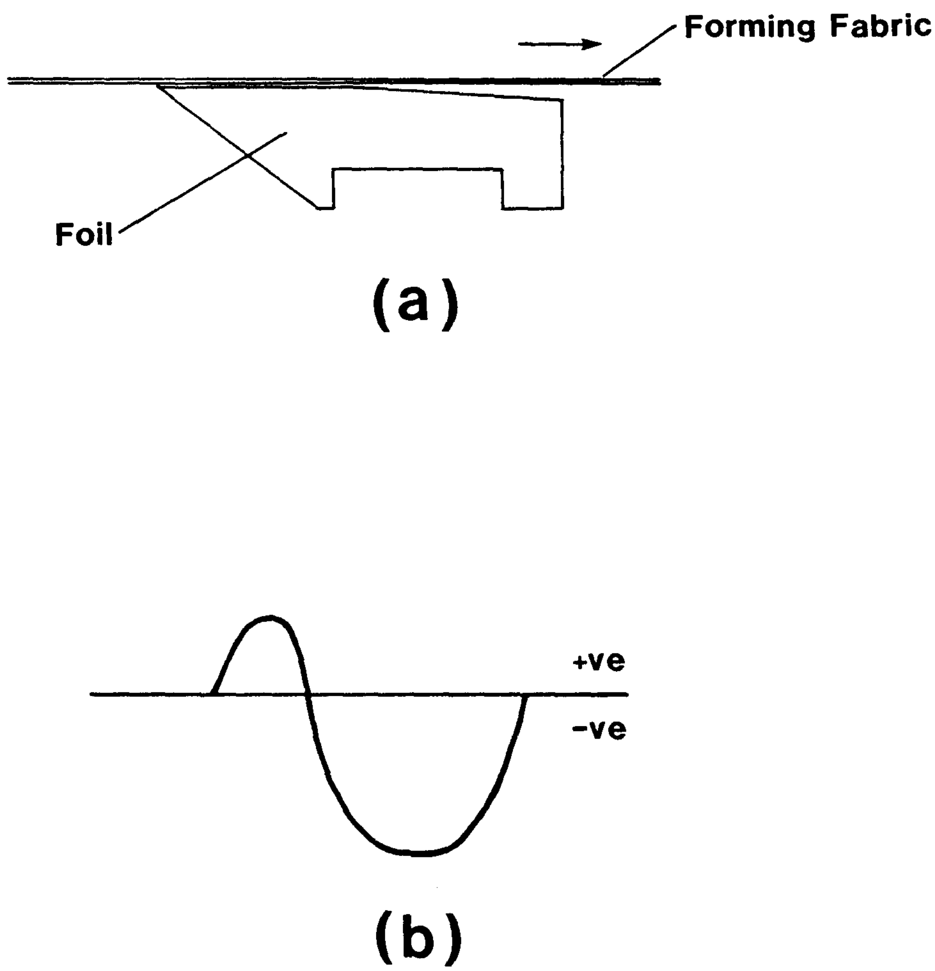

Figure 2-5 (a) The top surface of a foil is precisely angled to cause a pressure drop as the forming fabric passes over it. The change in pressure with distance across the top of the foil is shown in (b).

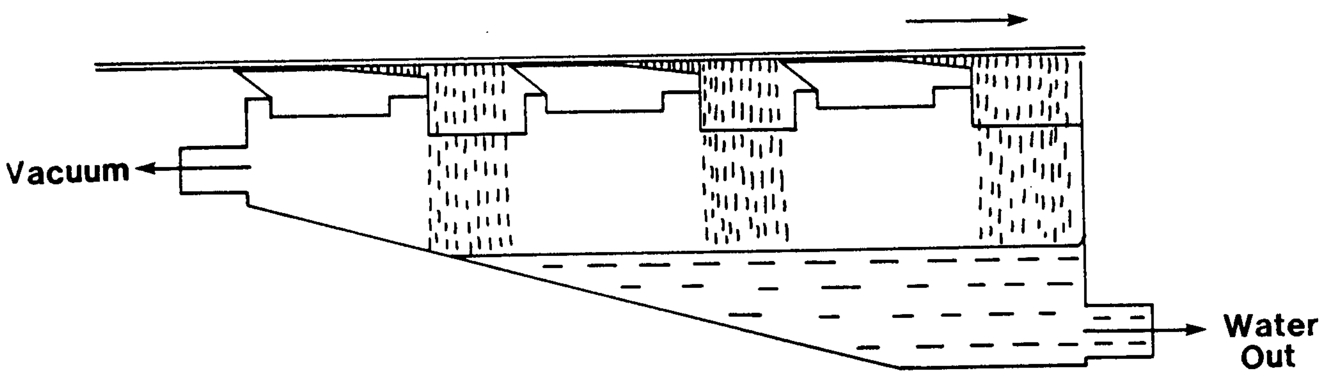

Figure 2-6 The combination of foils plus vacuum pumping in a "wet" suction box gives higher drainage rates than are possible with foils alone.

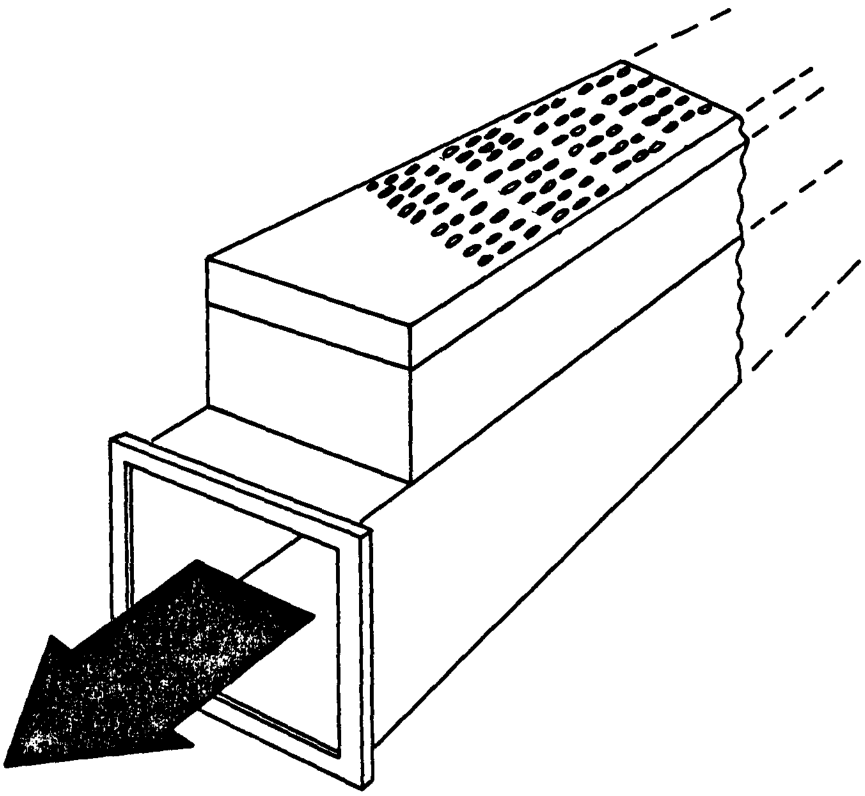

Figure 2-7 Dry suction boxes are placed just before the couch roll, and have the highest vacuum pumping rates of all. Because of the high working stresses, the ceramic elements on dry suction boxes are usually thicker than in the other drainage elements.

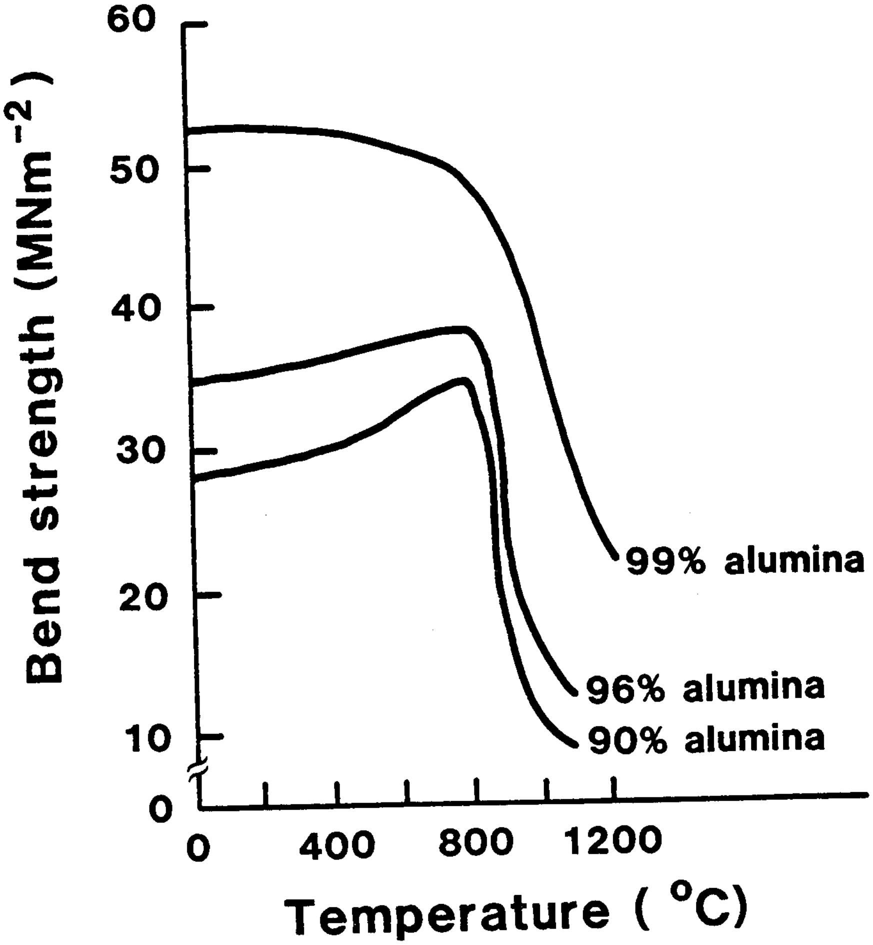

Figure 2-8 Bend strength of alumina as a function of temperature. Strength is significantly affected by the ceramic purity level

[Reference 4, reprinted by permission of Elsevier Science Publishing Co., Inc.]

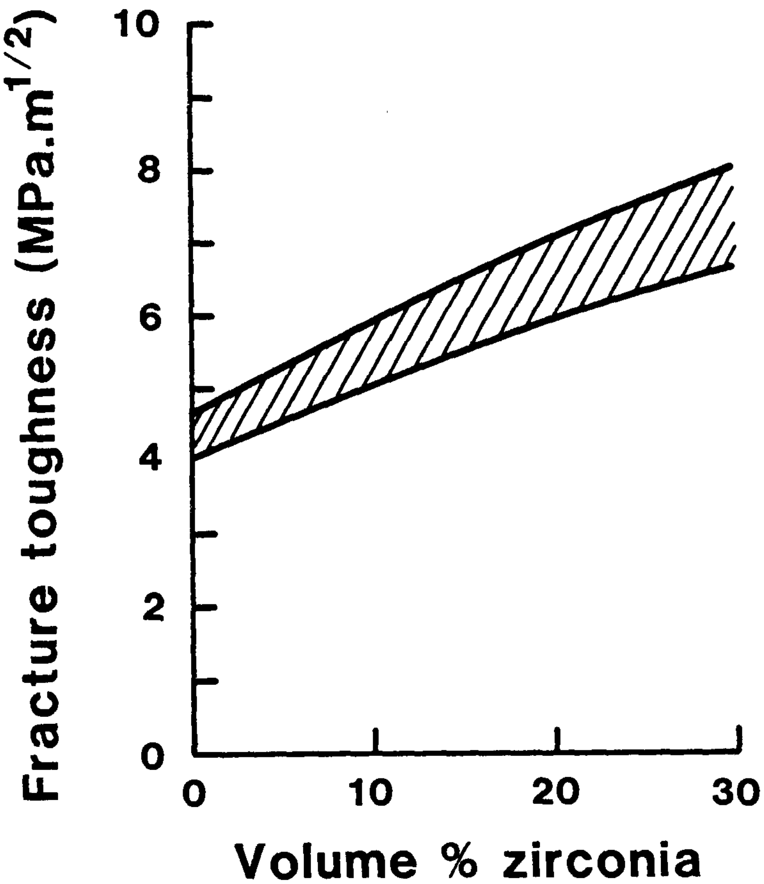

Figure 2-9 Fracture toughness of alumina as a function of zirconia content. Substantial improvements in toughness are obtained by the addition of 5 to 30% vol. zirconia. [reference 5].

