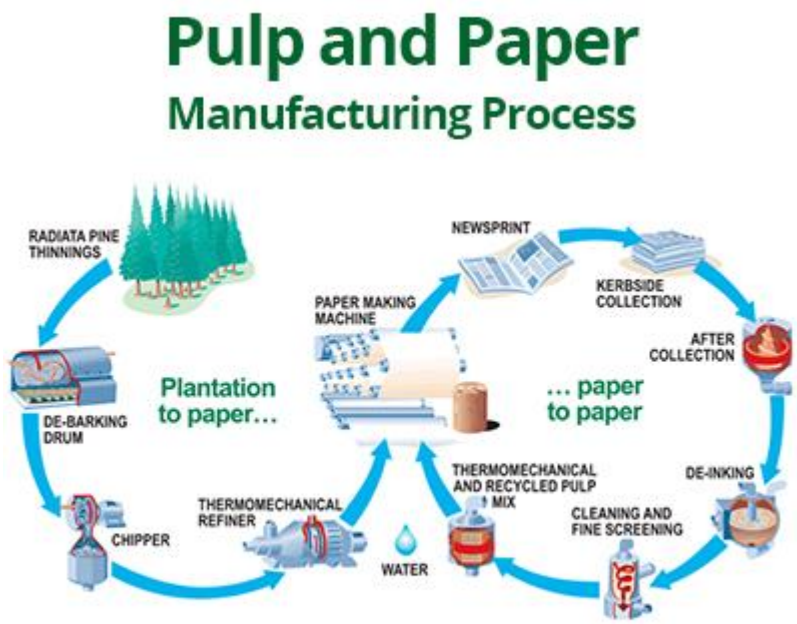
Lecture-16
(Bio Pulping)



Pulp and Paper Industry

PULP AND PAPER VECTOR IMAGE

Images help in proper understanding.

➢ INTRODUCTION

- Paper products and chemicals based on cellulose are highly significant for a nation, specially for a developing country like India.
- The per capita consumption of paper is a measure of the educational, social, cultural and industrial activities of a country.
- The following **Figure-1** shows the paper consumption per capita worldwide in 2016, by region(in kilograms):

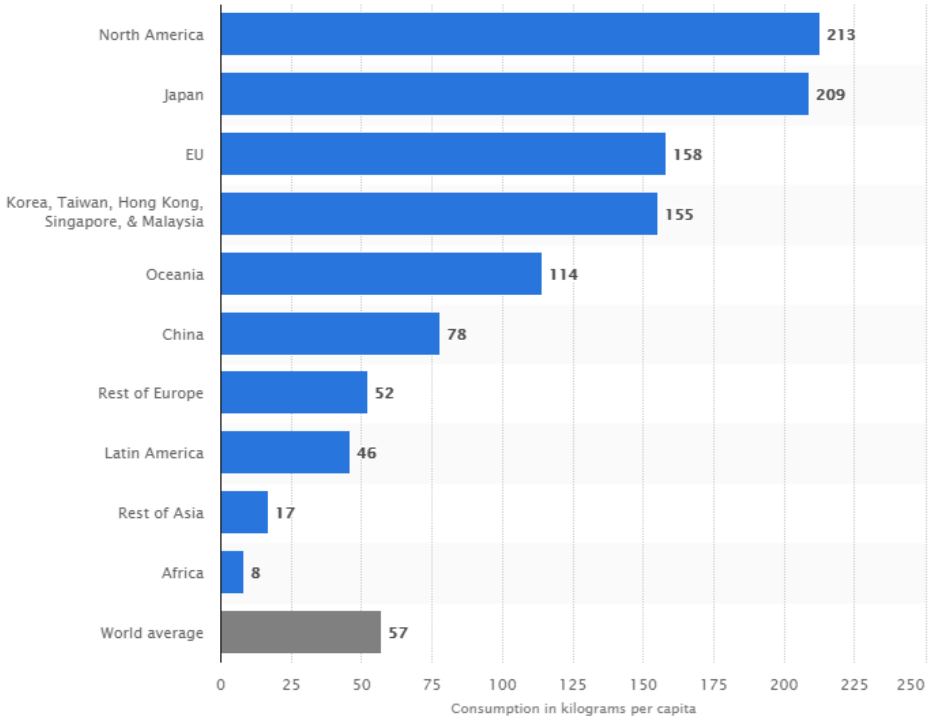


Figure-1: Paper consumption per capita worldwide in 2016, region wise.

- India has one of the lowest per capita consumption of paper in the world, as depicted in the **Figure-2**, below:

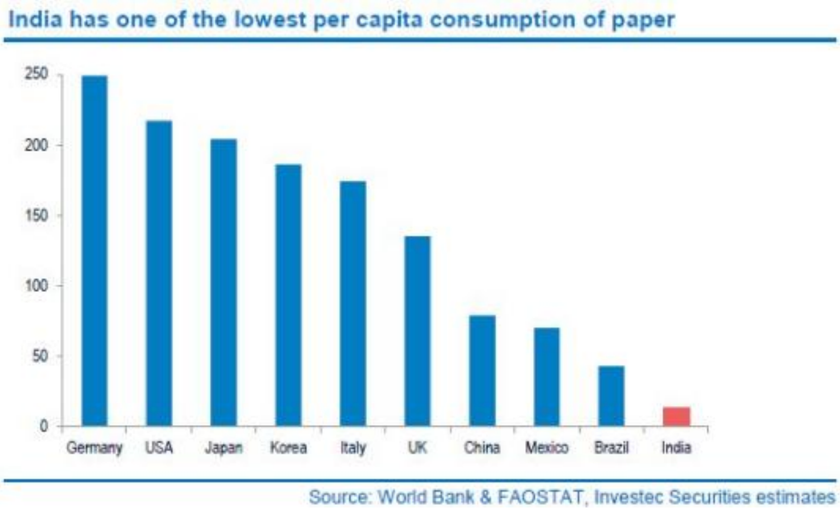


Figure-2: Country wise per capita consumption of paper in kg.

- The Indian paper industry turnover is estimated to be ~Rs 50,000 crores. India accounts for ~3% of the world's total paper production. Paper industry in India provides direct employment ~5 lakh people and ~15 lakh people indirectly.
- Key players in paper industries in India has been shown in the **Table-1**.

