Optimization Of Kraft Pulping: Investigation Of The Role Of Chemicals At Each Process Stage

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Abstract

The pulp and paper industry is a major contributor to the global economy providing essential materials for packaging communication and hygiene applications. Among the various pulping methods the Kraft process is the most widely used due to its ability to produce high-strength pulp and its efficient chemical recovery system. This study presents an overview of the pulp and paper industry with a focused discussion on the Kraft pulping process and the role of chemicals involved at different stages of production. The influence of key operational parameters such as chemical composition temperature and cooking time on pulp yield and quality is examined. In addition current industrial trends and environmental challenges associated with Kraft pulping are discussed emphasizing the need for sustainable and eco-friendly practices. The study highlights the importance of optimizing chemical usage to improve pulp properties while minimizing environmental impact thereby supporting efficient and sustainable paper manufacturing.

Key words

Kraft pulping, Chemical pulping process, Pulp and paper industry, Process optimization, Sustainable paper manufacturing, Environmental impact.

I. INTRODUCTION

The pulp and paper industry is a vital component of the global economy providing essential materials for communication packaging construction and hygiene applications. The industry operates on a large scale producing a wide spectrum of products ranging from commodity papers such as newsprint and cardboard to specialized papers used in electronics medical applications and high-strength materials. The magnitude of global production and trade highlights the importance of efficient and reliable pulping technologies particularly the Kraft process which dominates industrial pulp production.

The industry is strongly influenced by economic factors including fluctuations in supply and demand raw material availability and energy costs which significantly affect production efficiency and profitability. Rising environmental awareness and consumer demand for sustainable products have driven the adoption of environmentally responsible pulping and bleaching technologies. Simultaneously digitalization and increased reliance on electronic media have reduced demand for traditional printing and writing papers compelling the industry to diversify its product portfolio and focus on value-added segments.

The pulp and paper sector produces a diverse range of products including packaging papers printing papers tissue products and specialty papers designed for specific industrial and technical applications. Each category requires carefully controlled manufacturing processes to achieve desired physical and chemical properties. Consequently the industry continues to evolve through process optimization and technological advancements to meet changing market demands while addressing economic and environmental challenges.

II. WOOD AS A PRIMARY RESOURCE

2.1 Abundance and Renewability of Wood

Wood is the primary raw material for pulp and paper production. It is a naturally abundant resource, and its renewability is a key advantage, especially when compared to non-renewable resources. Sustainable forest management practices are essential to ensure the long-term availability of wood resources and to mitigate environmental impacts. These practices include reforestation, responsible harvesting, and the conservation of forest ecosystems. Emphasizing the environmental benefits of utilizing wood, particularly from sustainably managed forests, is crucial in the context of growing environmental awareness.

2.2 Types of Wood: Softwood vs. Hardwood Characteristics

Wood is broadly classified into two main categories: softwood and hardwood. Softwood comes from coniferous trees (gymnosperms) like pine and spruce, while hardwood comes from deciduous trees (angiosperms) like oak and maple. These types of wood differ in their anatomical and chemical composition, which affects their suitability for various pulping processes and paper products. Softwood fibers are generally longer, providing greater strength to the paper, which is why they are preferred for products where strength is a key requirement. Hardwood fibers are typically shorter, contributing to paper's smoothness and printability. Kraft pulping can utilize both softwood and hardwood. The benefits of softwood are that it yields thin and long cellulose fibers.

2.3 Chemical Composition of Wood: Cellulose, Hemicellulose, and Lignin

The chemical composition of wood is complex, with three main components: cellulose, hemicellulose, and lignin. Cellulose is a linear polysaccharide composed of glucose units and is the primary structural component of wood fibers, providing strength and flexibility. Hemicellulose is a branched polysaccharide that is closely associated with cellulose and affects the paper's properties like strength and water absorption. Lignin is a complex polymer that provides rigidity and structural support to plant cell walls. In the pulping process, lignin must be separated from cellulose to produce paper. Understanding the chemical structure and properties of these components is essential for optimizing the pulping process.

III. PULPING: THE FUNDAMENTAL PROCESS

3.1 Definition and Objectives of Pulping

Pulping is the process of separating wood fibers from each other to create pulp, which is the raw material for paper manufacturing. The primary objective of pulping is to remove lignin and other non-cellulosic components from the wood matrix while preserving the integrity of the cellulose fibers. This separation can be achieved through mechanical means, chemical treatments, or a combination of both. The quality of the resulting pulp is determined by the pulping method and significantly influences the characteristics of the final paper product.

3.2 Mechanical Pulping Methods

Mechanical pulping methods rely on physical forces to separate wood fibers. These methods include groundwood pulping, where wood logs are pressed against a rotating grindstone, and thermomechanical pulping (TMP), which involves grinding wood chips under the influence of heat and pressure. Mechanical pulping is characterized by high yield, meaning a large proportion of the wood is converted into pulp. However, the resulting pulp contains a significant amount of lignin, which contributes to lower strength and a tendency for the paper to yellow over time.

3.3 Chemical Pulping Methods: A Comparative Analysis

Chemical pulping methods use chemical reactions to dissolve lignin and separate wood fibers. These methods offer advantages in terms of pulp strength and quality compared to mechanical pulping.