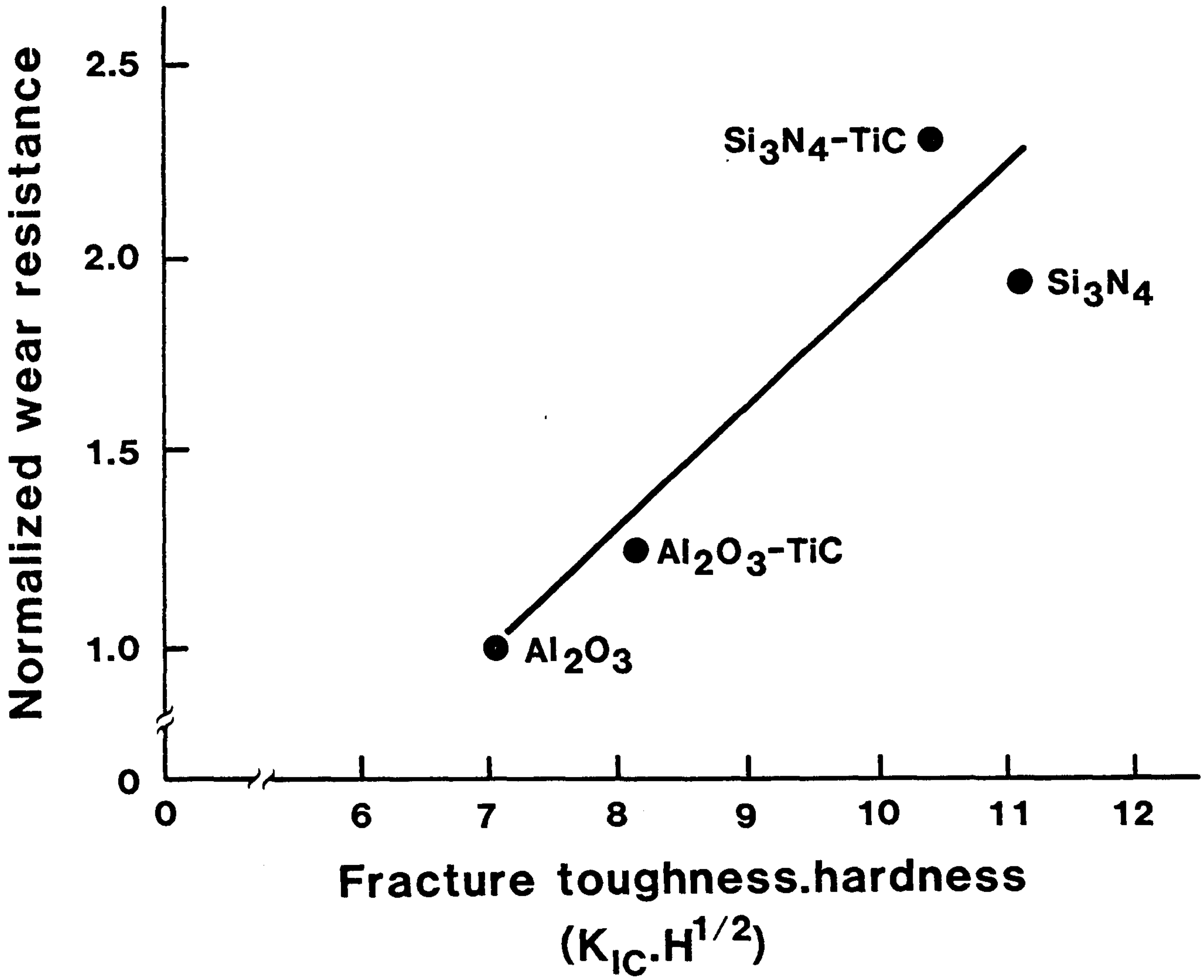

Figure 2-10 Wear resistance of a range of ceramics, as a function of fracture toughness and hardness. Generally, the wear resistance of ceramics improves with increasing hardness and toughness [reference 6, reprinted by permission of Plenum Press].

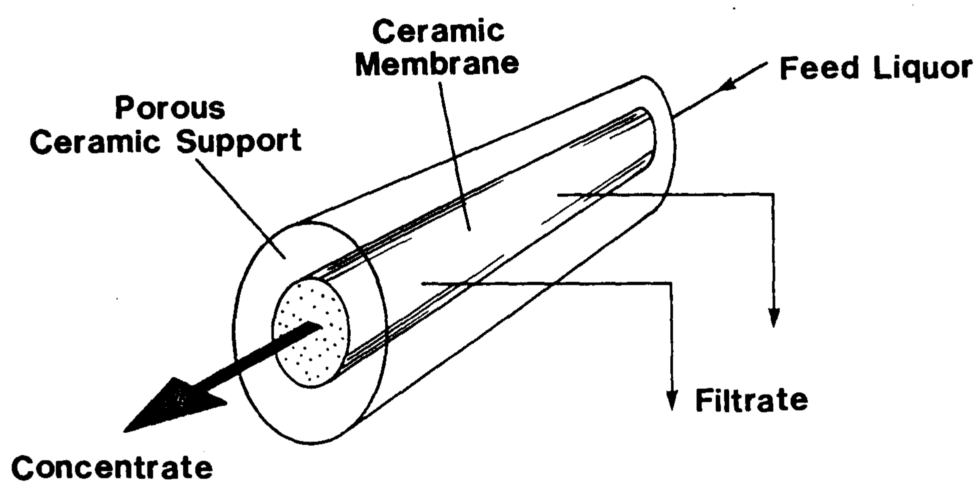

Figure 2-11 A schematic of a ceramic membrane filter element.

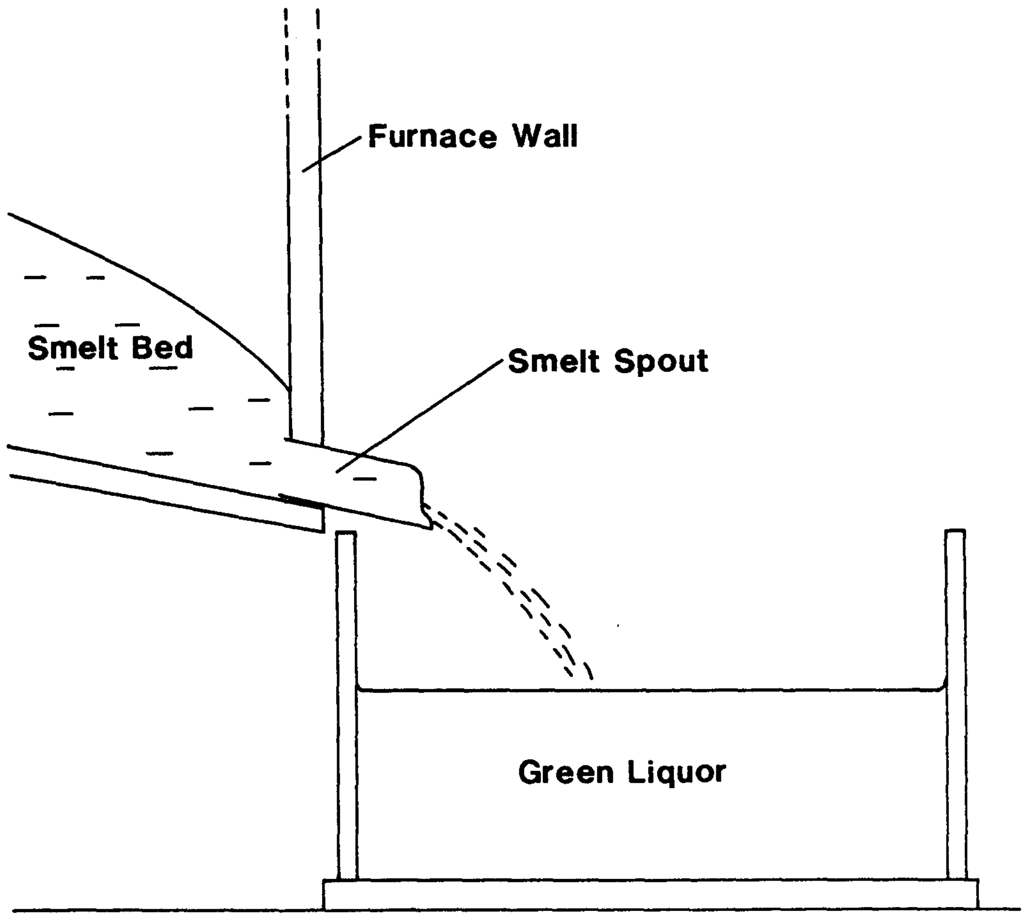

Figure 2-12 A recovery boiler smelt spout channels molten smelt from the smelt bed of the boiler into the dissolving tank.

CONCLUSIONS

1. Advanced ceramics are already well-established in the pulp and paper industry for specific applications. Generally, however, mill engineering staff are not familiar with either the ceramics being used in their mill or the range of properties available from advanced ceramic materials. The industry is almost totally reliant on suppliers for expertise in the use of advanced ceramics.

2. The survey has shown that there are significant areas of opportunity in the pulp and paper industry for either the application of existing ceramics technology, or for innovative research and development.

3. At present, the most fruitful area for the development of new applications for advanced ceramics is the paper machine.

4. The nature of the pulp and paper industry is such that, for many areas of opportunity, the cooperation and/or participation of the original equipment manufacturer will be crucial to the successful introduction of advanced ceramic components.

5. Generally, there appear to be more applications for ceramic coatings than for monolithic ceramics.

6. In some application areas, such as kraft cooking and recovery boiler operations, there are little data available on the corrosion resistance of candidate advanced ceramic materials. This lack of data is a significant barrier to the possible introduction of these materials.

Recommendations for Research and Development: Wood Preparation

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Jack-ladder chains	●				Not a suitable application for either monolithic or sprayed ceramics. Very limited market.
Spike roll teeth		●			Wear application. Low-cost ceramic inserts may compete with existing cast metal or metal hardfacings.
Debarker drums	●				High impact loadings; not a suitable application for ceramics.
Chipper knives			●		Primarily an application for coatings. High impact/wear area. Corrosion also a concern. Must compete with tool steels.
Pneumatic chip-line elbows		●			Opportunity for one-piece or near net-shape forming routes to compete with present tiles or plates. A diminishing market as mills turn to conveyors.
Hog hammers		●			High wear/impact area. Ceramic components must compete with short lifetime, low cost, steels presently used.
Shredder knives		●			As for hog hammers

Recommendations for Research and Development: Pulping (mechanical, chemical, repulping)

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Grindstones				●	Advantageous if advanced ceramics can increase pulping efficiency, or reduce need for stone re-sharpening/ conditioning. Mature technology; market penetration difficult
Refiner plates			●		Primarily an application for coatings. High impact loadings are a problem. Must compete with stainless steels, white cast irons.
Refiner plate gap sensor		●			
Screw feeder surfaces		●			Protection of wear surfaces by coatings or tiles. Low friction surfaces advantageous to reduce power consumption.
Rotary chip feed valves		●			Primarily an application for coatings. Low-friction surfaces advantageous to reduce power consumption. Must compete against metal hardfacings.
Chip cyclones			●		Possible application for slip-cast ceramic overlays to protect steel from erosion.
Digester linings	●				
Digester liquor control valves			●		Probably most applications would be for coatings. Corrosion resistance is an important factor.
Pulper		●			The possible use of protective ceramic liners on the bottom and lower sides of pulpers should be examined.

Recommendations for Research and Development: Stock Preparation

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Centrifugal cleaners		●			Ceramic cleaners are already established. Materials selection and alternative production routes, such as slip casting, may provide cheaper products of equivalent, or better, wear resistance.
Stock tank linings	●				Not an applicable area for advanced ceramics.
Bleach tower linings	●				Not an applicable area for advanced ceramics.
Bleach chemical storage tanks	●				
Seals			●		Many applications in a mill; well-established technology. A general opportunity for materials development.
Repulper stock pumps			●		Wear application. Ceramic coatings or solid ceramic components should be investigated. Spin-off applications to other industries.

Recommendations for Research and Development: Pulp and Paper Machines

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Stationary ceramic elements (foils, suction box covers, pick-up shoes etc.)			●		Considerable R&D has gone into this area. Main future emphasis should be on use of coated, versus monolithic, ceramics.
Granite rolls			●		Of concern to both papermakers and machine builders. Large size precludes monolithics. One patented thermal spray-coated roll already exists.
Yankee dryer, Impulse dryer cylinders			●		A demanding application for coatings. Requires thermal conductivity and sheet release properties as well as wear resistance. Must compete with existing thermal spray metallic coatings. Electrical conductivity needed for impulse dryer.
Dryer rotary joints		●			Opportunities for materials development.
Siphon nozzles		●			As for rotary joints.
Sensors		●	●		Considerable interest in sensors within the industry. A general area of opportunity for niche markets.
Infra-red radiant heaters			●		More efficient radiant heaters will be required as machine speeds increase. Fairly limited market at present.
Doctor blades		●			Opportunities for short-term coatings applications. Tissue doctoring especially severe. Plasma-spray ceramic-tipped doctors already available.

Recommendations for Research and Development: Recovery and Power Generation

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Recovery boiler anti-corrosion coatings				●	Coatings require combined thermal conductivity and high-temperature corrosion resistance. Large boiler size demands economic coating method.
Smelt spouts			●		Possible application for coatings or monolithics, but extreme service conditions.
Lime kiln refractories	●				Not an applicable area for advanced ceramics.
Mud pumps, valves			●		Niche market for coatings.
Grate blocks (hog fuel boilers)		●			Short-term development, but probably a limited market.
Hog fuel boiler feed screws		●			Again, may be a limited market, depending on boiler design. Application for coatings or monolithic ceramic pieces to protect screws from hot abrasive wear. Has to compete with metallic hardfacings.

Recommendations for Research and Development: Environmental

		R&D Time Scale			
Application	Ignore	Near	Medium	Long	Comments
Ceramic membranes			●		Potential use for ultra-filtration of mill effluent exists, but probably requires significant reduction in mill water usage. Other potential applications, such as cooking liquor clarification, should also be evaluated.

Recommendations for Research and Development: Strategy, Funding etc.

	Time Scale			
Item	Near	Medium	Long	Comments
Product liability	●	●	●	Needs to be addressed prior to any trials. Requires links between OEM's and ceramics manufacturers.
Peer review of survey	●			A priority issue, to get an unbiased critique of the survey conclusions and recommendations from all parties (government, mills, research, manufacturing).
Funding	●	●	●	Unlikely that individual companies will be able to undertake many of the R&D opportunities identified by the survey. Joint ventures and cooperative research programs are seen as more likely of success.
Technology transfer	●	●	●	Input/cooperation of OEM's will be vital to successful technology transfer in many applications. Paprican has established technology transfer paths to its maintaining members. As many OEM's are offshore based, technology transfer out of the country must be considered.
International collaboration				Should be pursued as appropriate.
Recycling	●			The contribution of advanced ceramics to recycling could not be addressed during the survey, due to circumstances outside the control of the survey team. This issue needs to be considered in the near term, due to the growing importance of recycling to the Canadian industry.
Environmental issues	●			Again, the importance of this subject to the Canadian pulp and paper industry, both now and in the foreseeable future, is such that the use of advanced ceramics should be studied in greater depth than was possible in this survey.