Table-1:Key Players in Paper Industries in India

Sl. No.	Company	Installed Capacity of Paper (MT)
1.	Ballarpur Industries Limited (BILT)	969568
2.	ITC Limited - PSPD	550000
3.	JK Paper Limited	455000
4.	Century Pulp and Paper	413810
5.	Tamil Nadu Newsprint & Papers Limited (TNPL)	400000
6.	The West Coast Paper Mills Limited	320000
7.	Rainbow Papers Limited	305000
8.	Murli Industries Limited	248200
9.	The Andhra Pradesh Paper Mills Limited	241000
10.	Seshasayee Paper & Boards Limited	175000
11.	Trident Limited	175000

- The pulp and paper industries have been categorized as one of the major sectors that pose a threat to the environment.
- Economic conditions and environmental pressures have hit the pulp and paper industry hard, and it has been under tremendous pressure to improve the performance related to release of pollutants.
- Increased environmental concerns are creating pressure for adoption of new, eco-friendly technologies.
- An integrated pulp and paper process includes the general steps of pulping, bleaching, and paper production.
- The production of the chemical pulps has been dramatically altered over the past decade in response to new environmental regulations and consumer activism.
- Two of the most promising technologies for delignification of high lignin pulps are (i) oxygen delignification, and (ii) modification of pulping process through biological means.
- Use of fungal inoculums prior to pulping offers an attractive opportunity for mechanical wood pulp facilities.
- This technology could save energy in the refining of mechanical pulp.
- Likewise, in the case of chemical pulping a biological method can be used to facilitate the removal of lignin from wood by modifying lignin for easier extraction in subsequent chemical pulping processes.
- **Biopulping** is the fungal pretreatment of wood chips for the production of mechanical or chemical pulps.

- Its concept is based on the ability of a restricted number of white rot fungi to colonize and degrade selectively the lignin in wood, thereby leaving cellulose relatively intact.
- This process appears to have the potential to overcome some problems associated with conventional chemical and mechanical pulping methods.
- Biopulping is an environmentally friendly technology that substantially increases mill throughput or reduces electrical energy consumption at the same throughput in conjunction with mechanical and chemical pulping.
- Electrical energy is the major cost of conventional mechanical pulping.
- By producing stronger pulp with longer fibers and increased fibrillation, biomechanical pulping may reduce the amount of kraft pulp required to increase pulp strength.
- Some selected lignin-degrading fungi can alter cell walls of wood in a short period after inoculation.
- A comprehensive evaluation of biopulping at the Forest Products Laboratory (FPL) showed that these fungi can be economically grown on wood chips in an outdoor chip pile-based system.
- Results also demonstrate the great potential of fungal pretreatment of wood chips prior to chemical pulp production.
- The most prominent benefit of fungal pretreatment is improved effects on cooking, leading to reduced kappa numbers/reduced active alkali charge and/or reduced cooking time after only 1–2 weeks of fungal treatment.
- Fungal pretreatment also reduces the pitch content in the wood chips and improves the pulp quality in terms of brightness, strength, and bleachability.
- The bleached biopulps are easier to refine than the reference pulps.
- The process has been scaled up toward industrial level, with optimization of various process steps and evaluation of economic feasibility.
- The process can be carried out in chip piles or in silos.
- The biochemical mechanism of biopulping is still mostly unknown.
- It is, however, likely that the biopulping effect is caused by the lignin-degrading system of white-rot fungi.
- There has been quite little correlation between removal of specific components of the wood by the fungi and efficacy of the fungal pretreatment in either energy savings or paper strength property improvement.
- Biopulping technology has advanced rapidly within recent years and pilot mill trials have been started worldwide.
- This technology coincides perfectly with environmentally safe production strategies and can be implemented in existing production plants without major changes.

PULP AND PAPER RAW MATERIALS

Different types of raw material used in pulping have been summarized in Figure-1 and the images have been shown by figures 3-9. However, the chemistry of lignocellulosic raw materials have been depicted by Figure-10.

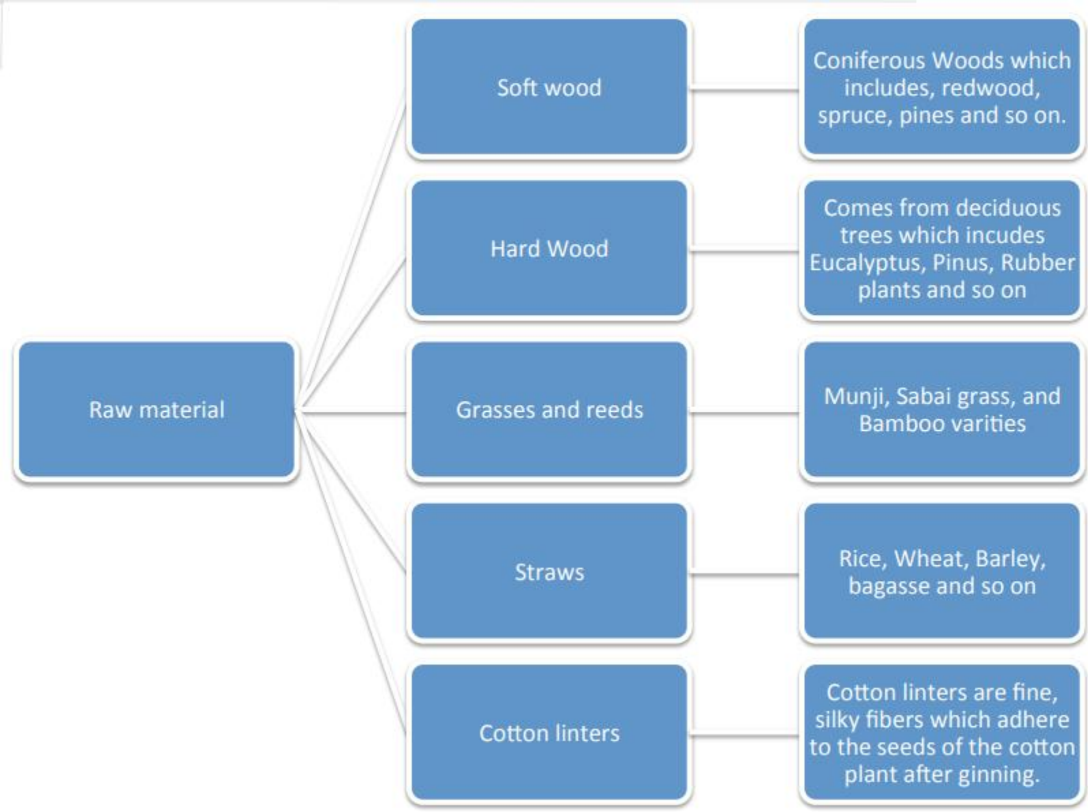


Figure-3: Various types of raw materials used for pulping.