Sulfite Process

The sulfite pulping process involves using sulfurous acid and its salts to dissolve lignin. The process operates under acidic conditions. While it was historically significant, it has been largely superseded by the Kraft process due to limitations in the range of wood species it can process and environmental concerns related to its effluents. Sulfite pulp is used in some specialty papers, but its overall production volume is much lower than Kraft pulp.

Alkaline Pulping (Kraft)

Alkaline pulping, most notably the Kraft process, utilizes an alkaline solution to delignify wood.

Kraft pulping is the dominating pulp manufacturing process in the world. Today this process is most widely used, with a production of 70-80% of the total pulp.

IV. FOCUS ON KRAFT PULPING

4.1 Dominance of Kraft Pulping in the Industry

The Kraft pulping process has become the dominant method in the pulp and paper industry due to its efficiency, versatility, and ability to produce strong pulp from a wide variety of wood species. The process's chemical recovery system, which allows for the regeneration and reuse of pulping chemicals, contributes to its economic viability and reduces its environmental impact compared to older processes. Kraft pulping process is the most widely used pulping process globally.

4.2 Advantages and Disadvantages of the Kraft Process

The Kraft process offers several advantages. It can process virtually any wood type, including softwood and hardwood, and produces pulp with superior strength, making it suitable for a wide range of paper products. The efficient chemical recovery system minimizes waste and reduces operating costs. However, the Kraft process also has disadvantages. It is associated with the release of odorous sulfur-containing compounds, although modern mills employ technologies to mitigate these emissions. The process can also generate wastewater that requires treatment to minimize its environmental impact.

4.3 Environmental Considerations and Sustainability

Environmental considerations are increasingly important in the pulp and paper industry. Kraft pulping, while efficient, has historically been linked to environmental challenges, including air and water pollution. Air emissions, particularly sulfur compounds, can contribute to odor and air quality issues. Wastewater from the pulping process contains dissolved organic matter and chemicals that require treatment to reduce their impact on aquatic ecosystems. Modern Kraft pulping mills implement various technologies to improve sustainability. These include closed-loop systems to minimize water usage and effluent discharge, advanced treatment systems to remove pollutants from wastewater, and technologies to reduce air emissions. Sustainable forest management practices are also crucial for ensuring the long-term environmental viability of the industry. The main benefit of the Kraft pulping process is that used pulping chemicals can be recovered economically. About 90% of the chemicals can be recovered.

V. KRAFT PULPING: DETAILED PROCESS - RAW MATERIALS AND INPUTS

5.1 Kraft pulping process

Sulfate or *Kraft pulp* is one of the chemical pulping processes. It is manufactured by alkaline method. Kraft pulping process is the dominating pulp manufacturing process in the world. Today this process is most widely used with a production of 70-80% of the total Pulp.

5.1.1 Raw material

Although soft wood are mostly used but any type of soft or hard pulp wood can be used for Kraft pulp manufacturing. The benefits of soft wood are that cellulose fiber is thin and long.

Cooking chemicals, this is known as white liquor. The white liquor contains the active cooking chemicals NaOH and Na_2S. NaoH and Na2S are used for cooking the wood chips in the digester. There is no fixed percentage of the chemicals NaOH and Na_2S in the white liquor, but it is better to keeping 25-35% sulfidity (based on Total Titratable Alkali). Low percentage of sulfidity (especially below 15%) may affect on the reaction rate and pulp quality.

Black liquor is used as makeup liquor to balance the liquid requirement. The ratio of the liquor to wood might be between 3 and 5 approximately. The concentration of the liquor should not be more dilute, it may be affect on the reaction rate. Furthermore steam is used for receiving temperature and pressure. Pressure and temperature are very important for cooking process. During *Kraft pulping* process above 360 ^{0}F temperature the strength of the fiber and yield percentage are greatly affected.

5.2 Description

Digester cooking process is two type; batch type and continuous type process. The capacity of the digester may be 10-20 ton pulp.

In batch type process, chips are taken a certain volume of the digester. Then a calculated amount of white liquor (contains NaOH and Na_2S) or caustic soda and black liquor (if **needed**) are taken into the digester, so that the cooking liquor soak and cover the chips. After the digester filled with chips and liquor, then the heat is applied on contents by cooking liquor circulation method though a heat exchanger. The circulating liquor is collecting from the middle point of the vessel through a pump and deliver to the top and bottom point of the vessel. Temperature is control from 320 to 350 ^{0}F. And pressure is control from 110 PSI to 150 PSI. To reach maximum temperature and pressure, it is needed from 1.5 hours to 3.0 hours. After reaching the maximum temperature and pressure then, the content is allowed to stay one to three hours to complete the cooking reaction. This time is called cooking time. The cooking time varies basis on uses purpose of the pulp. At this time the chips becomes softened. After completing the cooking time the content are ready to discharge into blow tank.

Pressure release control valve: At the top of the vessel, there is a pressure release control **valve** to release air and other non-condensable gases.

The main benefit of the *Kraft pulping process* is that used pulping chemicals can be recovered **economically**. About 90% of the chemicals can be recovered.