APPENDICES

APPENDIX 1

REFERENCE SOURCES FOR COMPLETE LISTINGS OF PULP AND PAPER-RELATED EQUIPMENT SUPPLIERS, REPAIRERS AND INSTALLERS.

Reference sources for complete listings of pulp and paper-related equipment suppliers, repairers and installers.

1. Pulp and Paper Canada Annual and Directory
Pulp and Paper Canada
3300 Cote Vertu, Suite 410
St. Laurent, Quebec H4R 2B7
Tel (514) 339-1399
Fax (514) 339-1396

2. Pulp and Paper Journal Annual Directory
Pulp and Paper Journal
777 Bay Street
Toronto, Ontario M5W 1A7
Tel (416) 596-5787
Fax (416) 593-3193

3. Fraser's Canadian Trade Directory
777 Bay Street
Toronto, Ontario M5W 1A7
Tel (416) 596-5086

4. Lockwood-Post's Directory of the Pulp, Paper and Allied Trades
Miller Freeman Publications Inc.
370 Lexington Avenue
New York, NY 10017
Tel (212) 683-9294
Fax (212) 725-0915

5. PPI International Pulp and Paper Directory
Miller Freeman Publications Inc.
600 Harrison Street
San Francisco, CA 94107
Tel (415) 905-2200
Fax (415) 905-2239

6. Phillips International Paper Directory
Benn Business Information Services Ltd.
PO Box 20, Sovereign Way, Tonbridge, Kent TN9 1RQ
England
Tel 0732 362666
Fax 0732 770483

APPENDIX 2

GUIDE TO PULP- AND PAPER-MAKING PROCESSES.

A PULP AND PAPER GLOSSARY

"Alphabet pulps": Chemi-Mechanical (CMP), Chemi-Thermomechanical (CTMP) and Thermomechanical (TMP) pulps are high-yield wood pulps that are used as partial or complete substitutes for more expensive chemical pulps, predominantly to produce newsprint and groundwood papers.

Bleached pulp: wood pulp that is whitened and brightened for further manufacture into products requiring these qualities.

Book, writing, and fine papers: a wide range of papers including printing papers, bond, ledger, duplicating, envelope, stationery, etc.; most are made of chemical wood pulps.

Chemical pulp: wood pulp produced by cooking wood chips under pressure and at high temperature in a chemical liquor.

Coated paper: paper coated with clay to achieve a glossy printing surface.

De-inking: a process that removes inks, clays, coatings, binders, and other contaminants from waste papers so that the fibres can be recycled into new products.

Kraft paper: strong and versatile, these papers are used for bags and packaging, and have many industrial applications.

Kraft pulp: chemical wood pulp noted for its strength and used to make wrapping papers, bags, sacks, and shipping containers; newsprint; printing and writing papers; and some paperboards, sanitary papers, food and milk containers and photographic papers.

Mechanical printing papers: made with mechanical pulp as the main furnish, these papers are usually uncoated (for directories, catalogues, and advertising inserts), often super-calendered (to take coloured ink), and sometimes coated (for magazines).

Mechanical pulp: wood pulp produced by mechanical methods such as grinding and refining, and used primarily to make newsprint and printing papers.

Newsprint: a relatively strong, opaque paper, able to absorb ink quickly, and designed for use on very fast printing presses.

Paperboard: light but strong, this category of packaging materials includes boxboard, used to make detergent, milk and juice containers, candy and shoe boxes; and containerboard, used to make shipping cases.

Recycling: the return of once-used material for reprocessing into new products. In the paper industry, recycling refers to the process involved in making new paper and paperboard out of previously used paper and paperboard, including in-plant and post-consumer waste, that would otherwise require disposal as solid waste.

Super-calendered: paper treated to achieve a smooth, glossy printing surface.

Tissue and sanitary papers: Generally absorbent, bulky and soft, these papers are used to make sanitary disposable products such as facial and bathroom tissue, napkins and towels.

Source: CPPA. Reproduced by permission.

PULP AND PAPERMAKING OPERATIONS

Pulp and paper mills in Canada encompass a wide range of activities. This appendix outlines the production of the two major products, i.e. newsprint and kraft. A brief description of sulphite pulping is also included. The appendix starts with wood preparation.

1. WOOD PREPARATION

All pulp mills require a source of fibre, either in the form of logs or chips. Many pulp and paper companies do their own tree harvesting, transporting the logs to the mill site by either truck, train, barge or as water-borne rafts. The area of tree harvesting is outside the scope of this paper, although advanced ceramics are of interest in wood-cutting technology. Further information on forest engineering may be obtained from the Forest Engineering Research Institute of Canada, Pointe Claire, Quebec, or Forintek Canada Corporation, Vancouver, B.C.

Once on the mill site, the logs go through various operations, including slash cutting to size, debarking and chipping. De-barking operations are usually carried out by tumbling the logs in a long steel drum; the bark is removed largely by the rubbing and impacting of the logs against each other. De-barking is increasingly a "dry" process, in order to avoid the disposal problems associated with large volumes of sludge. The change of wet to dry has, however, probably increased the amount of abrasive wear taking place in the wood room.

With the exception of stone groundwood operations, where the logs are cut to fit the grinder magazines, logs are chipped after being de-barked. Chipping is done by forcing the logs against rotating blades. In chemical pulping, chip size is important as it influences the diffusion rate of pulping liquors into the wood. Similarly, chipping efficiency is also important, as the production of undersize chips or fines will tend to clog-up the pulping vessels, impeding the passage of chemicals and heating steam. Therefore, chipper knives are frequently replaced, sometimes after as little as eight hours.

After washing and screening, chips are taken from the wood preparation area to other parts of the mill, typically by either pneumatic blow-lines or conveyor belts. Blow lines are energy intensive and can produce chip damage, and are becoming less common. Chips are usually stored in large chip piles before being used. An increasing trend is for mills to buy in chips from sub-contractors, thus avoiding the need for a wood-preparation area on the mill site. The transport of chips over long distances may increase the washing requirements, to avoid a higher abrasive content in the mill process streams.

2. NEWSPRINT MILL OPERATIONS

Newsprint is made from a variety of pulp furnishes. A general flow sheet is shown in Figure A-1. The oldest furnish is stone groundwood pulp reinforced with sulphite pulp. Stone groundwood pulp is an example of a mechanical pulp. Sulphite, like kraft, is made by cooking the wood in pressure vessels, and is thus a chemical pulp. Mechanical pulping has undergone considerable development in recent years. The stone groundwood method, in which logs are pressed against a rotating grindstone, is still an important sector of the industry; in 1987 stone groundwood capacity was 5.5 million tonnes compared to about 4.9 million tonnes for atmospheric and TMP refiners. Refiner pulps are stronger and freer than groundwood pulps, but darker, thus requiring additional brightening. Stone groundwood is also significantly less energy-intensive than refiner pulping. A schematic groundwood operation is shown in Figure A-2.

In refiners, pulp is produced by passing wood chips between two or more closely-spaced serrated disks, at least one of which is being rotated at high speed by an electric motor. Each disk is made by bolting refiner plates onto a backing plate. The working surface of a typical refiner plate is composed of a series of raised bars, against and over which the wood chips are broken down and fiberized. Figure A-3 shows some different types of disk refiners.

After pulping, the newsprint furnish goes through a variety of stages en-route to the paper machines, including latency removal, blending, brightening, cleaning and storage.

The paper machines are the heart of a newsprint mill, and they have undergone considerable development in recent years to meet the demands for higher machine speeds, increased machine utilization and improved product quality. Perhaps the single biggest change in paper machine design has been the shift from a single, horizontal forming section at the wet end (i.e. the fourdrinier) to the twin-wire concept, in which the fibre-water slurry from the headbox is fed into the converging gap between two forming fabrics. The advantages of twin-wire systems include greater dewatering capacity, better sheet formation and less two-sidedness.

The newsprint machine has five main sections, the wet-end, the press, the dryers, the calender and the winder-slitter. In the wet end, the following operations take place:

- introduction of the water-pulp furnish onto the machine.
- formation of the paper web.
- removal of water by dynamic drainage elements (i.e. table rolls) and/or stationary drainage elements (i.e. foils, blades, suction boxes), and a suction couch roll.

At the end of the wet-end, the paper sheet can contain up to about 20% solids. The following operations take place in the press:

- further removal of water by squeezing the paper between a press roll (i.e. a granite roll) and a suction roll or grooved or blind-drilled rolls. These latter types of rolls have either holes (through-drilled or blind) or circumferential grooves to carry away the expressed water. The paper is carried through the press by felts, which also help absorb and remove the expressed water.
- surface smoothing of the paper. Dependant on the machine design, smoothing is either on one or both sides of the sheet.

At the end of the press section, the paper sheet contains about 40% solids. The sheet is then transferred to the dryer section. Using another set of felts, the paper is passed over a series of steam-heated rotating cast iron cylinders each about 1 - 1.5 m in diameter. A newsprint machine may typically have about thirty to forty dryer cylinders.

At the end of the dryer section, the paper contains about 93% solids, and passes into the calender, a series of smooth rolls which optimize the surface finish and thickness of the paper by plastic deformation of the outer fibre layers. Calender rolls can be either hard (e.g. chilled cast iron) or soft (e.g. polymeric), heated or unheated. A typical calender stack may contain three to five rolls, with the paper passing between them unsupported by any fabric or felt.

The finished paper sheet is wound into a reel after coming off the calender. Typically, a finished reel would have a diameter of about 1.5 - 2 m. After building, the completed reel is transferred to a re-winder, where it is slit into the smaller- size rolls required by the mill's customers. Slitting of newsprint is done using circular disc slitters.

<u>Other types of paper machines</u>

a) <u>Kraft pulp</u>

A kraft pulp machine has some similarity to a newsprint machine, but is significantly slower-running. The sheet is also considerably thicker than in the case of newsprint. Because of its thickness, the pulp sheet is usually dried in an air float dryer rather than by using dryer cylinders. In the air float dryer, the pulp sheet passes over a series of blow boxes. Hot air forced through the boxes both supports and dries the sheet as it passes by. A calender is not used on a kraft pulp machine. The sheet is also cut to size and stacked as it exits the machine, as opposed to being formed into reels.

b) Coated paper

Coating of paper can be done either on-machine or off-machine; as a general rule, on-machine operations are best suited for light- to moderate-weight coatings. Various systems exist for applying coatings; in many cases, the same technology is used for either on- or off-machine operations. Systems include; roll coaters, air-knives, and blade coaters.

Drying of coated paper must not damage the coated surface(s). Drying systems include conventional steam-heated cylinders with high-velocity convective hoods, tunnel dryers and gas-fired infra-red heaters.

c) Paperboard:

A characteristic of these machines is their ability to make multi-ply sheet, in some cases up to seven different layers in a finished sheet being possible. The separate plies are created by multiple forming sections, either as headboxes or cylinder formers. Because of the heavier, thicker, sheet being formed, there are usually more drainage elements in the wet-end than are found on newsprint machines. Other sections of the machine, such as the press, dryers, etc., are generally comparable to those on other paper machines.

d) Tissue

Tissue machines run significantly faster than newsprint machines; speeds in excess of 1800 m/min are typical. These higher speeds are possible because of the lower basis weight of tissue compared to other grades, and the high drying rates required to create the tissue product. In contrast to a newsprint machine, where the sheet is dried by passing over numerous dryer cylinders, a tissue machine typically has only one large dryer, the "Yankee dryer". A Yankee dryer is a large (i.e. 4-5 m) diameter steam-heated cast iron cylinder. The top of the Yankee is enclosed in a hood through which high-velocity hot air is passed. Drying therefore occurs from both sides of the sheet. The tissue is removed from the surface of the Yankee by a heavily-loaded doctor blade. This doctoring causes the tissue to crepe as it leaves the dryer; the creping action is an essential part of the tissue-making operation.

3. KRAFT PULP

A general flowsheet is shown in Figure A-4. Chips are cooked, or pulped, in large steel pressure vessels called digesters. Digesters may be either of the batch or continuous type. The cooking liquor is essentially a strong caustic solution containing sodium sulphide and some sodium sulphate; fresh cooking liquor is called "white liquor" to distinguish it from other kraft process streams. Cooking is carried out at elevated temperatures (typically 155-175°C). Once cooked, the chips are discharged out of the digester to atmospheric pressure. As they leave the digester, the chips impact against a target plate, as a mechanical aid to fibre separation.

Liquor coming out of the digester with the cooked chips contains a high concentration of organic compounds and is termed "black liquor". An essential part of the kraft process is the recovery of cooking chemicals from the black liquor. Recovery starts by evaporating the black liquor to increase its solids content to about 65% and then using the liquor as a fuel in a recovery boiler. The recovery boiler serves two purposes. First, it produces steam for power generation and mill use. Secondly, combustion of the black liquor produces a smelt containing both sodium sulphide (from reduction of the inorganic sulphur compounds in the liquor) and sodium carbonate (from reduction of the sodium organic compounds in the liquor).

Molten smelt is continuously drained-off during operation of the boiler, and allowed to fall into a dissolving tank containing weak wash liquor, to form "green liquor". After clarification, the green liquor is reacted with lime to convert the sodium carbonate back to sodium hydroxide. The resultant sodium hydroxide/sodium sulphide solution is then clarified again to remove precipitated lime mud (calcium carbonate) and recycled as white liquor for further cooking. Meanwhile, the calcium carbonate is fed into a rotary kiln for calcining back to calcium oxide. Kiln temperatures range from 300°C to 1150°C, with a refractory lining being used in the hot zones.

After cooking and washing, the kraft pulp is bleached. Traditionally, bleaching uses chlorine, chlorine dioxide and sodium hydroxide to achieve the required degree of whiteness; alternative bleach reagents such as oxygen and hydrogen peroxide are now becoming common as well. As may be imagined, corrosion is the main materials concern in the bleach plant, with highly-alloyed stainless steels, nickel-base alloys and titanium being used for fabrication of the process plant. Glass-reinforced plastics are widely used for piping and filtrate storage vats. Large towers lined with ceramic tiles are used to contain the pulp during the various bleaching stages.