RAW MATERIALS

Figure-4

RAW MATERIALS

Hard Wood

Comes from deciduous trees which incudes Eucalyptus, Rubber plants and so on

Figure-5

Grasses and reeds

Munji, Sabai grass, and Bamboo varities

Figure-6

RAW MATERIALS

Figure-7

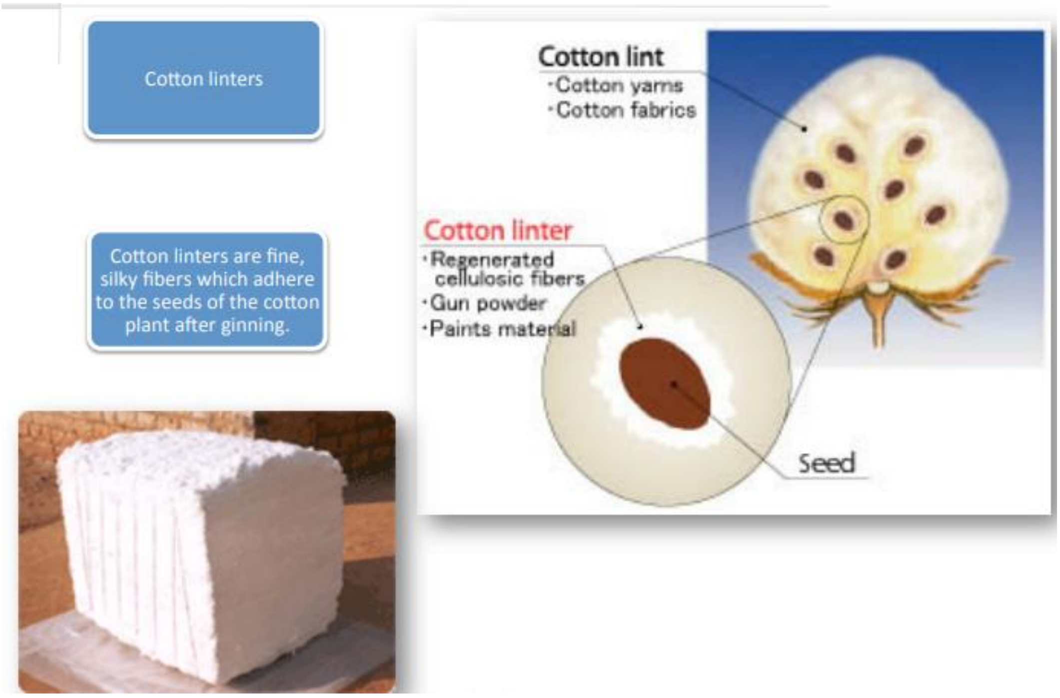


Figure-8

RAW MATERIAL

Figure-9

CHEMISTRY OF RAW MATERIALS

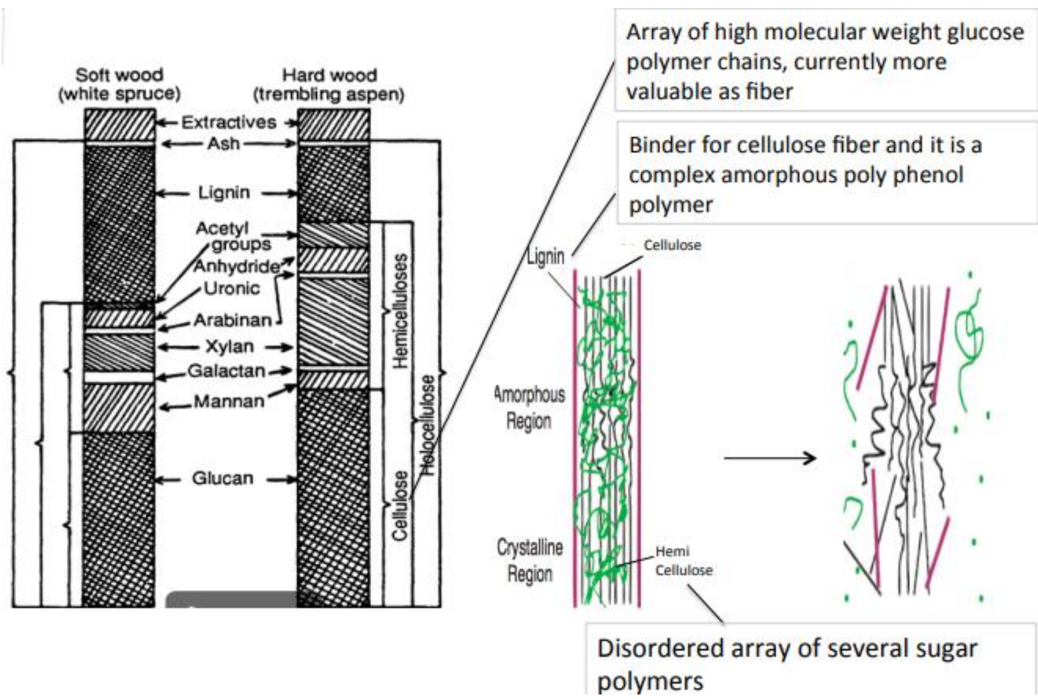


Figure-10

➢ PULPING METHODS

The pulping methods have been depicted by Figure-11. However, the methods have been differentiated and briefly explained in Table-1. The difference between sufate (Kraft) and sulfite methods have been highlighted in Table-2.