Kraft pulping process is the most used *pulping process* in the world. In this process lignin goes into the reactions with the cooking liquor chemicals and split into fragment. These fragments dissolved with the solution and wood disintegrates into fiber. During the *kraft pulping process*about 80 percent of lignin, 50 percent of hemicelluloses and 10 percent of celluloses are dissolved.

In Kraft pulping process, cooking liquor chemicals are NaOH and Na_2S. Although the high percentages of sodium sulfide darken the pulp color but it has huge benefits; it increase penetration of the wood, uniform cooking, low cooking time, high yield and strength. The Na_2S hydrolyzed in presence of water and gives hydroxide and hydrosulfide. The reaction is reversible and can be described as below:

$$Na_2S + H_2O \leftrightarrow NaOH + NaSH$$

In kraft pulping process NaOH is the key chemicals for completed the cooking process. Temperature also plays a significant rule. The main chemical reactions in the kraft cooking process can be expressed as:

NaOH + NaSH + Wood → Na-compound + S-compound

Here the wood represents various organic compounds as like: Cellulose, Hemi-cellulose, Lignin, fats, and Resins.

The average wood chemical compositions are:

- Cellulose: 40-45 %
- Lignin: 18-32 %
- Rest are Hemicelluloses, fat, Resins.
- **After the karft cooking process the chemical composition of the pulp are:**
- Cellulose: 70-75 %
- Lignin 2-5 %
- Rest are Hemicelluloses and others organic compounds.

At first step of the *karft pulping* process the white liquor penetration and diffusion into the interior of the wood chip.

When the wood chips are heated the delignification reactions starts, but the reaction rate is very slow. The specific kraft cooking temperature is generally 135-175°C in which the lignin structure and others organic compounds are broken down into small fragments and solubilized into the alkaline solution.

During the cooking process, mainly the alkali is consumed by five different ways: (1) reaction with lignin, (2) Neutralization of different organic acids (original wood acids or produced by hydrolysis) (3) reaction with resins in the wood (4) dissolution of carbohydrates and (5) adsorption by the fibers. About 60-70% of alkali is consumed by neutralizing of the organic acids; whereas about 20-30% of alkali is consumed by the degradation products of lignin.

5.3 Reactions with lignin

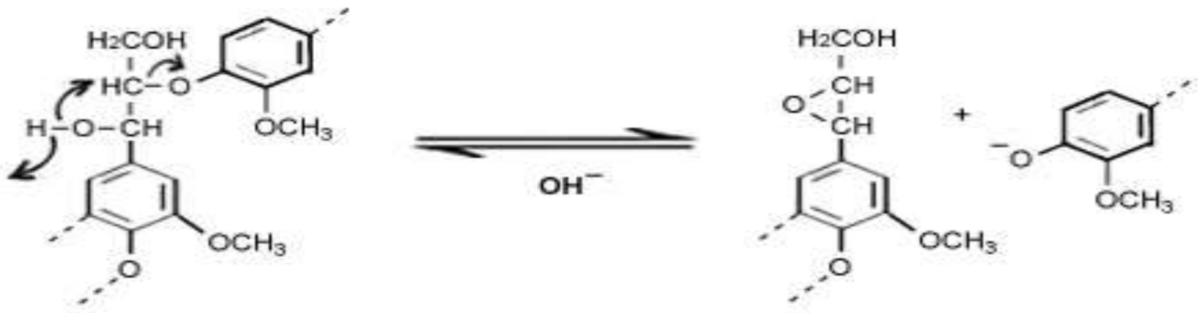
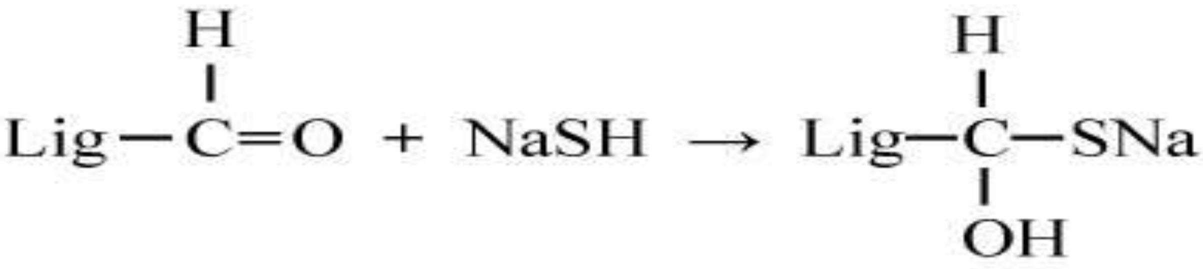


Figure 1 Reaction with Lignin

Lignin is chemically split into fragment by hydroxyl (OH and hydrosulfide (SH) ions. If the percentages of Na2S are low then the fragmentation process can be proceed through condensation reactions, either with themselves or undissolved lignin or carbohydrates; which is very difficult to remove.