4. SULFITE PULPING [+]

Sulfite chemistry

Sulfite pulping liquors are prepared by dissolving SO_2 in a solution of calcium, sodium, magnesium, or ammonium hydroxide. The pH of the resultant cooking liquor depends on the base and the amount of SO_2 dissolved, and it can range from 1 to above 13. The exact value is chosen according to the particular mill process and the desired pulp characteristics. Fresh sulfite liquor is essentially a mixture of sulfite and bisulfite ions in an aqueous solution of SO_2. The ratios of these three components can vary widely, according to the liquor pH. Bisulfite dominates at pH values less than 6, while sulfite ions dominate at pH values above 7. The concentration of aqueous SO_2 also increases at lower pH's.

Traditional sulfite pulping

For many years, most sulfite mills used a calcium hydroxide base cooking liquor, mainly because of the economy of the calcium carbonate feedstock. The calcium-base process is restricted to very low pH (typically 1.5) and low cooking temperatures (140 to 150°C) because of scaling and solubility problems. Furthermore, the process is difficult to adapt to high-yield pulping. These reasons, as well as increasingly stringent antipollution legislation, have led to the expanded use of soluble sodium, magnesium, and ammonium bases in recent years.

A typical sulfite operation is as follows:

Sulfur (either in powder or liquid form) is burned to produce SO_2. The gas is cooled rapidly to minimize the formation of sulfur trioxide (SO_3) and then passed into absorption towers, where it is dissolved in the hydroxide base to form the raw pulping liquor. Pulping is carried out in either batch or continuous digesters; when the cook is complete, the chips are released into a blow tank. The chips are then taken for washing, screening, and bleaching as required. The spent cooking liquor (red liquor) can be evaporated and burned in a furnace for steam generation and/or recovery of cooking chemicals, or it can be further treated to obtain chemical by-products. A typical operation might also include equipment for SO_2 recovery from the cook and an acid accumulator.

Recent developments in sulfite mills have centred around the need to decrease pollution, to increase pulping efficiency (that is, increase the proportion of usable fibre obtained per cook), and

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[+] C.B. Thompson and A. Garner, Metals Handbook, 9th Edition, Volume 13, p. 1196. Reprinted by permission of ASM International.

to adapt to market demands for specific grades of pulp. These requirements have resulted in a variety of processes, such as high-yield sulfite pulping and chemi-thermomechanical pulping, in which sulfite chemical treatment of the chips is combined with additional treatment of the fibre in a disk refiner. An important practical point to note is that high-yield and very high-yield sulfite pulping require the use of a digester, but chemi-mechanical and chemi-thermomechanical pulping use smaller impregnation vessels or steaming tubes for pretreatment of the chips.

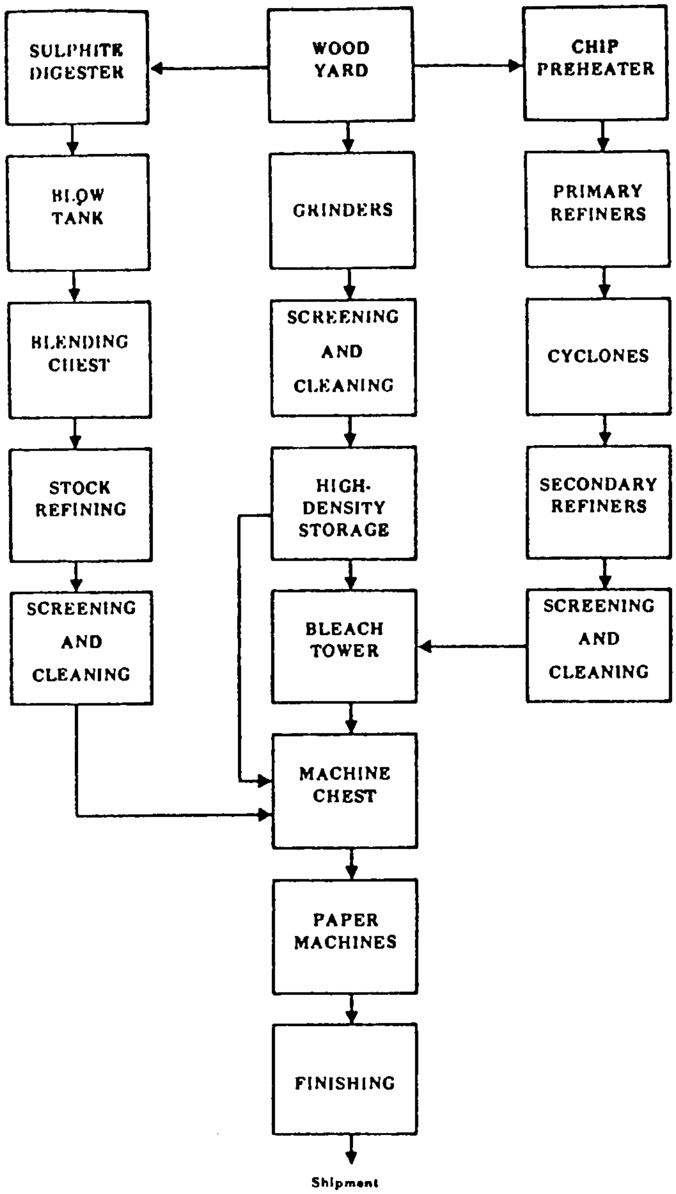


Figure A-1 A general flowsheet for a newsprint operation. Note that not all newsprint operations will have the three processes combined, as shown above. Some may run a combination of sulphite plus stone groundwood, others will run 100% refiner pulp.

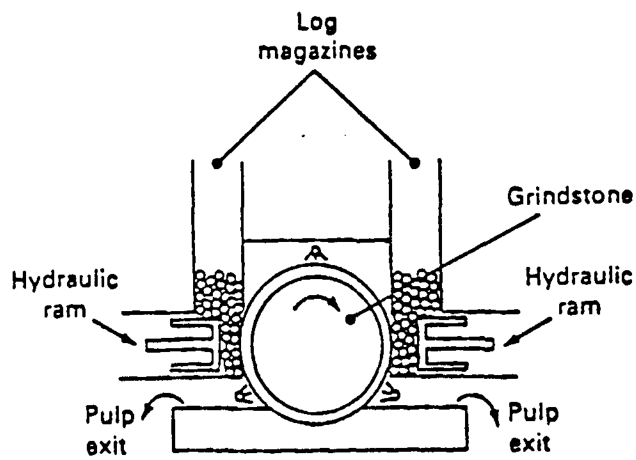


Figure A-2 Schematic cross-sectional view of a stone groundwood machine. The debarked logs are held in magazines, from which they are pressed against the rotating grindstone to be pulped. Cooling water is applied to the grindstone by shower lines.

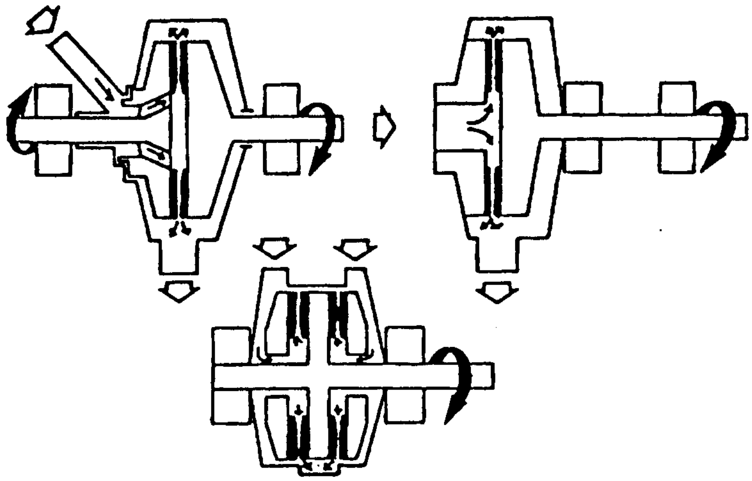


Figure A-3 Cross-sectional arrangements of three different types of refiner. The refiner plates are shown in black. The direction of stock flow is indicated by the small arrows.

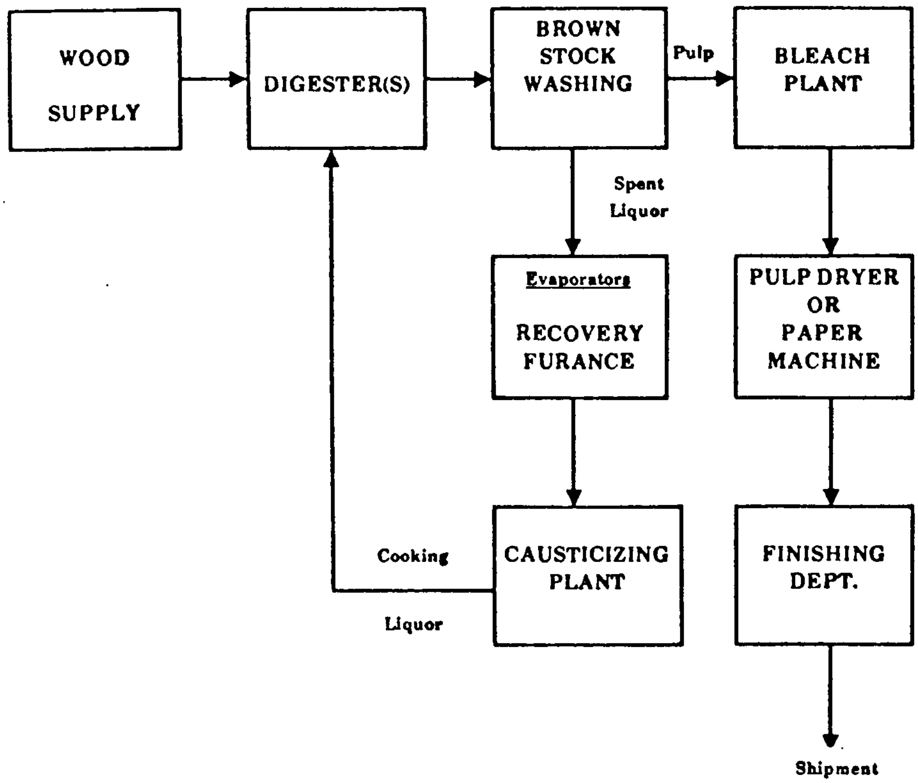


Figure A-4 A general flowsheet for a kraft mill.

APPENDIX 3

a) LIST OF CANADIAN PULP AND PAPER COMPANIES

b) AN OVERVIEW OF THE CANADIAN PULP AND PAPER INDUSTRY

ABITIBI-PRICE INC.

Newsprint, groundwood papers, sanitary and coated papers

Head Office, Trade Enquiries and Mailing Address:
207 Queen's Quay West, Suite 680, P.O. Box 102
Toronto, Ontario M5J 2P5
Tel.: 416-369-6700 Telex: 065-24264 Cable: ABITIBIPA
Telecopier: 416-369-6794

Mills:
Pine Falls, Manitoba; Grand Falls, Stephenville, Newfoundland; Georgetown, Iroquois Falls, Thunder Bay, Ontario; Alma, Beaupré, Kénogami, Lachute, Québec

ATLANTIC PACKAGING PRODUCTS LTD.

Containerboard, boxboard and sanitary papers

Head Office, Mill and Trade Enquiries:
111 Progress Avenue, Scarborough, Ontario M1P 2Y9
Tel.: 416-298-8101 Telex: 065-25269

BENNETT FLEET INC.

Boxboard, containerboard, miscellaneous and specialty boards

Head Office:
Division QUÉBEC
380, rue Fortin, Ville de Vanier (Québec) G1M 1B1
C.P. 394, Succursale postale St-Sauveur
Québec (Québec) G1K 6W8
Tel.: 418-681-4163 Telecopier: 418-681-1468

Mill and Trade Enquiries:
Division CHAMBLY
2700, Bourgogne, Chambly (Québec) J3L 4B6
Tel.: 514-658-1771
Telecopier: 514-658-5037

BOISE CASCADE CANADA LTD.

Newsprint, bleached kraft pulp, groundwood specialty printing papers.

Head Office:
Boise Cascade Canada Ltd.
P.O. Box 227
Suite 1807, Scotia Plaza
40 King Street West
Toronto, Ontario M5H 3Y2
Tel.: 416-360-6111 Telecopier: 416-360-1979

Fort Frances Region:
Boise Cascade Canada Ltd.
145 Third Street West
Fort Frances, Ontario P9A 3N2
Tel.: 807-274-5311 Telecopier: 807-274-6596

Kenora Region:
Boise Cascade Canada Ltd.
P.O. Box 5000, 504 - 9th Street North
Kenora, Ontario P9N 3Y1
Tel.: 807-468-6411 Telecopier: 807-468-6168

Mills:
Fort Frances, Kenora, Ontario

BOWATER MERSEY PAPER COMPANY LIMITED

Newsprint and groundwood papers

Head Office, Mill and Trade Enquiries:
P.O. Box 1150, Liverpool, Nova Scotia B0T 1K0
Tel.: 902-354-3411 Cable: NUSEPRINT
Telecopier: 902-354-2271

CANADIAN FOREST PRODUCTS LTD.