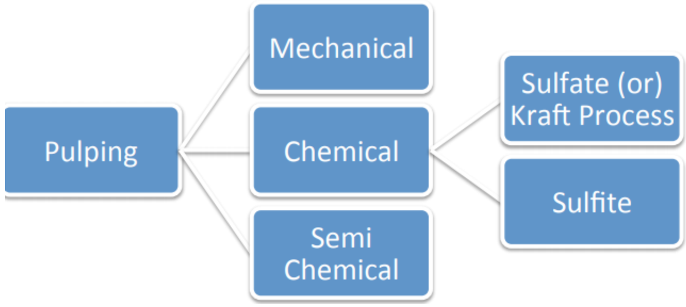


Figure-11: Pulping methods.

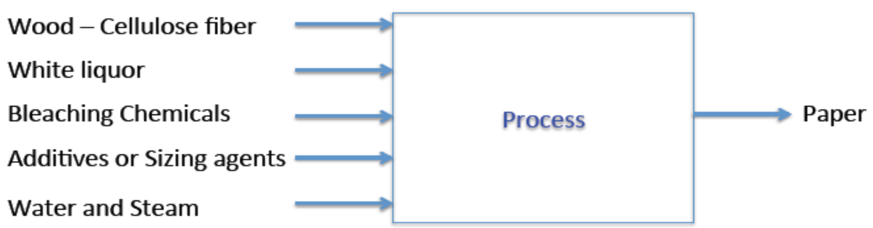
Table-1: Brief Explanation of Pulping Methods

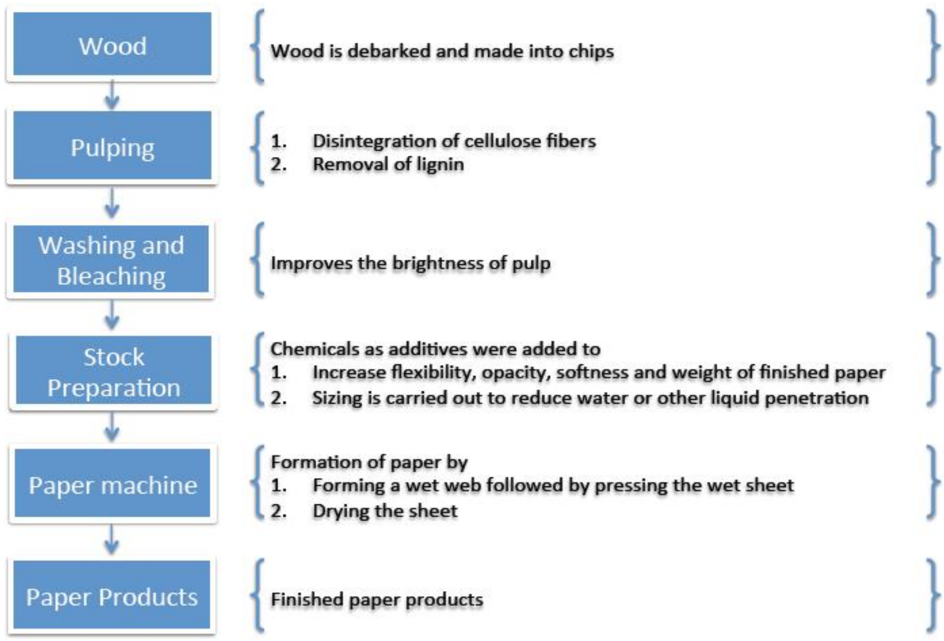
Mechanical	Chemical	Semi chemical
Wood is debarked and it is mechanically shredded to form fibers.	The cellulose from the wood is freed from lignin by chemical reagents.	Wood chips are given with mild chemical treatment with dilute mixture; of sulfite, sulfate, caustic soda, and or soda ash reagents.
Suitable for the production of newsprint, toweling, toilet tissues and cheap paper books where strength and ease of bleaching.	Pulp produced has high strength and fine texture. Suitable for the production of rayon, cellulose derivatives and high strength paper.	The wood is softened sufficiently to allow mechanical separation of fibers without excess power. Suitable for printing-writing and newsprint papers.

Table-2: Differe nce Between Sufate (Kraft) and Sulfite Processes

Characteristics	Sulfate, or Kraft pulp(Alkaline)	Sulfite Pulp (Acid)
1. Cellulosic or fibrous raw material	Any kind of wood, soft or hard	Coniferous; must be good color and free from phenolic compounds
2. Cooking liquor or white liquor composition	60% NaOH 25% Na_2S 15% Na_2CO_3	Composition depends on process modifications, but all use SO_3 (a)Magnifite process: Mg(HSO3)2 + free SO2 in acid media (b)Neutral Sulfite process: Na_2SO_3, Na_2CO_3, $NaHCO_3$ (c)Acid Sulfite process: $NaHCO_3$, Na_2CO_3
3. Cooking conditions	Time 2 – 5 h, temp 170 – 176 deg. C, Pressure 660 – 925 kPa	Time 6 – 12 h, temp 125 – 160 deg, C, Pressure 620 – 755 kPa
4. Chemical recovery	Most of the process is devoted to the recovery of cooking chemicals, with recovery of heat through organic matter dissolved in liquor from wood; Chemical losses from the system is replenished with salt cake and Na_2SO_4	SO_3 Relief gas recovered; magnesium liquor recovered and reused after wood digestion and pulp washing
5. Material of construction	Digesters, pipelines, pumps, and tanks can be made of mild steel or, preferably of stainless steel	Acid and magnifite process requires digester lining of acid-proof brick; fittings of chrome-nickel steel, lead and bronze
6. Pulp characteristics	Brown color; difficult to bleach; strong fibers; resistant to mechanical refining	Dull white color; easily bleached; fibers weaker than Kraft
7. Typical paper products	Strong brown bag and wrapping, multiwall bags, gumming paper, strong white writing and printing paper, corrugated boards and cartons	White grades: book paper, bread wrap, fruit tissue, sanitary tissue

General Process





CONCERNS OF THE CONVENTIONAL METHODS (Mechanical & Chemical)