By blocking the reactive groups as like hydroxyl in benzyl alcohols or alkyl ether groups hydrosulfide ion reduce the condensation reactions (sulfur combine with reacting groups and produce thiolignin). This compound easily goes into alkaline solution and removed.



$$\mathrm{Lig-\overset{\displaystyle H}{\overset{|}{C}}=O + NaSH \rightarrow Lig-\overset{\displaystyle H}{\overset{|}{\underset{\underset{\displaystyle OH}{|}}{C}}}-SNa}$$

Figure 2 Formation of Thiolignin

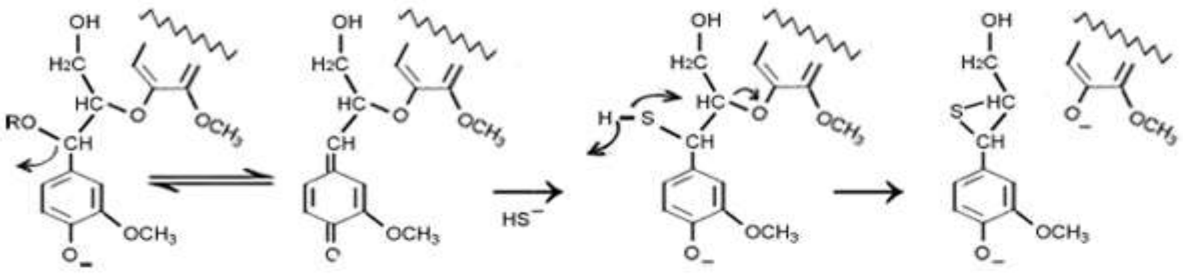


Figure 3. Cleavage of β-O-4 Ether Linkages in Lignin during Kraft Pulping.

The sulphide promotes and accelerates the cleavage of the ether links in phenolic units. In alkaline conditions the carbon-carbon bond is more stable than the oxygen-carbon bonds, hence the cleavage of oxygen-carbon bonds are the most significant reaction in the cooking process. Through this reaction phenolic hydroxyl groups and carboxylic compound are produced from the cleavage of the aryl-alkyl-ether and dissolved as phenolate and carboxylate ions.

In presence of alkali, the carbohydrates (cellulose and hemicellulose) are degraded and huge amount of cooking liqor is consumed. Hemicelluloses are a polysacchrrinic compounds including galactoglucomannan, arabinoglucoronxylan, arabinos, arabinogalactane, xylan, glucoronxylan, glucomannan, glucorans, galactorons etc. During cooking process the polysacchrrinic compounds are hydrolysised and degraded into saccharine acids. For neutralization of these organic acids another portion of alkaline is consumed. In this way hemicelluloses dissolved into the pulping liquor. During kraft pulping process about 50% of hemicelluloses and 10% of celluloses are dissolved.

In the cooking reaction Most of the extractives, fat, resins are converted into soap and dissolved in the cooking liquor. This are generally floated of from the black liquor in the evaporation area and can be processed to make tall oil.

In this process many unwanted gas are produced that are non dissolvable in the black liquor such as CH_3SH, CH_3SCH_3, $CH_3S_2CH_3$ etc. sometimes these unwanted gas should be released. Again, others countable by-products are turpentine and methanol.

5.4 Pulp Washing

There are different methods are available for pulp washing such as rotary vacuum washer, rotary pressure washer, pressure and atmospheric diffusion washers, horizontal belt washer and dilution/extraction equipment. Among them the rotary vacuum washer method is well-known to paper makers for long times. This method of pulp washing is employing a series of rotary vacuum washers working in a countercurrent flow system. Here, rotary vacuum washer is described.

Used chemical recover is the most important part for Kraft pulping process. The chemicals are separated from fiber as black liquor. Concentration of the black liquor is very significant for recovery; on the other hand pulp should be well washed. In one word, the liquor should be minimum dilution to get better evaporation benefits and better wash pulp.

Rotary Vacuum Washer may contain three or four single stages. These arrangements are necessary to achieve an overall satisfactory elimination of 99% of the “washable” liquor solids. Every single stage contains a rotating vacuum drum washer. The drum washer is a cylinder that covered with clothes. The clothes of washer may be made by synthetic fabric or metal wire. Washer drum rotated in a vat, which contains the mixer of pulp and liquor. When the rotating drum washer enters the mixer, then the vacuum is started and a thick layer of pulp developed on the clothes of washer. The pulp layer is disconnected by a plate (known as doctor blade) and ready for next stage. The black liquor is collected in a tank. To keep minimum dilution of the black liquor a typical countercurrent mechanism arranges.

There are many factors that affect brown stock washing displacement efficiency such as fiber characteristics, shower characteristics, sheet formation/thickness, and operating factors. Fiber characteristics involve Pulping process, Species, Stock hardness and freeness; whereas Shower Characteristics engages the method of showering application, nozzles, temperature and shower distribution. If the shower does not place at right position and does not choice right nozzles, then it may create foam and effects on brown stock washing.

Dilution factor, air in stock, stock temperature, fabric mesh and fabric unclean are most significant operating factors. Normally, a higher dilution improves pulp washing performance. But at this time, it dilutes the black liquor that effects on evaporation. Hence, it is batter to keep balanced to get washing benefit achieved. In this system a specific amount of air is continuously pulled throughout the pulp sheet, it may create foaming problems and effects on pulp washing. It could be overcome by installing large seal tanks; it helps air to escape and foam bubbles to break. Sheet formation that depends on loading, Vat consistency and rotational speed also effects on pulp washing.

Pulp Properties:

In this initial and second stage of washing, the Brightness of the pulp is around 28% and 35 %, respectively. This unbleached pulp is going to the next stage for Post Oxygen press or Press 3 for delignification by Oxygen.