Pulp, kraft papers, hardboard and chemicals

Head Office and Trade Enquiries:
2800 - 1055 Dunsmuir Street
P.O. Box 49420, Bentall Postal Station
Vancouver, British Columbia V7X 1B5
Tel.: 604-661-5241 Cable: CANFOR HO VCR
Telecopier: 604-661-5226

Mills:
New Westminster, Prince George, British Columbia

CANADIAN PACIFIC FOREST PRODUCTS LIMITED

Newsprint, uncoated mechanical paper, pulp, containerboard, solid bleached paperboard, white paper, sanitary papers, lumber and chemicals

Executive Offices and Trade Enquiries:
1155, rue Metcalfe
Montréal (Québec) H3B 2X1
Tel.: 514-878-4811 Telex: 055-60635
Telecopier: 514-878-4850

P.O. Box 430
Thunder Bay, Ontario P7C 4W3
Tel.: 807-475-2110 Telex: 073-4576
Telecopier: 807-475-8643

1000 - 1040 West Georgia Street
Vancouver, British Columbia V6E 4K4
Tel.: 604-640-3400 Telex: 04-53285
Telecopier: 604-684-1026

Mills:
Gold River, British Columbia; Calgary, Alberta; Dryden, Thunder Bay, Toronto, Rexdale, Markham, London, Burlington, Ontario; Gatineau, La Tuque, Matane, Trois Rivières, Vaudreuil, St-Léonard, Pointe-aux-Trembles, Quebec; Dalhousie, New Brunswick; East River, Nova Scotia; Usk, Washington.

CARIBOO PULP & PAPER COMPANY

Pulp

Head Office and Trade Enquiries:
1055 West Hastings Street, P.O. Box 2179
Vancouver, British Columbia V6B 3V8
Tel.: 604-687-7366 Telex: 04-508846

Mill:
Quesnel, British Columbia

CASCADES INC.

Boxboard and containerboard

Head Office and Mill:
404, rue Marie Victorin, C.P. 30
Kingsey Falls (Québec) J0A 1B0
Tel.: 819-363-2245 Telex: 05-268593

Trade Enquiries:
2100, rue Drummond, bureau 520
Montréal (Québec) H3G 1X1
Tel.: 514-282-0520 Telex: 055-61434

CASCADES (EAST ANGUS) INC.

Kraft, building and specialty papers and folding boxboard

Head Office:
404, rue Marie Victorin, C.P. 30
Kingsey Falls (Québec) J0A 1B0
Tel.: 819-363-2245 Telex: 05-268593

Trade Enquiries:
1, Place Ville Marie
Bureau 3615
Montréal (Québec) H3B 3P2
Tel.: 514-393-4160 Telecopier: 514-393-4164

Mill:
East Angus, Québec

CASCADES (JONQUIÈRE) INC.

Boxboard and pulp

Head Office:
404, rue Marie Victorin, C.P. 30
Kingsey Falls (Québec) J0A 1B0
Tel.: 819-363-2245 Telex: 05-268593

Trade Enquiries:
1, Place Ville Marie
Bureau 3615
Montréal (Québec)
H3B 3P2
Tel.: 514-393-4160 Telecopier: 514-393-4164

Mill:
Jonquière, Québec

CELGAR PULP COMPANY

Pulp

Head Office:
P.O. Box 1000, Castlegar, British Columbia V1N 3H9
Tel.: 604-365-7211 Telex: 041-554

Trade Enquiries:
Consolidated Celgar Inc.
800, boul. René-Lévesque ouest, Montréal (Québec) H3B 1Y9
Tel.: 514-875-2160 Telex: 055-61502
Telecopier: 514-875-2160, local 375

CITIC BC Inc.
1870 - 401, West Georgia Street
Box 139, Vancouver, British Columbia V6B 5A1
Tel.: 604-681-7204 Telex: 045-08719
Telecopier: 604-681-7230

Mill:
Castlegar, British Columbia

CRESTBROOK FOREST INDUSTRIES LTD.

Pulp

Head Office:
P.O. Box 4600, Cranbrook, British Columbia V1C 4J7
Tel.: 604-426-6241 Telex: 041-45114
Telecopier: 604-426-7055

Trade Enquiries:
Suite 1200 - 1055 West Hastings Street
Vancouver, British Columbia V6E 2E9
Tel.: 604-685-3221 Telex: 04-507518
Telecopier: 604-685-1340

Mill:
Skookumchuck, British Columbia

DAISHOWA FOREST PRODUCTS LTD.

Newsprint, pulp, boxboard, kraft papers and chemicals

Head Office and Trade Enquiries:
Suite 880, 207 Queen's Quay West, Toronto, Ontario M5J 1A7
Tel.: 416-862-5000 Telex: 065-24326
Telecopier: 416-862-7051

Mill:
Québec, Québec

DOMTAR INC.

Pulp, kraft, book, coated and writing papers, specialty, envelope, blotting, building and miscellaneous papers, bristols, newsprint and groundwood papers, boxboard, containerboard, rigid insulating board, miscellaneous and specialty boards

Head Office:
395, boul. de Maisonneuve ouest, Montréal (Québec) H3A 1L6
Tel.: 514-848-5400

Trade Enquiries:
Fine, printing and specialty papers:
Domtar Inc.
Fine Papers Division
395, boul. de Maisonneuve ouest, Montréal (Québec) H3A 1L6
Tel.: 514-848-6709 Telecopier: 514-848-6776

Newsprint and groundwood papers:
Domtar Inc.
Newsprint & Kraft Pulp Division
395, boul. de Maisonneuve ouest, Montréal (Québec) H3A 1L6
Tel.: 514-848-5071 Telecopier: 514-848-5769

Pulp:
Domtar Inc.
Newsprint & Kraft Pulp Division
395, boul. de Maisonneuve ouest, Montréal (Quebec) H3A 1L6
Tel.: 514-848-5540 Telecopier: 514-848-5769

Corrugating medium and linerboard:
Domtar Inc.
Containerboard Division
6789 Airport Road, Malton, Ontario L4V 1N2
Tel.: 416-671-7200 Telecopier: 416-671-7410

Roofing and insulation products:
Domtar Inc.
Roofing and Insulation Products Division
2021, av. Union, 12ᵉ étage
Montréal (Québec) H3A 2S9
Tel.: 514-848-5985 Telecopier: 514-848-5084

Mills:
Cornwall, Mississauga, Red Rock, St. Catharines, Toronto, Trenton, Ontario; Beauharnois, Dolbeau, Donnacona, Lebel sur Quévillon, Windsor, Québec

DONOHUE INC.

Newsprint

Head Office:
801, chemin St-Louis, Québec (Québec) G1S 4W3
Tel.: 418-684-7700 Telecopier: 418-684-7707
Telex: 051-2234

Trade Enquiries:
As above, or:
Donohue Paper Sales Corporation
100 Jericho Quadrangle, Suite 105, Jericho, NY 11753
Tel.: 516-433-5000 Telex: 960960

Mill:
Clermont, Québec

DONOHUE CHARLEVOIX INC.

Newsprint

Head Office and Trade Enquiries
801, chemin St-Louis, Québec (Québec) G1S 4W3
Tel.: 418-684-7700 Telecopier: 418-684-7727
Telex: 051-2234

Mill:
Clermont, Québec

DONOHUE MALBAIE INC.

Newsprint

Head Office and Trade Enquiries:
801, chemin St Louis, Quebec (Quebec) G1S 4W3
Tel.: 418 684 7700 Telecopier: 418 684 7727
Telex: 051 2234

Mill:
Clermont, Québec

DONOHUE NORMICK INC.

Newsprint

Head Office and Trade Enquiries:
801, chemin St-Louis, Québec (Québec) G1S 4W3
Tel.: 418 684 7700 Telecopier: 418-684-7727
Telex: 051-2234

Mill:
Amos, Québec

DONOHUE ST-FÉLICIEN INC.

Pulp

Head Office:
801, chemin St-Louis, Québec (Québec) G1S 4W3
Tel.: 418-684 7700 Telecopier: 418-684-7727
Telex: 051-2234

Trade Enquiries:
As above, or:
Mead Pulp Sales
Courthouse Plaza Northeast, Dayton, Ohio 45463
Tel.: 513-222 6323 Telex: 288328

Mill:
St-Félicien, Québec

E.B. EDDY FOREST PRODUCTS LTD.

Kraft, book and writing papers, bristols, specialty, envelope and miscellaneous papers, pulp and chemicals

Trade Enquiries and Executive Office:
1335 Carling Ave., P.O. Box 3521, Station C
Ottawa, Ontario K1Y 4L5
Tel.: 613 725 6700 Telecopier: 613 725 6820

Mills:
Espanola, Ottawa, Ontario; Hull, Quebec

F. F. SOUCY, INC.

Newsprint and groundwood papers

Head Office and Trade Enquiries:
Newsprint Sales Ltd.
80 Field Point Road, Greenwich, Connecticut 06830
Tel.: 203 661 3344 Telex: 13 1473 Telecopier: 203 661 3349

Mill:
Rivière-du-Loup, Québec

FINLAY FOREST INDUSTRIES LTD.

Newsprint

Head Office:
P.O. Box 250, MacKenzie, British Columbia V0J 2C0
Tel.: 604 997 3201 Telecopier: 604 997 6723

Trade Enquiries:
Fletcher Challenge Canada Ltd.
10th Floor 700 West Georgia Street
P.O. Box 10058 Pacific Centre
Vancouver, British Columbia V7Y 1J7
Tel.: 604 654 4282 Telecopier: 604 654 4911 Telex: 04 51203

Mill:
MacKenzie, British Columbia

FLETCHER CHALLENGE CANADA LIMITED

Newsprint, groundwood papers, pulp, boxboard, containerboard, specialty, building and kraft papers

Head Office and Trade Enquiries:
10th Floor - 700 West Georgia Street
P.O. Box 10058 Pacific Centre
Vancouver, British Columbia V7Y 1J7
Tel.: 604 654 4000 Telecopier: 604-654 4327 Telex: 04 51203

Mills:
Campbell River, Crofton, Mackenzie, British Columbia

J. FORD & COMPANY LTD.

Kraft, tissue, building papers, coated papers, sanitary, miscellaneous and specialty papers

Head Office, Mill and Trade Enquiries:
Portneuf (Québec) G0A 2Y0
Tel.: 418 286 3361 Telex: 051 3933
Telecopier: 418 286 6874

FRASER INC.

Pulp, boxboard, book and writing, coated and miscellaneous papers

Head Office and Trade Enquiries:
27 Rice Street, Edmundston, New Brunswick E3V 1S9
Tel.: 506-735-5551 Telecopier: 506-739-8879

Mills:
Atholville, Edmundston, New Brunswick, Madawaska, Maine

GASPESIA PULP & PAPER COMPANY LTD.

Newsprint

Head Office:
2, Place Québec, Québec (Québec) G1R 4S1
Tel.: 418-647-1152 Telex: 051-3511

Trade Enquiries:
Abitibi-Price Inc., Newsprint Sales Division
207 Queen's Quay West, Suite 680, P.O. Box 102
Toronto, Ontario M5J 2P5
Tel.: 416-369-6700 Telex: 065-24264 Cable: ABITIBIPA
Telecopier: 416-369-6794

Mill:
Chandler, Québec

GLASSINE CANADA INC.

Specialty, writing and miscellaneous papers

Head Office and Mill:
C.P. 1783, 845, avenue Industrielle
Québec (Québec) G1K 7K7
Tel.: 418-522-8262 Telecopier: 418-648-2725

HOWE SOUND PULP AND PAPER LIMITED

Pulp and newsprint

Head Office, Mill and Trade Enquiries:
Port Mellon, British Columbia V0N 2S0
Tel.: 604-884-5223 Telex: 04-53154
Telecopier: 604-884-5363

IRVING PULP & PAPER, LIMITED

Pulp

Head Office and Trade Enquiries:
300 Union Street, Saint John, New Brunswick E2L 4M3
Tel.: 506-632-7777 Telex: 014-47262
Telecopier: 506-632-5113

Mill:
Saint John, New Brunswick

IRVING TISSUE COMPANY

Sanitary papers

Head Office and Trade Enquiries:
300 Union Street, Saint John, New Brunswick E2L 4M3
Tel.: 506-632-7777 Telex: 014-47262
Telecopier: 506-632-5113

Mill:
Saint John, New Brunswick

ISLAND PAPER MILLS COMPANY

Book and writing papers, kraft papers, envelope papers and coated papers

Head Office, Mill and Trade Enquiries:
P.O. Box 2170, 1010 Derwent Way, Annacis Island
New Westminster, British Columbia V3L 5A5
Tel.: 604-526-5521 Sales: 1-800-663-6200
Telecopier: 604-526-2356

JAMES MACLAREN INDUSTRIES INC.

Newsprint and kraft pulp

Head Office:
2, chemin Montréal ouest, Masson (Québec) J0X 2H0
Tel.: 819-986-3345 Telecopier: 819-986-5045
Mailing Address and Trade Enquiries:
Buckingham (Québec) J8L 2X3
Tel.: 819-986-3345 Telecopier: 819-986-5045

Mills:
Masson, Thurso, Québec

JAMES RIVER-MARATHON, LTD.

Pulp and chemicals

Head Office, Mill and Trade Enquiries:
Postal Bag "JR", Marathon, Ontario POT 2E0
Tel.: 807 229 1200 Telex: 067-7335
Telecopier: 807 229 2954

KRUGER INC.

Newsprint, coated paper, groundwood printing and specialty papers, containerboard and boxboard

Head Office and Trade Enquiries:
3285, chemin Bedford, Montréal (Québec) H3S 1G5
Tel.: 514-737-1131 Telex: 055-60579
Telecopier: 514-737-2941

Mills:
Corner Brook, Newfoundland; Bromptonville, Montreal, Trois-Rivières, Quebec; Rexdale, Ontario

LAKE UTOPIA PAPER, LIMITED

Containerboard

Head Office and Trade Enquiries:
300 Union Street, Saint John, New Brunswick E2L 4M3
Tel.: 506-632-7777 Telex: 014 47262
Telecopier: 506-632-5113

Mill:
St. George, New Brunswick

MACMILLAN BLOEDEL LIMITED

Newsprint, pulp, containerboard, hardboard and groundwood papers

Head Office and Trade Enquiries:
1075 West Georgia Street
Vancouver, British Columbia V6E 3R9
Tel.: 604 661 8000 Telex: 04 51471 Cable: HARMAC
Telecopier: 604 661 8377

Mills:
Nanaimo, Port Alberni, Powell River, British Columbia; Sturgeon Falls, Ontario

MINAS BASIN PULP & POWER COMPANY LIMITED

Boxboard and containerboard

Head Office, Mill and Trade Enquiries:
53 Prince Street, Hantsport, Nova Scotia B0P 1P0
Tel.: 902-684-3236 Telex: 019 32133 Cable: MINASBASIN

NORTHWOOD PULP AND TIMBER LIMITED

Pulp

Head Office and Mill:
P.O. Box 9000, Prince George, British Columbia V2L 4W2
Tel.: 604-962-9611 Telecopier: 604-962-3582

Trade Enquiries:
As above or:
Mead Pulp Sales
Courthouse Plaza Northeast, Dayton, Ohio 45463
Tel.: 513-222-6323 Telecopier: 513-461-0318

PAPERBOARD INDUSTRIES CORPORATION

Boxboard, containerboard, building papers and specialty boards

Head Office and Trade Enquiries:
Suite 600, 144 Front Street West, Toronto, Ontario M5J 1G2
Tel.: 416 596 7148 Telecopier: 416 977 4500

Mills:
Burnaby, British Columbia; Glen Miller, Toronto, Ontario; Montréal, Québec; Palmyra, Michigan

PAPIER CASCADES (CABANO) INC.