- The pulp and paper-making industry has major impacts on natural ecosystems, air and water quality and human health.
- As the report and case studies demonstrate, the type and intensity of impacts vary considerably around the world.
- However, a number of common patterns can be seen, and some of the most important are examined in the following three sections. They include:
- **Resources**: the demand for timber and other plant fibres, and the consequent impacts on a range of natural ecosystems, including particularly forests;
    - **Processing**: the impacts of air and water pollution, and of resource use, during the pulping, bleaching and paper-making processes;
    - **Disposal**: the consequences of waste paper disposal.
- **The impact on forests**
    - The increasing importance of pulp and paper-making means that paper consumption now has enormous impacts on forest ecosystems.
    - Natural forests continue to be logged for paper-making, although the industry has often tried to conceal this.
    - Pulp is also the output from some of the world's most intensively managed monoculture timber plantations, which have sometimes themselves been established in the place of native forests.
    - New technology is allowing the use of poorer quality pulp fibre, opening up fresh areas for exploitation including some virtually pristine boreal forests.
    - Plantations seldom offer the ecological or social benefits of other forests.
    - Paper production also sometimes utilises non-timber plant material, which can itself have a number of environmental side effects.
- **Natural forests are still being logged for pulp and to clear land for plantation establishment.**

Details of the Concerns:

- **Excess Use of Water**
  - The pulp and paper industry have been large users of water.
  - Nowadays, strenuous efforts are being made to decrease the water usage, as any treatment of the effluent is made easier if the volume is decreased.
  - Also, by intensive recirculation and reuse of liquid waste streams within the mill, the amounts of contaminants can be reduced in the effluent.
  - Efforts are being made to recycle used water after proper cleaning and purification.
- **Pollutants in Water**
  - The major categories of water pollution of concern to the pulp and paper industry are: suspended solids (mainly fibre), biological oxygen demand, toxicity and colour.
  - Each of these effects can be minimized by internal or external means, external meaning treatment of the final effluent outside the mill.
  - The suspended solids can be decreased internally by recirculating fibre containing process streams within the mill.
  - Externally, suspended matter can be removed from the effluent in a conventional clarifier by settling.
  - Removal efficiencies in the order of 80-90% of the suspended solids are generally achieved.
  - The recovered sludge can be taken to landfill or further dewatered and burnt.
  - Oxygen demand (usually measured as BOD - biological oxygen demand - or COD - chemical oxygen demand) in the effluent can be decreased by in-mill measures, like good washing, recovery of black liquor spills, treatment of methanol containing condensates, and especially by the oxygen delignification process, described in the section on bleaching.
  - However, biological treatment of the effluent is usually required to decrease the BOD sufficiently.
  - This can be done in large stabilisation basins with oxygen supplied by surface diffusion, or in aerated basins in which the oxygen transfer rates are increased by the use of mechanical aerators.
  - Nutrients are often added to enhance bacterial activity and thus promote the biological breakdown of wastes.
  - When space is limited, more intensive processing of effluent is possible by using the activated sludge process.
  - Effluents from pulp and paper mills are only weakly toxic by conventional measurements, especially if they have been through biological treatment.
  - However, the effluent from the bleaching process contains of variety of substances, some of which are known or suspected of being toxic, genotoxic or mutagenic.
  - Chlorinated organics that are produced in the chlorine bleaching processes are of particular concern.
  - There has therefore been a trend to change from chlorine to the much more benign chlorine dioxide as a bleaching agent.
  - If oxygen delignification is used, it will substantially decrease the amount of chlorinated compounds in the effluent.

- Colour can be a problem, especially when the effluent is discharged into receiving waters with a high transparency.
- Most of the colour derives from the bleaching process, and oxygen delignification will help substantially against this pollutant as well.
- External removal of colour can be carried out, but it is difficult and expensive.
- The wastewater that finally leaves the plant is discharged into the river, lake or large water body.
- The quality of water discharged must routinely be monitored and the results should be reported to the Pollution Regulatory Authority.

- **Atmospheric Emission**
  - Chemicals are emitted to the atmosphere as gaseous and particulate emissions (dust).
  - Gaseous emissions consist of sulphur dioxide, nitrogen oxides, chlorine dioxide and reduced sulphur gases.
  - The first two are not generally a problem, and chlorine dioxide emissions can be virtually eliminated by scrubbing with suitable liquids.
  - However, reduced sulphur gases are a major problem because of their intensive odour.
  - The typical kraft mill odour is due to small discharges of hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide.
  - Recovery boilers used to be the major source of emissions of reduced sulphur, but improved technology has mainly eliminated this problem.
  - Collection of sulphurous gas streams from various vents in the pulp mill, and incinerating these gases in the lime kiln or in a dedicated incinerator has also decrease the odour problem, but not wholly eliminated it.
  - Dust (particulate) emissions are in the form of 'saltcake' (sodium sulphate) from the recovery boiler, lime dust from the lime kiln and fly ash from the bark boiler.
  - All these emissions can be decreased to low levels by using efficient scrubbers, and especially by using electric precipitators, which is now the method of choice for removing particulates from all these sources.
  - As for water all discharges into the air should be routinely monitored and reported.

➢ SIGNIFICANCE OF BIOPULPING

- Biopulping, is envisioned as a method for saving energy, reducing pollution and making a stronger paper product.
- **Table-3** shows some of the benefits of biopulping technology.
- The naturally occurring white rot fungi can alter the plant cell wall structure and provides its recalcitrance against biological attack.
- The application of enzymes to wood chips is an attractive alternative way which decreases energy demand in the refining process and to introduce novel functional properties on fibers.
- During refining progression of Scots pine, wood chips treated with manganese peroxidase (MnP) and it was found out that specific energy consumption decreased about 11% as compared to that of untreated reference chips, also in the refining of Norway spruce it was 6% less (Maijala et al. 2008).