5.5 Oxygen delignification process

Oxygen Delignification is one of the most significant and well proven pulp bleaching process for ECF (elemental chlorine free) and TCF (total chlorine free) bleached pulp production. It is the first stage of the bleaching process; in this case oxygen and alkali are used to eliminate a portion of the residual lignin in the pulp after cooking. This stage is frequently recognized as a “bridging step” between cooking and final bleaching. This process is work at high temperature and pressure. The process may be operating at medium consistency or high consistency; but medium consistency system is mostly used due to easy maintaining. It can be single or multiple stages. This bleaching process is environmental friendly and cost effective.

With a single *Oxygen Delignification* stage, it can be reduced about 30-50% lignin and colored substances from unbleached pulp. Whereas with the external stage, it can be reduced about 60 -70%. After *oxygen bleaching* the lignin content may reduce to about 1.5-2% from 3-5% or kappa number 8-10.

Condition for oxygen delignification

- Pulp consistency 10 – 15%
- Retention time: 50 – 60 min
- Temperature: 80 – 120 °C
- Pressure: 600 – 800 kPa (or 6 – 8 bar)
- Alkali: 20 – 25 kg/ton
- pH value: above 10
- Oxygen consumption: 20 – 25 kg/ton

Temperatures and pressures

Oxygen is a low reactive oxidant. Therefore, oxygen delignification requires elevated temperatures from 80°C to 120°C and pressures from 6 to 8 bars for increase reactions rate. However, an unacceptable degradation of carbohydrates is shown in case of high temperature above 120°C.

NaOH and pH

Amount of NaOH and pH value is very significant for oxygen delignification. The pH value should be above 10, it is better keeping around 12 for effectiveness. If the oxygen gas bubbles are not well distributed, it may hamper on effectiveness. On the other hand, high alkali charges arises loss of yield and pulp strength.

Advantages of oxygen delignification

Environmental friendly

Oxygen Delignification process is environmental friendly process which is helping to reduce the uses of chlorinated chemicals in next steps. These chlorinated chemicals are produced some organic halide compound which is very poisonous for our health. The other environmental benefits are lower BOD, COD and fewer colors in effluent, as all the effluent from the oxygen bleaching system is recycled back to the recovery boiler.

Cost effective

Oxygen Delignification significantly reduced the consumption of bleaching chemicals (such as chlorine gas, chlorine dioxide, ozone, hydrogen peroxide) of next stages. Although the installation cost of oxygen bleaching plant is expensive, but the overall oxygen production cost is extremely minimal.

All the effluent containing spent chemicals and reaction products from the oxygen bleaching process is recycled back to the recovery boiler. Whereas without this stage all the effluent would go to wastewater treatment plant due to presence of corrosive chlorinated compounds, which might be harmful for recovery boiler. Hence, it reduced chemical consumption cost.

By optimizing the cooking kappa number in cooperation with the oxygen delignification, it can enhance pulp yield percentage and maintained pulp strength. After this stage there are lower shives and extractives content.

Disadvantages of Oxygen Delignification

Oxygen bleaching process is less selective compared to others bleaching agent, as the process undergoes with the free radical reactions system. This can lead to significant degradation of polysaccharides (by hydroxyl radicals); consequent of carbohydrate reactions the viscosity of pulp and fiber strength could reduce. It is a drawback of oxygen bleaching.

Another significant disadvantage of Oxygen delignification is that it is weak reactive oxidant. Therefore, it required alkaline conditions, high temperature and pressure to obtain a reasonable reaction rate. Raising the alkali charge also creates a negative effect.

Moreover, primary high installation cost of oxygen delignification is another drawback.

5.5.1 Lignin Reactions during oxygen bleaching

At lowest energy state Oxygen molecule contains two unpaired electrons; each of these electrons has an affinity to opposite spin of other electrons. Therefore it can act as a free radical. Although at normal temperature it will un-reactive, but at higher temperatures and alkaline condition it has a strong tendency to react with organic compounds.

At initiated state phenolic hydroxyl group in lignin reacts with alkali to generate a phenolate ion. The phenolate ion then reacts with oxygen to form a resonance-stabilized phenoxy radical and a superoxide anion.