Containerboard

Head Office:
404, rue Marie-Victorin, C.P. 30
Kingsey Falls (Québec) J0A 1B0
Tel.: 819 363 2245 Telex: 05-268593

Trade Enquiries:
2100, rue Drummond, bureau 520
Montréal (Québec) H3G 1X1
Tel.: 514 282 0520 Telex: 055 61434

Mill:
Cabano, Québec

PERKINS PAPERS LTD.

Sanitary papers

Head Office and Trade Enquiries:
2345, Autoroute des Laurentides
Chomedey, Laval (Quebec) H7S 1Z7
Tel.: 514 688-1152 Telex: 055 60965
Telecopier: 514-682-5533

Mill:
Candiac, Laval, Québec

PROCTER & GAMBLE CELLULOSE, LTD.

Pulp

Head Office:
1001 Tillman Street
P.O. Box 8407, Memphis, Tennessee 38108-0407 USA
Tel.: 901 320 8397 Telecopier: 901-320-8131

Mill and Trade Enquiries:
Postal Bag 1020, Grande Prairie, Alberta T8V 3A9
Tel.: 403-539-8500

QUEBEC AND ONTARIO PAPER COMPANY LTD.

Newsprint

Head Office and Trade Enquiries:
80 King Street, St. Catharines, Ontario L2R 7G2
Tel.: 416 688 5030 Telex: 061 5243
Telecopier: 416 688 6005

Mills:
Thorold, Ontario; Baie-Comeau, Québec

REPAP ENTERPRISES CORPORATION INC.

Coated and groundwood papers and pulp

Head Office:
Bureau 3200 1150, rue Peel, Montréal (Quebec) H3B 4V9
Tel.: 514 879 1316 Telex: 05 25628
Telecopier: 514 875 5051

Trade Enquiries:
Coated paper:
Repap Sales Corporation
99 Park Avenue, 18th Floor, New York, New York 10016
Tel.: 212 687 7111

Pulp:
Repap International
Bureau 3200 1150, rue Peel, Montréal (Québec) H3B 4V9
Tel.: 514 879 1316 Telex: 05 25628
Telecopier: 514-875-5051

Unbleached Kraft Paper:
Repap Manitoba Inc.
P.O. Box 1590, The Pas, Manitoba R9A 1L4
Tel.: 204 623 7411 Telex: 0766 6579
Telecopier: 204 623 5995

Mills:
Prince Rupert, British Columbia; Nelson Miramichi, Newcastle, New Brunswick; The Pas, Manitoba

ROLLAND INC.

Book and writing, specialty, tissue, kraft, envelope and miscellaneous papers and bristols

Head Office:
Tour l'Industrielle Vie
2000, av. McGill College, bureau 1400
Montreal (Quebec) H3A 3H3
Tel.: 514 289 1779

Trade Enquiries:
Fine Papers Division
100, boul. Alexis Nihon, bureau 500
Saint Laurent (Quebec) H4M 2P1
Tel.: 514 744 8500 Telex: 058 24645
Telecopier: 514 747 6674

Mill
St Jerome, Québec

ROTHESAY PAPER LIMITED

Newsprint

Head Office and Trade Enquiries:
300 Union Street, Saint John, New Brunswick E2L 4M3
Tel.: 506 632 7777 Telex: 014 47262
Telecopier: 506 632 5113

Rothesay Newsprint Sales, Inc.
Soundview Drive, Greenwich, Connecticut 06830
Tel.: 203 622 0205 Telecopier: 203 622 8385

Mill:
Saint John, New Brunswick

ST. ANNE-NACKAWIC PULP COMPANY LTD.

Pulp

Head Office, Mill and Trade Enquiries:
P.O. Box 1000, Nackawic, New Brunswick E0H 1P0
Tel.: 506 575 2221 Telex: 01 446104 Cable: STANPAP

SCOTT MARITIMES LIMITED

Pulp

Head Office:
P.O. Box 549D, New Glasgow, Nova Scotia B2H 5E8
Tel.: 902-752-8461 Telex: 019 36524
Telecopier: 902-752-0258

Trade Enquiries:
Scott Paper Company, Fiber Division
Scott Plaza 1, Philadelphia, PA 19113
Tel.: 215-522-6338 Telex: 0083-4273
Telecopier: 215-522-5577

Mill:
Abercrombie Point, Nova Scotia

SCOTT PAPER LIMITED

Non-woven products, sanitary and specialty papers

Head Office and Trade Enquiries:
P.O. Box 3600, Vancouver, British Columbia V6B 3Y7
Tel.: 604-688-8131 CCI 7601353 Cable: SCOTTPAPER
Telecopier: 604-643-5543

Mills:
New Westminster, British Columbia; Crabtree, Lennoxville, Hull, Québec

SONOCO LIMITED

Boxboard

Head Office and Trade Enquiries:
33 Park Avenue East, P.O. Box 1208, Brantford, Ontario N3T 5T5
Tel.: 519-752-6591 Telecopier: 519-752-1214

Mills:
Brantford (2), Ontario; Terrebonne, Québec

SPRUCE FALLS POWER AND PAPER COMPANY, LIMITED

Newsprint and groundwood papers

Head Office and Mill:
P.O. Box 100, Kapuskasing, Ontario P5N 2Y2
Tel.: 705 337 1311 Telecopier: 705 337 9708

Trade Enquiries:
2 Carlton Street, Toronto, Ontario M5B 1J9
Tel.: 416 977 0211 Telecopier: 416 977 4780

STONE-CONSOLIDATED INC.

Newsprint, pulp, containerboard, writing papers (continuous forms), groundwood papers and tissue

Head Office and Trade Enquiries:
800, boul. René Lévesque ouest, Montréal (Québec) H3B 1Y9
Tel.: 514 875 2160 Telex: 05 25165
Cable: CONBATH MONTREAL Telecopier: 514 875 6284

Mills:
Bathurst, New Brunswick; Grand Mere, La Baie, New Richmond, Portage du Fort, Shawinigan, Trois Rivieres, Quebec

STORA FOREST INDUSTRIES LIMITED

Pulp and newsprint

Head Office and Trade Enquiries:
P.O. Box 59, Port Hawkesbury, Nova Scotia B0E 2V0
Tel.: 902 625 2460 Telex: 019 37531 Cable: STORADOCK
Telecopier: 902 625 1105

Mill:
Point Tupper, Nova Scotia

STRATHCONA PAPER COMPANY DIVISION OF ROMAN CORPORATION LIMITED

Boxboard, miscellaneous and specialty boards

Head Office and Mill:
Box 130, Napanee, Ontario K7R 3L6
Tel.: 613 378 6672 Telecopier: 613 378 6158

Trade Enquiries:
As above, or:
Suite 204A, 150 Consumers Road,
Willowdale, Ontario M2J 1P9
Tel.: 416-491-1701 Telecopier: 416-491-0444

159, rue Merizzi, Montréal (Quebec) H4T 1Y3
Tel.: 514-342-2471 Telecopier: 514-342-3943

TEMBEC INC.

Pulp, coated boards and chemicals

Head Office:
800, boul. René-Levesque ouest, bureau 2790
Montréal (Québec) H3B 1X9
Tel.: 514-871-0137 Telecopier: 514-871-1584

Mill and Trade Enquiries:
C.P. 3000, Témiscamingue (Quebec) J0Z 3R0
Tel.: 819-627-3321 Telex: 06776281
Telecopier: 819-627-3622

WELDWOOD OF CANADA LIMITED (HINTON DIVISION)

Pulp and chemicals

Head Office and Trade Enquiries:
1055 West Hastings Street, P.O. Box 2179
Vancouver, British Columbia V6B 3V8
Tel.: 604-687-7366 Telex: 04-508846

Mill:
Bag Service 8000, Hinton, Alberta T0E 1B0
Tel.: 403-865-2251 Telex: 037-2288
Telecopier: 403-865-8129

WESTERN PULP LIMITED PARTNERSHIP

Pulp

Head Office:
1300 355 Burrard Street
Vancouver, British Columbia V6C 2G8
Tel.: 604-665-8801 Telex: 04-508828 Cable: WESTPULP VCR
Telecopier: 604-665-8806

Trade Enquiries:
As above, or:

Europe:
1 Lewins Yard, East Street, Chesham, Bucks.
England H5P 1HQ

Mills:
Port Alice, Squamish, British Columbia

WEYERHAEUSER CANADA LTD.

Pulp and chemicals

Head Office and Trade Enquiries:
P.O. Box 800
Kamloops, British Columbia V2C 5M7
Tel.: 604-372-2217 Telecopier: 604-828-7585

Mills:
Kamloops, British Columbia; Prince Albert, Saskatchewan

COMPANIES WHO ARE NOT MEMBERS OF THE CPPA

Alberta Newsprint Co. Ltd. 10055-106th Street Edmonton Alberta T5J 2Y2 Tel: 403-423-3385	Newsprint
The Beaver Wood Fibre Co. Ltd. Allanburg Road Thorold Ontario L2V 3Z8 Tel: 416-227-6651	Boxboard, gypsumboard papers
BPCO Inc. 10500 Cote de Liesse, Suite 200 Lachine Quebec H8T 3E3 Tel: 514-636-6810	Asphalt shingles, fibreboard
CKF Inc. 48 Prince St., PO Box 419 Hantsport N.S. BOP 1PO Tel: 902-684-3231	Molded pulp products
Eurocan Pulp and Paper Co. Eurocan Way, PO Box 1400 Kitimat B.C. V8C 2H1 Tel: 604-632-6111	Kraft linerboard, paper
Fibreco Pulp Inc. Slocan Forest Products 240-10451 Shellbridge Way Richmond B.C. V6X 2W8 Tel: 604-278-7311	Pulp
IKO Industries Ltd. 1603-42nd Ave. SE Calgary Alberta T2P 2L2 Tel: 403-265-6022	Roofing, building papers and boards

Kimberly-Clark of Canada Ltd. 90 Burnhamthorpe Road West Mississauga Ontario L5B 3Y5 Tel: 416-277-6500	Pulp
Louisiana-Pacific Canada Ltd. PO Box 900 Ste 209 5016 50th Avenue Chetwynd B.C. VOC 1JO Tel: 604-788-7857	Pulp
Malette Inc. Highway 101 West, PO Box 1100 Timmins Ontario P4N 7H9 Tel: 705-268-1462	Pulp, groundwood specialties
Marlboro Paper Inc 191 St. Henri Street Drummondville Quebec J2C 2H4 Tel: 819-477-4413	Toilet paper
Millar Western Pulp Ltd. 16640-111 Avenue Edmonton Alberta T5M 2S5 Tel: 403-486-2444	Pulp
Nordfibre Co Eloy Road, PO Box 910 North Bay Ontario P1B 8K1 Tel: 705-474-2300	
Produits Desbiens CP 220, 752 rue Hebert Desbiens Quebec GOW 1NO Tel: 418-346-5593	Absorbent hygiene products

Quesnel River Pulp Co. Finning Road near Two Mile Flat PO Box 9500 Quesnel B.C. V2J 5C3 Tel: 604-992-8919	Pulp
Slave Lake Pulp Corp. PO Box 1790 Slave Lake Alberta, TOG 2AO Tel: 403-849-5771	Pulp
St. Mary's Paper Inc. 75 Huron St. Sault Ste Marie Ontario P6A 5P4 Tel: 705-942-6070	Groundwood specialties
St. Raymond Pulp Ltd. 1 Ave de l'Hôtel de Ville Rivière-du-Loup Quebec G5R 3Z1 Tel: 418-862-3403	Groundwood pulp
Welclad International Inc. 515 Munroe Avenue Winnipeg Manitoba R2K 1H7 Tel: 204-667-5060	Fibreboard

b) AN OVERVIEW OF THE CANADIAN PULP AND PAPER INDUSTRY

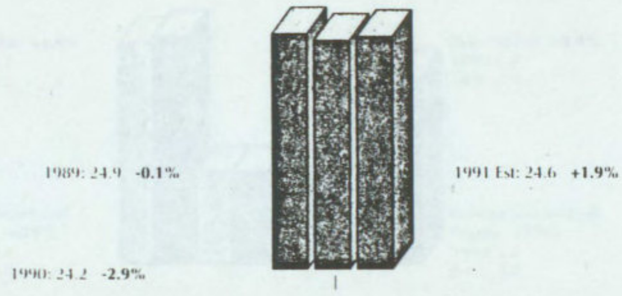
CANADIAN PULP AND PAPER INDUSTRY
ECONOMIC AND ENVIRONMENTAL REPORT 1990

(Reprinted by permission)