Table-3: Benefits of Wood Pretreatment with Selected Fungi

Fungus	Raw material	Benefits	Reference
Physisporinus rivulosus	Sterilized wood chips	Selective lignin degradation; growth in broad temperature range; less refining energy consumption; reduced wood pitch content	Hatakka et al. (2003)
Ceriporiopsis subvermispora	Sterilized wood chips	Selective lignin degradation; reduced refining energy consumption; decreased wood pitch content; improved chemical pulping	Fischer et al. (1994), Akhtar et al. (2000), Bajpai et al. (2003)
Phlebiopsis gigantea	Wood logs	Reduced wood pitch content; superior chemical pulping; lesser refining energy consumption; staining of wood abridged; better debarking	Behrendt and Blanchette (1997)
Phanerochates chrysosporium	Fresh, unsterilized wood chips, wood logs	Reduced energy consumption, decreased pitch content, enhanced pulp quality	Singh and Chen (2008)

- Pre-treatment on spruce with fungi resulted in similar energy savings as MnP treatment.
- Hence MnP treatment seems to be a promising concept for energy savings and fiber surface modifications.
- Biopulping has the potential to be an environmentally kind means of improving both the economics of pulp production and the quality of pulp produced.
- It is reported that cultures of *C. subvermispora* on soft wood and hardwoods, glucan losses usually are very low up to 90 days biotreatment indicating that cellulose is more resistant to the attack by this fungus.
- Environmental Significance
  - ✓ Since the fungal pretreatment is a biological process, environmental influence is expected to be minimal.
  - ✓ When compared to nitric acid pulping, biopulping produce lower yield but uses only a small amount of chemicals without any environmental menace
  - ✓ Fungal pretreatment is effective in improving chemical pulping and bleaching efficiency of kraft pulp.
  - ✓ It follows that paper mills that have bottlenecks in their recovery operations could benefit from decreased active alkali as a result of using fungal pretreatment.
  - ✓ With the same active alkali charge and under the same cooking conditions, treated chips cooking time is less, and a reduction in beating time of unbleached pulp is also observed.
  - ✓ Fungal pretreatment reduces consumption of pulping chemicals and leads to significant reductions in effluent pollution load and emissions of hazardous gasses.
  - ✓ Pretreatment is also responsible for significant improvement in physical properties of the pulp.
  - ✓ From the stand point of environment, BOD, COD, AOX, and colour values are reduced.
- Economical Significance
  - ✓ The fungal pretreatment with *Phanerochates chrysosporium* has been shown to save approximately 30% of energy costs for fiberizing and refining, paper strength properties have been improved, and pitch content has been reduced.
  - ✓ The biomechanical pulp fibers are stronger than the TMP fibers; the amount of bleached softwood pulp in the final product is reduced.

- ✓ Conclusion can be drawn from results of experiments conducted that steaming the wood chips briefly (as short as 15 s) before treatment decontaminates the surface of the chips and allows the fungus to perform effectively.
- ✓ Thus, in biopulping steam exposure eradicates the other miscellaneous sporulating fungi which cause respiratory problems in mill workers.
- ✓ This will reduce cost of cooking chemicals and improve the physical properties of fibres.
- ✓ Cellulose could be depolymerize by using endocellulases produced by *C. subvermispora*.
- ✓ Changes in tensile indexes of *Eucalyptus grandis* biopulps prepared on laboratory and mill scale has been reported by several workers .
- ✓ Biotreated samples are soft and refine well even in lab-scale refiners, giving good quality fibers.
- ✓ When refining is performed in optimized industrial disk refiners, high quality fibers are obtained even from control wood chips.
- ✓ Biopulping helps to reduce the energy in the cooking and beating process.

➢ LIST OF SOME WHITE ROT FUNGI SPECIES USED FOR BIOPULPING

Coriolus versicolor, Dichomitus squalens, Phellinus pini, Phlebia tremellosus, Poria medullapanis, Scytinostroma galactinum, Coriolopsis rigida, Coriolus versicolor var. antarcticus, Peniophora sp., Phanerochaete sordida, Pycnoporus sanguineus, Steccherinum sp., Trametes elegans and *Trametes villosa.*

➢ BIOPULPING PROCESS

- Overview of the Biopulping Process
  - ✓ Mechanical pulping process use wood but consume considerable amount of electrical energy during refining.
  - ✓ In biopulping the wood chips are pretreated with inoculums of fungi prior to refining, the wood chips become softened and more porous.
  - ✓ Consequently, these treated chips are more easily broken apart when they are purified. This reduces substantial energy during refining.
  - ✓ **Figure-12** shows with conceptual overview of the biopulping process.

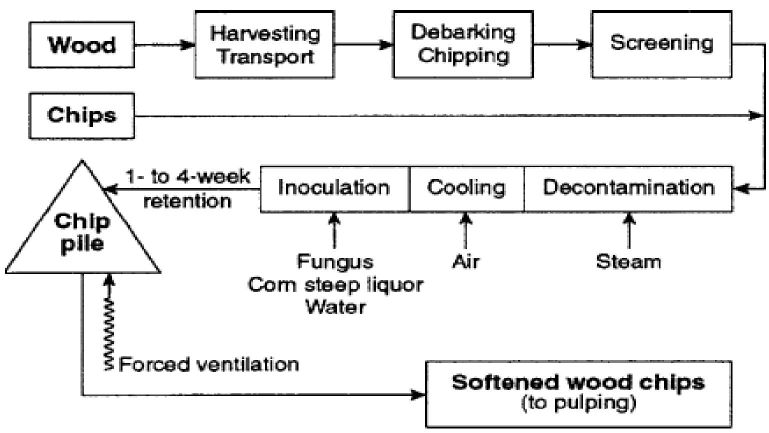


Figure-12:Overview of the steps involved in biopulping process.

- ✓ The biopulping procedure involves decontaminating wood chips with steam to eliminate competitive naturally occurring bacteria and fungi.
- ✓ Next they are sprayed with a dilute inoculum of a selected fungus.
- ✓ Inoculated chips are incubated in an aerated chip pile for 2 weeks.
- ✓ Under warm, moist conditions the lignin degrading fungi colonize chip surfaces and penetrate chip interiors with a network of hyphae.
- ✓ These treated chips are more readily broken apart during subsequent refining, and produces flexible, intact fibers.
- ✓ There are few considerations for a fungus to be used commercially in biopulping:
  - [1] Relatively faster growth rate,
  - [2] Ability to nurture on both hard as well as soft wood,
  - [3] Preferred action against hemicellulose and lignin united with low activity on cellulose,
  - [4] Since the expansion of moulds on chip piles cause health problems for the workers in the pulp and paper industry, fungi should be enable to elicit allergies,
  - [5] Small pigmentation that might decrease pulp brightness,
  - [6] First-rate capability to sporulate in order to cause the inoculation of the wood chips.
- Various species of white rot fungi have been used for biopulping, however, *Ceriporiopsis subvermispora* has proven to be very competitive both on softwoods and hardwoods.
- The physiology and biochemistry of *C. subvermispora* has been studied to allow an intensification of the biopulping process.
- Evaluation of enzymes produced during biopulping process have shown that *C. subvermispora* produces several manganese peroxidase (MnP) and laccase isoenzymes, each exhibiting isoelectric points that vary according to the composition of the medium.
- White rot fungi and their enzymes (specially ligninases and xylanases) are considered for the wood chips treatment of prior to pulping.
- While ligninases attack the lignin content of wood, xylanases degrade hemicelluloses and make the pulp more permeable for the removal of residual lignin.
- Thus, biopulping process not only removes lignin but also some of the wood extractives, thus reducing the pitch content and effluent toxicity.
- As the white rot fungi consumes some of the pitch enclosed in the lignocellulosic material (wood chips), both the toxicity and biological oxygen demand (BOD) content of mill process water are decreased.
- Also these pulps are more responsive to oxidative and reductive bleaching chemicals.
- Biopulping produces a superior mechanical pulp, therefore it can be considered a viable alternative to chemical pulping and it cost less to construct because it requires simpler equipment and produces an effluent with reduced BOD.
- For an existing pulping plant for biopulping required no additional equipment.