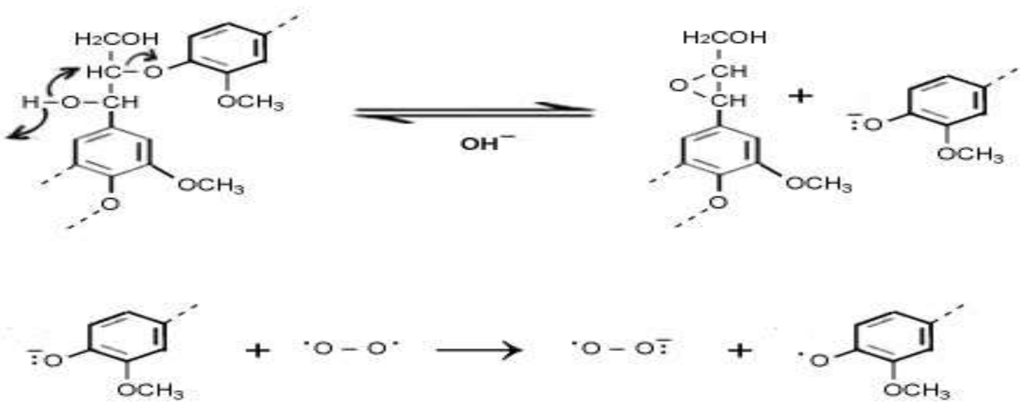


Figure 4 Lignin Reactions during Oxygen Bleaching

Then the phenoxy radical undergo reaction with themselves or with oxygen species radicals for example hydroxyl (HO•), hydroperoxy (HOO•) and superoxide (O2•–) and produce different organic acids, carbon dioxide and other lower molecular mass organic compounds through side chain elimination, ring opening and demethoxylation reactions.

5.6 Chlorine dioxide bleaching

Chlorine dioxide is an oxidizing agent for pulp bleaching. The chemical formula of this *chlorine dioxide bleach* is ClO2. It is a yellowish-green gas, bad odor and liquefied in 11ºC which is red in color. It is an ECF (elemental chlorine-free) bleaching processwhich is currently most important bleaching technology in worldwide, especially for sulfate pulp. It is highly soluble in water, particularly in cold water. *Chlorine dioxide bleaching* is used in single or multi-stages process. Unlike chlorine, it does not react with water. It remains as a dissolved gas in water. It selectively attacks the phenolic groups of lignin without degrading cellulose fiber, allowing for increased yield and higher strength bleached pulp. For this property (selectivity), normally it is used in later bleaching stages when the lignin content is lower. Commercially, it is first started in Sweden in 1946 for pulp bleaching. After 1950 it becomes a well established as bleaching agent for kraft pulp.

Effect of pH

The pH is a significant factor for chlorine dioxide bleaching. At high pH, it is less corrosive and rapidly reacts. A fraction of chlorine dioxide is converted to chlorite, chlorate or chloride. The overall reaction mechanisms are quite complex. The formation of chlorite increases with increasing of pH value whereas the formation of chlorate increases with decreasing the pH value, and the chloride ion is increased at a pH value below 3.4. The chlorite (ClO_2^-) exists as inert at above the pH 7. On the other hand this compound is very active below pH 7. However, the most efficient bleaching and maximum brightness are obtained in the first ClO_2 stage (D0) at a pH level of about 3.5 – 4.0 while it is obtained in the second ClO_2 stage (D1) at pH of 5.5 to 6. Normally, the pH varies from 7 to 3.5. So, less chlorine dioxide bleach is required for low pH than for high pH bleaching, but the temperature and retention time should be increased to speed up the reaction rate. At a lower pH (below 3.0) ClO_2 can produced organic chlorine compounds which is not environment friendly.

It is possible to take advantage of the chlorite with maintaining a rapid rate of bleaching by keeping the pH level high at starting position and then lower. Corrosion is kept under control by using tile lined or acid proof brick towers and plastic-lined or ceramic pipe.

The residual ClO_2 can create toxic fumes and corrosion at subsequent washing step. Therefore, SO_2 or NaOH is used at the bottom of the tower to neutralizing it so that can be reduced corrosion and eliminated toxic fumes.

$$2ClO_2 + 2NaOH \rightarrow NaClO_2 + NaClO_3 + H_2O$$

Retention time

The retention time may be as short as 15 to 60 minutes to complete the chlorine dioxide bleaching reactions. The average time maintains about two hours but some cases as much as 3 to 5 hours are allowed. The retention time over 3 hours may affect on the fiber. To control retention time some bleaching plants construct an up-flow tower followed by a bigger down-flow tower. Although some bleaching plants are carried out either up-flow or down-flow tower.

Effect of temperature

During the chlorine dioxide bleaching, generally, the temperature is maintained from 50 to 80°C. High temperatures can increases the reaction rate but above 80°C the strength of the fiber may be affected. The optimum temperature of this bleaching agent is 70-75°C.

Effect of consistency

The consistency of the pulp is very little effects on the reaction rate during chlorine dioxide bleaching. It is better to keep the stock consistency from 10 to 14%. High consistency increases the effectiveness of the bleaching. It reduces the consumption of the bleach, steam and the size of the towers. The ratio of the chlorine dioxide beach to pulp is not very important, except that above 0.6% on the pulp weight the brightness may be reduced slightly. The amount of ClO2 added to the pulp depends on the final brightness desired. Commercial, the amount of chlorine dioxide bleach usually consumed from 0.4 to 0.6 % for kraft pulps and 0.3 to 0.4 % for sulfite pulps.

Advantages

Chlorine dioxide is an ECF bleaching agent, which is used instead of elemental chlorine. The elemental chlorine bleaching has large environmental and health issues. It produces many toxic compounds as like organochlorine compounds, dioxins and furans, but the chlorine dioxide bleaching agent does not produce this chemicals. It is five to 10 times more soluble in water than chlorine.

Chlorine dioxide bleach is highly selective. It reacts rapidly with lignin without affect on cellulose fiber. It oxidizes, brighten and solubilize the lignin. Therefore the fiber achieve high brightness without pulp degradation; so, more strength, and more yield %.