SHIPMENTS BY PRODUCT (000 Tonnes)		**1990**		1989	% Change
Newsprint		9 075		9 607	-5.5
Printing and Writing Papers		3 588		3 204	12.0
Uncoated Mechanical	1 777		1 670		6.4
Uncoated Freesheet	1 233		1 048		17.7
Coated Papers	578		486		18.9
Kraft Papers		484		518	-6.6
Tissue and Special Papers		495		496	-0.2
Containerboard		2 065		1 940	6.4
Boxboard		760		755	0.7
Wood Pulp (exports only)		7 686		8 347	-7.9
Total		24 153		24 867	-2.9

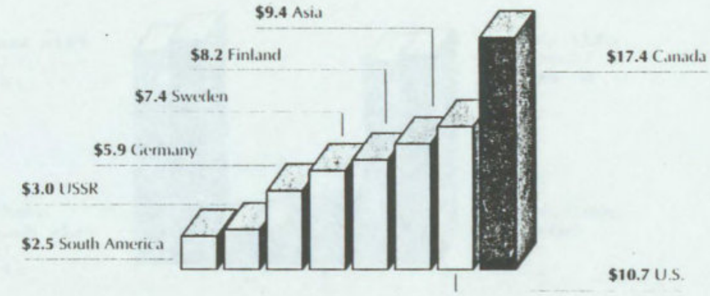
SHIPMENTS BY AREA (000 Tonnes)	**1990**	1989	% Change
Canada	4 703	4 886	-3.7
United States	13 131	12 993	1.1
United Kingdom	733	906	-19.1
Western Europe	2 311	2 408	-4.0
Japan	1 085	1 471	-26.2
Latin America	578	526	9.9
All Others	1 612	1 677	-3.9
Total	24 153	24 867	-2.9

EXPORTS (000 Tonnes)		**1990**		1989	% Change
Newsprint		7 943		8 466	-6.2
Printing and Writing Papers		2 525		2 094	20.6
Uncoated Mechanical	1 547		1 433		8.0
Uncoated Freesheet	601		410		46.6
Coated Papers	377		251		50.2
Kraft Papers		324		331	-2.1
Tissue and Special Papers		74		80	-7.5
Containerboard		732		561	30.5
Boxboard		166		102	62.7
Wood Pulp		7 686		8 348	-7.9
Total		19 450		19 982	-2.7



PULP AND PAPER SHIPMENTS 1989-1991

Million Tonnes - Source: CPPA - January 1991



WORLD EXPORTS OF FOREST PRODUCTS

Billions of Dollars (U.S.) - Source: FAO 1988

Canadian shipments of pulp, paper and board were down substantially in 1990. Factors contributing to this decline were: weaker than expected economic growth in the North American market which accounts for approximately 75% of industry shipments; a substantial drop in market pulp shipments to Japan; and some production losses due to labour disruptions at Eastern Canadian mills.

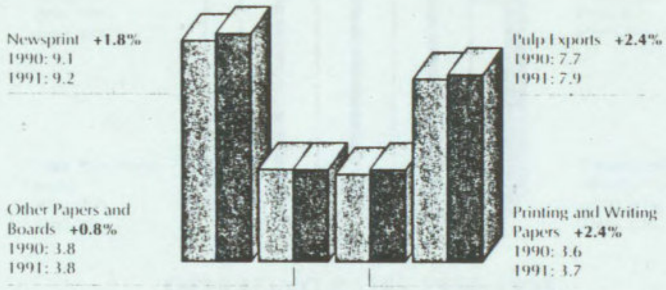
Overall, shipments of pulp, paper and paperboard were down by about 700 000 tonnes, or 2.9%, from the 24.9 million tonnes shipped in 1989. The 1990 shipments had a value of $18.5 billion, with exports accounting for $14 billion of that amount.

In 1991, shipments are forecast to increase modestly by about 450 000 tonnes, or 1.9%, to reach 24.6 million tonnes. Significant increases in capacity in some products, and the end of an inventory adjustment cycle for others, are expected to lead to these increased shipments by Canadian producers in 1991.

Canada is the world's largest exporter of pulp, paper and other forest products — a position it has maintained for 70 years.

According to FAO statistics, Canada's share of world markets for pulp, paper and other forest products is continuing to grow — from 20% in 1980 to 22% in 1988. Today, Canadian companies account for approximately 60% of the newsprint, 36% of the market pulp, and 40% of the softwood lumber sold in international markets.

There are a number of factors which contribute to Canada's pre-eminent position in world markets: the high quality of its pulp and paper products; a sensitivity to markets; a large renewable forest resource; the skills and dedication of Canadian papermakers; and large capital expenditures — $30 billion in the past decade — to improve operations and competitiveness.

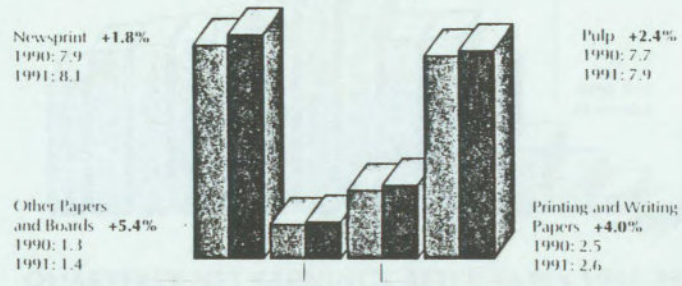


SHIPMENTS BY PRODUCT 1990-1991

Million Tonnes - Source: CPPA - January 1991

1990

1991 estimate



EXPORTS BY PRODUCT 1990-1991

Million Tonnes - Source: CPPA - January 1991

1990

1991 estimate

Shipments of pulp, paper and paperboard varied in 1990, depending on the product group. Significant gains in shipments of printing and writing papers and containerboard were offset by a substantial decline in shipments of newsprint and market pulp.

Shipments of printing and writing papers were up sharply once again in 1990, led by a 50% increase in coated paper exports. In the "Other Papers and Boards" category, shipments were up 3% over 1989. Newsprint and market pulp shipments were down significantly by 5.5% and 7.9%, respectively. Weakening economic activity in the industry's major markets and production losses during labour negotiations at some Eastern Canadian mills were factors in these declines.

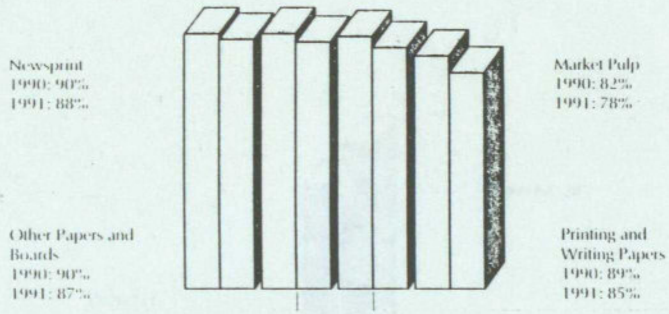
In 1991, increased exports are forecast to contribute to higher shipment levels in most product areas. Newsprint shipments are expected to rise by 1.8% to reach 9.2 million tonnes; printing and writing papers by 2.4%, to 3.7 million tonnes; other papers and boards by 0.8%, to 3.8 million tonnes; and pulp exports by 2.4%, to 7.9 million tonnes.

In 1990, exports of Canadian pulp, paper and paperboard were down by 2.7%, or 530 000 tonnes, compared to 1989.

The influence of improved market conditions in Latin America and parts of Asia was offset by slower economic growth in the United States and Western Europe, and destocking by pulp consumers.

Exports to the United States were up by 1.1%, supported by significant increases in the shipments of printing and writing papers, up 20% over last year. Shipments to the United Kingdom and Western Europe were down by 19.1% and 4%, respectively, while shipments to Japan declined by 26.2% in 1990.

In 1991, exports of newsprint are expected to increase by 1.8%, and exports of pulp by 2.4%. Exports of printing and writing papers are forecast to rise by 4%, and other papers and boards, most of which are packaging grades, by 5.4%.

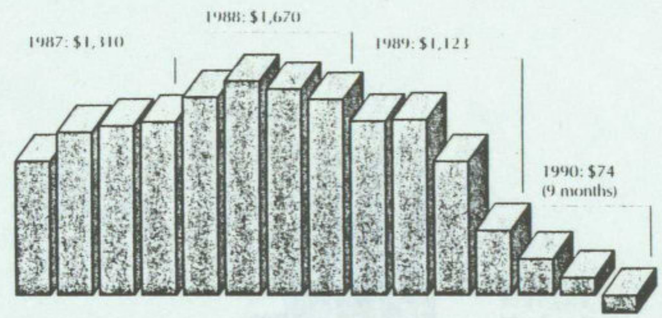


OPERATING RATES 1990-1991

Source: CPPA - January 1991

1990

1991 estimate



QUARTERLY NET EARNINGS AFTER TAXES 1987-1990

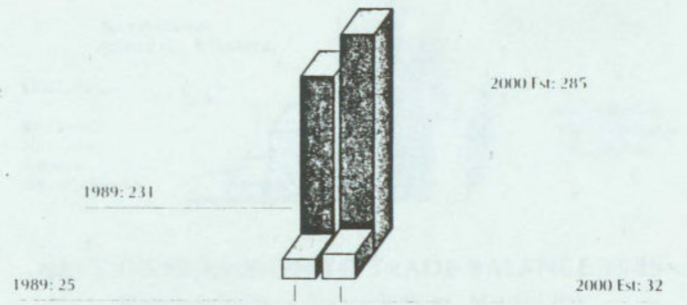
Millions of Dollars - Source: CPPA - December 1990
Based on Annual and Quarterly Reports
of 15 Canadian Forest Products Companies

During 1990, shipments as a percent of capacity averaged 87%, down from 93% in 1989. In the newsprint sector, the average operating rate was 90%, compared to 96% the previous year, while in the market pulp and printing and writing sectors, the operating rates averaged 82% and 89%, respectively.

In 1991, weak demand growth and additions to capacity are expected to result in lower operating rates in most segments of the industry. The newsprint sector is forecast to operate at 88% of capacity; printing and writing at 85%; other papers and boards at 87%; and market pulp at 78%.

Pulp and paper, a commodity-based industry, is vulnerable to swings in the business cycle. As a world trader, it is vulnerable to changes in international exchange rates. Because it is highly capital-intensive, it is vulnerable to elevated real interest rates. The combined effect of these factors on earnings can be seen in the graph above.

In 1988-89, a steep rise in the levels of the Canadian dollar and short-term interest rates had a dramatic impact on Canada's pulp and paper industry. Results for the first nine months of 1990 indicate that the continued climb of interest rates, the widening of the short-term interest rate differential between Canada and the U.S., and the continued appreciation of the Canadian dollar, have contributed to a further significant deterioration in industry earnings and return on investment. It is expected that the nominal return on capital employed in 1990 will drop to 0.5 - 1.0%, a level comparable to that registered during the 1981-1982 recession.



OUTLOOK 2000 A.D.

Million Tonnes - Source: CPPA - December 1990

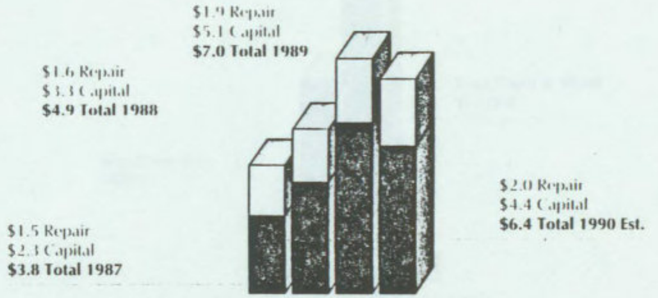
World Consumption Paper and Paperboard

Canadian Shipments

World consumption of paper and board is expected to grow by 54 million tonnes between 1989 and the year 2000, an average annual increase of 1.9%, and more than double the current size of Canada's entire paper and board industry.

If Canadian producers remain competitive and have access to fibre and capital for investment, pulp and paper shipments from Canada could reach some 32 million tonnes by the year 2000, an increase of 7 million tonnes over 1989.

Canadian companies are preparing to meet the anticipated demand for paper and paperboard products: a decade-long drive to modernize mills continues to go forward; capacity to produce pulp and paper products continues to grow; and emerging market opportunities are being identified around the world.



CAPITAL EXPENDITURES 1987-1990

Billions of Dollars - Source: Statscan - August 1990

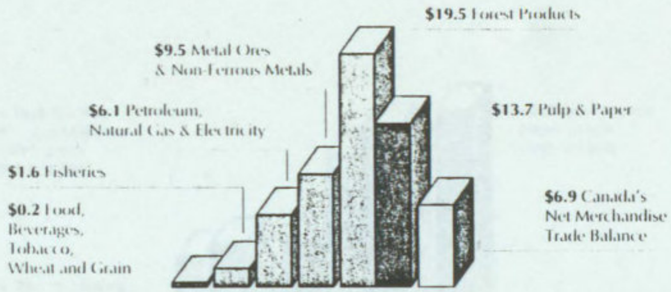
Repair

Capital

Pulp and paper is a highly capital-intensive industry. Generating and securing funds, a difficult undertaking in a period of declining earnings, is critical to the industry's ability to invest.

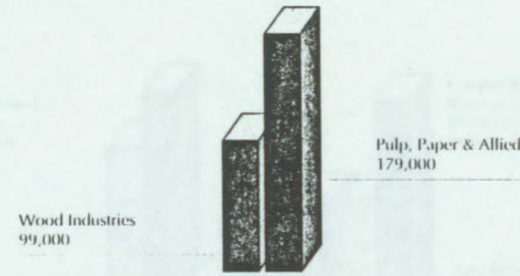
The Canadian pulp and paper industry invested a record $7 billion in its operations in 1989. This money went to maintaining, modernizing and expanding existing operations, and building new ones, as well as to environmental improvement. In 1990, investment dropped marginally to $6.4 billion with almost $1 billion of that amount dedicated to spending on the environment.

The recent sharp reductions in net earnings mean that total capital expenditures will decline by about a quarter in 1991. However, the portion representing environmental expenditures will not only be maintained but likely increase by about a third, to reach a level nearly twice as high as in 1989.