- However, equipment for asepsis and inoculation, such as a conveyor system, steam, and inoculadelivery, is needed.
- Paper made from pretreated wood chips are robust than that made from conventional mechanical pulp.
- Moreover it displays better optical properties, except for brightness.

CONSTRAINTS OF BIOPULPING

- No single organism is ideal for all biopulping applications.
- Enzymes are catalyst they can be used in mill scale.
- The organisms of choice must be capable of accomplishing delignification in a reasonable period of time.
- High moisture content (around 55–60%) should be kept in wood chips during the biotreatment step to ensure an optimal colonization and penetration of fungalhyphae.
- The degree of asepsis should be controlled to ensure a successful wood colonization by the particular fungal strain used depending on its resistance against contamination and ability to compete with the microbial biota existing in the wood chips.
- Data obtained from a single fungal species or from abundant species considered altogether point to the fact that there is no clear correlation between biopulping efficiency and wood weight or component losses.
- Enzymes are known to be precise, but their action is usually considered to be restricted on wood, due to the relatively high MW.
- On the other hand, enzymes may be more easily applicable to mill-scale operation.
- Removal of some minor wood components such as resins or polyphenols (extractives) could be related to the biopulping gain.
- According to the reports, the main limitations of biological pretreatment process are slow in reaction rate and complexity in process control.

CONCLUSIONS

- The demand for the wood pulp is expected to increase more in near future, so there will be more stress on pulp and paper industry.
- A good number of the pulping industries are still using conventional methods i.e., mechanical and chemical pulping.
- The pulp and paper industry competes in a global marketplace, where energy and material costs determine profitability.
- Manufacturing of pulp uses a lot of chemicals as well electrical energy.
- Also bleach plant effluent are responsible for the generation of large amount of wastewater which contain high toxicity and colour.
- Lignin and other degradation products are the most important contributors to environmental pollution.
- These constraints associated with usual pulping methods can be overcome with the biopulping technology.
- The industrial application of biopulping can be successfully established to save chemicals and to augment pulp quality.

- As biopulping process reduced the cooking time thus consumption of energy decreases and also there is a significant rise in paper strength.
- The rise in price of wood and high energy demand is a serious concern thus biopulping can be the best alternative for improving pulp technology.
- Biopulping holds enormous potential in the future of the paper making industry making it viable both economically and environmentally.
- It might play a key role in maintaining environment unpolluted.
- Undoubtedly, biopulping is set to transform the paper production to a basis that is more harmonious to the biosphere.

International Paper Company, a pulp mill that makes fluff pulp for use in absorbent products with the kraft process (USA).

Commercialization of Biopulping: An Energy-Saving and Environmentally-Friendly Technology for the Paper Industry

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ABSTRACT

The biopulping process for treating wood chips prior to mechanical pulping has been scaled up through an extensive development program and has been demonstrated at 50 ton semicommercial scale. Detailed engineering analyses and design studies have been performed for full production-scale mill implementation, and the technology is ready for commercial use.

This paper will summarize the 50 ton pilot scale equipment constructed to allow in-mill evaluation tests, and design studies for commercial scale implementation of biomechanical pulping. Economic evaluation of the process will be presented, including production economics and operating costs.

The economic advantages of biomechanical pulping derive from several effects, led by significantly improved strength properties and significantly reduced refiner energy requirements. Production cost savings can be substantial. For example, at least $5 million/year net savings before license fees can be realized in an operation producing 242 ton/d of biomechanical pulp for 800 ton/d of blended LWC furnish.

The work is being funded by the Wisconsin Department of Commerce and the U.S. Department of Energy through its Inventions and Innovations program and the National Industrial Competitiveness through Energy, Environment, and Economics (NICE^3) program.

INTRODUCTION

Biopulping is the process of treating wood chips with a selective lignin-degrading fungus prior to pulping. The microscopic fungal action modifies the internal bonding in the wood fiber composite structure, producing "softened" chips that are far superior for mechanical pulping. This new process has progressed through an extensive development program ranging from laboratory studies to large scale demonstrations. Full-scale process implementation work is now underway.

The current process originated with research conducted at the University of Wisconsin Biotechnology Center and the USDA Forest Service Forest Products Laboratory (FPL), Madison, WI. Patents on the technology are held by the Wisconsin Alumni Research Foundation (WARF). Recently, BioPulping International, Inc. (BPI) was formed to commercialize the technology under exclusive license from WARF. Collaboration and support from state and federal agencies and institutions continues. Active projects with industrial partners are underway.

This paper describes the process economics of biopulping for application to mechanical pulping. Equipment constructed to allow in-mill evaluation of the process is described, along with an engineering design study of a full-scale implementation. Process development work is described in [1].

BASIC PROCESS DEVELOPMENT RESULTS

The biopulping process is the product of an extensive R&D program. Details of the original development work are presented in [2-7].

The following outcomes were achieved:

An extensive search and screening effort identified a fungus (*Ceriporiopsis subvermispora*) with outstanding selective biopulping efficacy and consistency of performance.

A successful surface steaming method of decontamination was developed to suppress competitor organisms economically.

An inexpensive inoculum nutrient was identified that permits very minute quantities of fungal inoculum to be effective on the large scale.