The oxidizing power of ClO_2 is two and a half times more than the oxidizing power of Cl_2on a mole per mole basis.

$$ClO_2 + 2.5\ H_2 \rightarrow HCl + H_2O$$

The bleached pulps that are manufactured with using Chlorine dioxide bleach shows less tendency to revert in color than hypochlorite bleach.

Disadvantage

Chlorine dioxide bleaching agent is a very unstable compound, it is considered extremely toxic and explosive to handle and transport. At high concentration it is spontaneous explosive. Moreover, it is exploded by uv light, contact with mercury and organic matter, or by electric spark. Thus it is always produced on the plant site where it is used so that it could be applied immediatately after generation. It is expensive compare to calcium hypochlorite. To eliminate explosion, the chlorine dioxide bleach should protect from uv light, keep lower concentration, uncontaminated and cool. Moreover, to reduce consumption pH would to be controlled carefully.

5.7 Alkaline extraction stage for pulp bleaching (Press 5)

Alkaline extraction stage is essential after chlorination bleaching stage is to remove chlorinated and oxidizing lignin products from the pulp. It is also help to reactivate the remaining lignin for the next oxidation stage. All the chlorinated lignins are not soluble in the water. About 40-42% of them are soluble in water and wash out. Consequently, the rest of the chlorinated lignin products are not possible to remove. The rest insoluble parts of the products dissolve fairly readily in weak caustic soda solution under a certain condition. The required amount of caustic is directly related to the chlorine usage in earlier stage. Normally, it may be two-third of the chlorine usage. In this stage many modern bleaching plant add oxygen and hydrogen peroxide with caustic soda to get better result. The condition of oxygen and hydrogen peroxide usage are almost same as like as the condition of *alkaline extraction*. This stage is designated as E.

After chlorination bleaching stage a thorough wash is given to remove acidic and water soluble products. Otherwise the caustic uses will increase to neutralize the acidic products. Then, the alkaline extraction is carried through as an independent stage. Reaction time, consistency, temperature and amount of caustic applied depend on the quality of pulp required. The application of caustic should be uniformed so that it works well. It is better to use with a shower pipe. Additional caustic dosage can increase the effectiveness but it will also raise the overall bleaching expenses. On the other hand low dosage may affect on the solubilization. So pH maintain is very significant.

Condition - In alkaline extraction stage the sodium hydroxide is added to the pulp at medium consistency, about 10-15%. The sodium hydroxide is added such an amount so that the final pH of the stock should be 10.5 to 11. The temperatures are maintained from 60ºC to 80ºC and the reaction time is 30 to 60 minutes. Some cases the reaction time reach up to 2 hours. If all the condition cannot maintain properly, then the solubilization may be incomplete.

Oxygen reinforced alkaline extraction

Currently, it is almost common practice adding oxygen and hydrogen peroxide to the pulp in Alkaline Extraction. The oxygen selectively reacts with remaining lignin and reducing the consumption of subsequent stage bleaching chemicals such as chlorine dioxide. A small amount of oxygen, about 10 lb per ton of pulp is sufficient for the action. The oxygen reinforced alkaline extraction stage is designated as EO whereas addition of peroxide for further reinforcement stage is designated as EOP. To create a pressure, normally a bleaching plant installs an upflow tower followed by a downflow tower.

5.8 Hydrogen peroxide bleaching

Hydrogen peroxide is a total chlorine free (TCF) bleaching agent. It is appropriate for chemical, mechanical and recycled pulp to achieve a wide range of brightness. It has both oxidizing and reducing properties which is pH depended. The chemical formula of this bleach is H_2O_2. Pure hydrogen peroxide is very light blue color but colorless in solution. Recently, the use of this bleaching agent increased significantly in the pulp and paper industry due to easy to use, lower production costs, improved paper quality, increased yield percentage and environmental friendly. The brightness of the paper that is made from hydrogen peroxide bleach is more stable. A color reversion of about 1% is obtained over a long period. The results obtained from hydrogen peroxide bleaching depend upon the species of wood, age of wood, lignin content etc.

Hydrogen *peroxide bleaching* is a single-stage or two-stage process. This bleaching agent can be used in extraction stage of the bleaching sequence. However, it is also useful as a terminal stage. When it is used, it can be saved a great amount of ClO2 chemical in the subsequent stage. Some bleaching plant design the system as the first tower is at medium consistency whereas the second tower at high consistency. Ours bleaching plant is two stages and medium consistency system. We used it in extraction stage. At both stages we used 3-4 kg/ton whereas the magnesium sulfate is 1-1.5 kg/ton. At first extraction stage we also used oxygen with it. A two-stage process has an advantage in providing a cleaner pulp. The chemistry is very similar to that involved in oxygen delignification.

HOO^- ion is the active agent of hydrogen peroxide bleaching. This ion is originated by the ionization process.

$$H_2O_2 \quad \leftrightarrow \quad H^+ + HOO^-$$

It is a reversible reaction. As the front reaction produce H+, so high pH will increase the HOO– ion. This ion little effect on cellulose, but selectively reacts with the organic coloring matter. It reacts with lignin through the carbonyl groups. Peroxide is catalytically decomposed in the presence of metal ions such as iron, copper, lead and manganese. In order improvement the efficiency of hydrogen peroxide bleaching sodium silicate and magnesium sulfate are added during preparation of the peroxide bleach. It controls the metal levels. Peroxide bleaching introduces in the year 1907, but commercial development took place at 1941. After that the development comes in rapidly.