NET CONTRIBUTION TO TRADE BALANCE 1989

Billions of Dollars - Source: Statscan - March 1990



EMPLOYMENT

Source: Statscan / CPPA - 1990

Pulp and paper, and other forest products, make an enormous contribution to Canada's balance of trade.

In 1989, the industry's net contribution to Canada's trade balance was $19.5 billion dollars — larger than that of mining, petroleum, fisheries and agriculture combined.

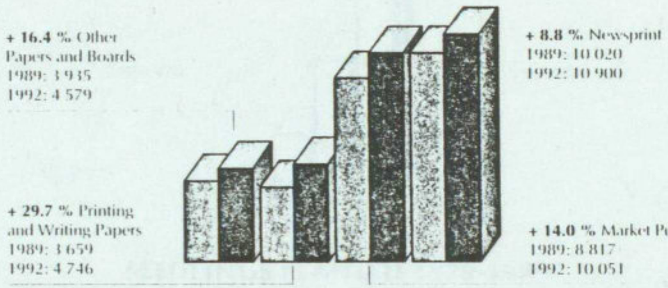
The net contribution by the pulp and paper industry — $13.7 billion dollars — was $7 billion dollars higher than Canada's total net merchandise trade surplus in 1989.

The forest products industry is critical to Canada's ability to maintain its international accounts and standard of living. For this reason, the industry and governments in Canada share a high degree of interest in ensuring the widest possible market access for pulp and paper companies, effective programs to renew Canada's forests, and an investment climate which encourages a healthy degree of international competitiveness.

The various industries that make up Canada's forest products sector represent one of the most important segments of the Canadian economy. The pulp and paper industry accounts for about two-thirds of Canada's forest products sector, and is the country's largest manufacturing industry in terms of value added, exports, and employment.

Statistics Canada data indicate that pulp and paper mills and related logging operations provide employment for 179,000 Canadians; the solid wood products sector of the industry provides employment for another 99,000. In fact, the forest products industry directly and indirectly supports some one million jobs in Canada. Many are in communities dependent on the industry for their economic livelihood.

Over the years, the industry has provided Canadians with highly-skilled jobs, and offered training and development opportunities to those employed in woods and mill operations. It also has been a source of above-average industrial wages. According to Statistics Canada data, remuneration to employees in salaries and wages alone amounted to some $9.3 billion in 1989.

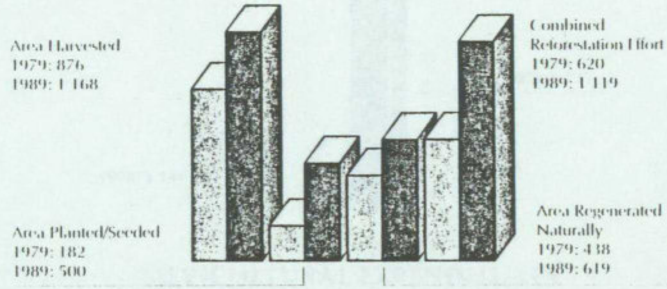


CANADIAN CAPACITY GROWTH 1989-1992

Thousand Tonnes - Source: CPPA - May 1990

1989

1992 estimate



HARVEST VS REFORESTATION EFFORT 1979-1989

Thousand Hectares - Source: CPPA

1979

1989

Growth rates in the Canadian pulp and paper industry have been higher than average since 1986, a situation which is expected to continue during 1989-92.

Total paper and paperboard capacity will increase from 17.6 million tonnes in 1989 to 20.2 million tonnes in 1992, an increase of 14.8%. Capacity for printing and writing papers will show the most significant increase with the biggest growth occurring in coated mechanical papers, which are forecast to rise 62% to 615 000 tonnes by 1992.

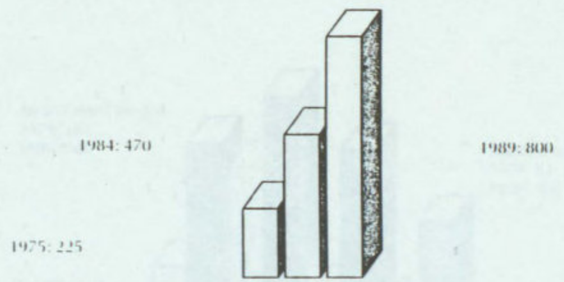
Newsprint capacity, which stood at just over 10 million tonnes in 1989, is expected to increase by 900 000 tonnes, or 8.8%, by the end of 1992. Sanitary papers will rise substantially by 160 000 tonnes, or 31.4 percent; containerboard and boxboard by 14.1 and 21.3 percent, respectively; and kraft papers by about 27 000 tonnes, or 5.3%.

Total pulp capacity will climb 12.5% over the same period, from 25.7 million tonnes to 28.9 million tonnes. Market pulp, which accounts for over one-third of total pulp capacity, will rise 14%, from 8.8 million tonnes in 1989, to 10.1 million tonnes in 1992. Kraft pulp accounts for about 60% of the increase, and mechanical pulp the remaining 40%.

Two principles underlie current harvesting practices: environmental needs will be taken into account; and activities will be initiated to establish the new forest as the mature forest is harvested.

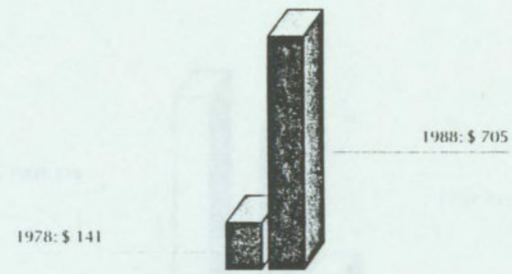
Canadian foresters renew harvested areas in three ways: natural regeneration; direct seeding; and the planting of nursery-grown seedlings. Natural regeneration is successful where species, soil and climatic conditions are appropriate, and relies on nearby trees to serve as a source of seed. Direct seeding is accomplished by the dissemination of seed from aircraft or from the ground. Nursery-grown seedlings are planted to establish a new crop in an area which would otherwise take too long to regenerate naturally.

The graph above illustrates the commitment over the past decade to integrate harvesting activities with forest renewal or regeneration programs in Canada. Areas planted, seeded, and regenerated naturally (the combined reforestation effort) were equivalent to 71% of the area harvested in 1979. By 1989, only ten years later, this figure had risen to 95%. In the decades ahead, this effort will be continued and intensified as the new forest is put in place.



SEEDLINGS PLANTED 1975-1989

Million Seedlings - All provinces - Source: CPPA / Forestry Canada



SILVICULTURAL EXPENDITURES

Government and Industry - 1978 vs 1988

Millions of Dollars - Source: CPPA / Forestry Canada

Canadian forests occupy half the country's land mass and are harvested on a sustained yield basis. Approximately 240 of the 450 million hectares of forest land in Canada are considered productive, or capable of producing continuous crops of trees. The Canadian forest industry annually harvests about 1 million hectares, less than 1/200th of the country's productive forest land. The yield from this harvest is about 170 million cubic metres of wood.

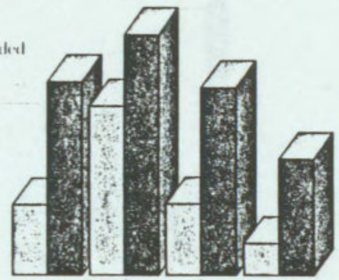
Canadian forest product companies operating under forest management agreements harvest the allowable cut and promptly ensure the establishment of the next crop. It is in their best interests, and that of all Canadians, to do so. Today, provincial governments and industry jointly manage Crown-owned forests; improvement programs on privately-owned timberlands are expanding; and industry and governments have substantially increased their investment in forestry.

One measure of the intense activity now underway is the 250% increase in the number of seedlings being planted in Canada — from 225 million in 1975 to an estimated 800 million in 1989.

Silviculture is the art and science of growing forests — giving nature a helping hand in order to enhance the values of the resource base.

It involves a wide variety of activities undertaken to spur regeneration of valuable tree species, accelerate rates of tree growth, increase wood yield, and ensure rapid establishment of the new forest.

Expenditures on silviculture have been increasing dramatically in recent years, — from $141 million in 1978 to $705 million in 1988. This 400% increase is indicative of the commitment being made by industry and governments to replenish and renew Canada's forest resource. Silvicultural expenditures are a cooperative effort in Canada involving the provinces, which own 92% of the forests of Canada; the federal government; and the industry which, increasingly, is responsible for the cost-effective expenditure of funds on silvicultural programs.

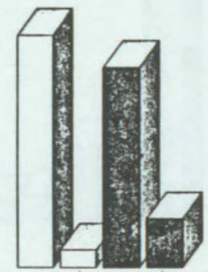


PRODUCING TOMORROW'S FORESTS 1979 VS 1989

Thousand Hectares - Source: CPPA

1979

1989



EFFLUENT CONTROL PROGRAM 1960-1988

kg/t - Source: CPPA

Suspended Solids

Biochemical Oxygen Demand

Nature and forest managers work in close cooperation to ensure that Canada's harvested forests are renewed.

About half the harvested area will easily and promptly regenerate itself. In fact, in certain parts of Canada, nature may be too efficient, producing more seedlings than can survive or grow to a substantial size. Forest managers will eventually be required to thin out the growing trees to ensure strong healthy forests. Other harvested areas receive a variety of silvicultural treatments. Planting of nursery-grown seedlings is important, as is seeding from the ground or aerially. About 485 thousand hectares are "site prepared" (treated mechanically or otherwise to better receive seeds or seedlings). Some 300 thousand hectares receive "stand tending" (treatment by manual, mechanical or chemical means to protect the new growth from vegetation that competes for light, space, moisture, or nutrients).

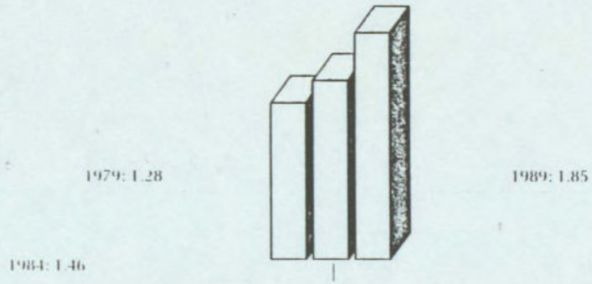
The response of the industry and governments to the challenge of creating a new forest is illustrated here: impressive increases in the thousands of hectares planted; and equally impressive increases in the thousands of hectares receiving stand tending and site preparation.

Since 1960, pulp and paper companies have spent $3.2 billion on air and water pollution abatement. Steady improvements in Canadian mills have reduced the quantity of total suspended solids to only 9% (per tonne of production) of levels that existed before 1960, and BOD (the term used to describe oxygen depletion) has been reduced to 16%. Work continues to reduce these levels still further. Capital spending on environmental measures is expected to be in excess of $5 billion over the next several years.

Today, the industry's attention is focused on limiting trace levels of dioxins, furans, and other chlorinated organics found in some bleached pulp mill effluents.

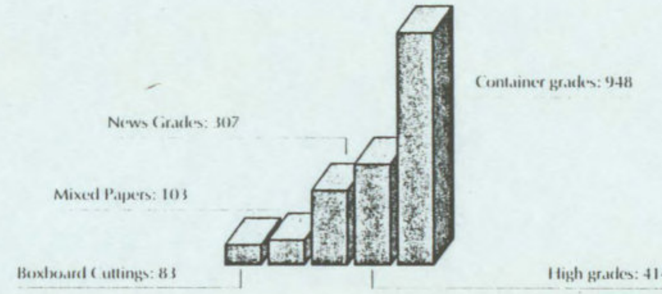
The use of chlorine has been cut by 50% in the past two years. The amount of dioxins and furans that are formed has now been reduced to 150 grams per year, one-half of what it was in 1989. This is expected to fall to less than 10 grams in the next year or so.

Modifications now being made at bleach plants are bringing chlorinated phenols (the potentially harmful components of organochlorine compounds) below levels at which they have any environmental significance.



RECYCLED PAPER CONSUMPTION 1979 VS 1989

Million Tonnes - Source: CPPA



RECYCLED PAPER CONSUMPTION BY GRADE GROUP 1989

Thousand Tonnes - Source: CPPA - October 1990

Current interest in recycling and the demand for recycled paper products reflect increased concern about waste disposal in North America. Although most waste papers are biodegradable, their disposal contributes substantial quantities of material to landfill sites. Greater recycling of reusable materials, including waste papers, is a part of the solution.

Of the 110 paper and paperboard mills in Canada, almost half draw on waste paper for all or part of their raw material needs. Some mills have been doing so for more than 50 years. In 1989, they consumed over 1.8 million tonnes of waste paper, double the amount used in 1979. Of this amount, nearly 600 000 tonnes were imported, mostly from the United States. The total amount collected in 1989 increased to 28% of apparent consumption of paper and board in Canada, up from 23% in 1988. It is estimated that, by 1992, consumption will rise to over 3 million tonnes as Canadian newsprint producers install de-inking plants at a number of mills, and board, tissue, and other paper manufacturers also increase their capacity to meet the demand for recycled paper products.

Fibre for recycling comes from several sources. About 50% of the recycled fibre consumed in Canada in 1989 came from old corrugated containers collected from manufacturing plants, shopping malls, department stores, and other commercial establishments. It is used in the manufacture of corrugating medium, linerboard, boxboard and towelling.

The high grade "pulp substitutes", which accounted for about 22%, are waste papers of superior quality. They are relatively free of contaminants (adhesives and plastic coatings) and can often be used instead of virgin pulp. They come mainly from paper converters, printers, envelope manufacturers, and office building waste. The "news" grades (old newspapers, over-runs from pressrooms, unprinted newsprint and other groundwood papers), are a growing source of recycled fibre, accounting for some 17% of waste paper consumed. They are used in the manufacture of newsprint, boxboard and molded paper items.

The "mixed" paper grades (waste papers unsorted before delivery) and boxboard cuttings (the trim left over from the conversion of boxboard) accounted for 6% and 4%, respectively, of the waste paper consumed in 1989.

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