The process conditions required for optimal biopulping effect were determined.

The process was demonstrated at the 50 ton scale in proving trials.

The results established conclusively that the process provides the following benefits for mechanical pulping: fiber strength improvement, refiner electrical power savings, improved uniformity of quality in the chips produced, and pitch reduction. These are achieved with very low yield loss and no observed environmental liabilities. Some brightness loss occurs, but this can be restored using additional bleach chemicals.

Economic Analysis

The primary economic advantage of biopulping results from the greatly improved strength of the biomechanical pulp fibers. Substitution for expensive chemical pulp produces large savings. For instance, in the case of LWC, data confirm a replacement of kraft with biomechanical pulp amounting to 5% of the furnish.

In addition to strength improvement, refiner electrical power savings are substantial. For LWC, at least 33% less refiner energy is required.

These two major savings sources are readily quantified. Potentially supplementing these are several ancillary benefits worthy of note, although they will not be quantified and credited here. First, biopulping reduces the pitch content of the chips. Further, other spore–forming organisms are eliminated. Additionally, biopulping tends to reduce variations present in feed chips, resulting in improved uniformity in refiner feed. Also, the reduction in refiner energy requirement can provide a possible refiner throughput increase in situations where this would be advantageous.

Expenses associated with biopulping include:

Inoculum and nutrient supply cost.

Steam for decontamination and ventilation conditioning.

Power for ventilation and other equipment.

Wood yield loss (< 2%).

Bleaching chemical consumption increment.

Labor, maintenance, and overhead for the biopulping unit.

To see the net effect of the above savings and expense factors, consider the example case of LWC production described in Table I. The base case blends conventional mechanical pulp, kraft pulp, and groundwood at rates of 220, 400, and 180 ton/d respectively. With biopulping, these rates become 242, 360, and 198 ton/d respectively. Table II summarizes the relative production costs for conventional mechanical and biomechanical pulps, including 33% refiner electricity savings and biopulping operating costs (northern U.S. climate). Table III shows the total furnish production costs. The net savings amount to about 18 \$/ton of furnish pulp, or \$5 million/y for the example mill before payment of license fees.

Table I. Basis for 800 ton/d LWC Example.

TMP:	220 ton/d	Wood:	$ 80 /ton
Kraft:	400 ton/d	Kraft:	$ 500 /ton
GW:	180 ton/d	GW:	$ 233 /ton

Production:	350 d/year
Refiner power:	3,033 kW·h/ton
Electricity cost:	0.04 $/kW·h
TMP yield:	95 %
TMP / Kraft / GW:	27.5 / 50.0 / 22.5 %

Table II. TMP Pulp Manufacturing Costs ($/ton)

Cost	Conventional	Biopulping TMP
Energy:	121	81
Wood:	84	86
Bleach:	10	16
Other Costs:	60	60
Biotreatment:	-	15
Total	275	258

Table III. Total Furnish Manufacturing Costs

Conventional			
Pulp	Ton/d	$/ton	10^6 $/year
TMP	220	275	21.2
Kraft	400	500	70.0
GW	180	233	14.7
Total	800		105.9

Biopulping			
Pulp	Ton/d	$/ton	10^6 $/year
TMP	242	258	21.9
Kraft	360	500	63.0
GW	198	233	16.1
Total	800		101.0

CURRENT ACTIVITIES

Mobile Pilot Plant

Since biopulping has been demonstrated at the 50 ton batch scale, the remaining tests needed for commercial adoption involve demonstration of commercial paper machine operation and resulting sheet properties. To allow these tests, and anticipating that various producers with different products will desire individual in-mill confirmation, a mobile pilot plant facility has been designed and constructed. This facility is designed to produce 50 ton batches of biopulped chips at the mill site.

The processing equipment is mounted on two trailers. The first one contains the decontamination and inoculation equipment (see Figures 1-3). In a 12 h operation it will lay out a 50 ton batch of inoculated chips in a semicircular arc pile. Underneath the pile is a distribution tunnel system for the ventilation air (Figure 4). The second trailer (Figure 5) contains the ventilation/conditioning equipment and transport space for the portable under-pile ventilation tunnel. This system allows mill-site tests to be conducted in a modest space requirement and with only minor site provisions. After the 14 day bioreaction time, the biotreated chips are reclaimed from the pile and fed to the mill as a 50 ton batch.

Figure 1 show the steam injection manifold feeding the decontamination steaming conveyor. The conveyor lies parallel to the integral steam boiler mounted on the trailer. Figure 2 shows the chip cooling system during assembly. Figure 3 show the pivoting inoculation/pile-building conveyor cantilevered off the rear end of the trailer. This conveyor swings through a semicircular arc, depositing the inoculated chips on top of the ventilation tunnel to form the arc-shaped incubation pile. The conveyor rotates forward and stows for highway transport. Nominal throughput for the inoculation/pile-building system is 4 ton/h.

Figure 4 shows a portable section of the ventilation tunnel, which is positioned on the ground to run along the centerline of the incubation pile. Figure 5 shows the second trailer with the ventilation /conditioning equipment that feeds the air tunnel. This system maintains careful control of the temperature and humidity of the air fed to the pile. It adjusts to remove the metabolic heat release over the 14 day incubation period while accurately maintaining the chip pile temperature profile and moisture content.

Figure 1. Mobile pilot plant inoculation and pile-building trailer: Decontamination steaming conveyor alongside of boiler.

Figure 2. Chip cooling belt and blower system (partially assembled).

Figure 3. Decontamination and inoculation trailer end view. Rotating inoculation/pile-building conveyor raised in operating position.

Figure 4. Section of portable under-pile ventilation tunnel.

Figure 5. Ventilation/conditioning equipment trailer.

Engineering Study for Production Plant

Harris Group, Inc. was commissioned to prepare a preliminary plant design and capital cost estimate for a full-scale production facility for a potential first site of commercial implementation. Results of this study will be described in the conference presentation.

CONCLUSIONS

Detailed engineering analyses and design studies have been performed for full production-scale mill implementation of biopulping as a pretreatment for mechanical pulping operations. The technology is ready for commercial deployment. A mobile pilot plant has been constructed to permit direct in-mill testing of 50 ton batches by prospective paper mill adopters.

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