Effect of pH

The pH is an important factor for hydrogen peroxide bleaching. Maximum brightness is obtained at pH 10.5 or higher. The consumption rate of peroxide is also maximum at this pH because of OH– ion. This ion forwards the reaction rate into right side and helps to produce more perhydroxyl ion (HOO–).

$$\mathbf{H_2O_2 + OH^- \rightarrow HOO^- + H_2O}$$

Usually the pH level is maintained by addition of sodium hydroxide and sodium silicate. Here, the sodium silicate acts as both a stabilizer and a buffering agent. It is usually added with magnesium sulfate. Higher pH has one drawback that it can cause the development of yellow color and reversion of brightness. This drawback can be arise if the pulp left alkaline after the peroxide is all consumed; otherwise not. So, to get better benefit from *hydrogen peroxide bleach*, it is requires a careful control of alkali application to the pulp. Generally, it is applied so that the pulp will be neutral or slightly acidic at the end point of this bleaching.

Higher concentrations would harmful to human skin and corrode many materials. Over 75 ppm of its vapor is risk to human health. It should be stored in a cool, dry, well-ventilated area and away from any flammable substances. The stored container materials should be non-reactive.

Effect of temperature

Temperature plays an important role on the rate of bleaching action. Lower temperature can increase the reaction time. On the other hand, higher temperature accelerates the reactions rate but can lead to a slight color reversion due to undesirable side reactions. Moreover, in the presence of heavy metal ions the stability of peroxide is badly affected. Generally, the temperature is maintained from 40 to 6o^{0}C to obtain maximum brightness. At moderate temperatures hydrogen peroxide bleach improving the brightness of pulps without significant yield loss.

Effect of Consistency

The consistency of the pulp has noticeable effects on the reaction rate during hydrogen peroxide bleaching. High consistency can reduce reaction time and effectiveness of the bleaching. It is also economical. At first, most of the bleaching plant installed lower consistency (3 to 6%), but at present higher consistency is desirable. Now, most of the bleaching plant operates at 10 to 15% consistency whereas some are operate at 40 to 50% consistency. It reduces the consumption of the bleach and steam requirement. Lower consistency is mostly carried out as a batch wise in a beater, pulper or circulating tank. High consistency is great for maximum brightness, retention time and lower chemical dosage, but it can create maintenance problems and the equipment costs are higher. So it is better to keep medium consistency from 10 to 15%. It requires the retention time 45 minutes to 5 hours and 40 to 60°C temperature.

5.9 Final Chlorine dioxide stage at near-neutral pH for bleaching Eucalyptus pulp

It is well known that pH is an important parameter for controlling the eucalyptus pulp bleaching when using the final chlorine dioxide stage, since it affects the effectiveness of the process. Recommendations found in the literature for operating are in the 3.5 to 4.0 range. However, it was shown that final chlorine dioxide has better performance, with significant brightness gain while also preserving pulp quality, when it is operated at near neutral pH.

The best performance of the D1 stage at pH 5.5 to 6.0 can be attributed at the slow regeneration of chlorous acid ($HClO_2$), which is responsible for maximizing the bleaching performance at pH near neutral; the chlorous acid is slowly regenerated from the chlorite ion which reacts oxidizing lignin.

$$\mathbf{ClO_2 + H^+ \leftrightarrow HClO_2}$$

$$\mathbf{HClO_2 + Lignin \rightarrow HClO + Oxidized\ Lignin}$$

In general, chlorous acid tends to be reactive, except when it reacts with phenolic lignin, in this case it is produced hypochlorous acid as a product of reduction reaction. It is also observed an equilibrium among hypochlorous acid and chloride ion versus chlorine, which is dependent on the pH. Chlorate ion tends to be suppressed due to formation of chloride ions.

$$\mathbf{HClO + Cl^- + H^+ \leftrightarrow Cl_2 + H_2O}$$

If no chloride ion is present in the reaction medium, hypochlorous acid reacts with the chlorous acid promoting the regeneration of the chlorine dioxide.

$$\mathbf{HClO + 2HClO_2 \rightarrow 2ClO_2 + H_2O + H^+ + Cl^-}$$

At this stage, the residual Chlorine dioxide is presents in final bleached pulp. After Oxidation of lignin, the Brightness of the pulp is much better compared with earlier stages at nearby neutral pH.

VI. RESULTS AND DISCUSSION

Oxygen bleaching under alkaline conditions resulted in effective lignin degradation, as indicated by a noticeable reduction in residual lignin content and the formation of low–molecular-weight degradation products such as organic acids and carbon dioxide. The process predominantly targeted phenolic lignin units, where alkali-induced phenolate ions reacted with molecular oxygen to form resonance-stabilized phenoxy radicals and reactive oxygen species, including superoxide, hydroxyl, and hydroperoxy radicals. These highly reactive intermediates promoted oxidative reactions such as side chain cleavage, demethoxylation, and partial aromatic ring opening, leading to a decrease in lignin molecular weight and enhanced solubility. As a result, delignification efficiency was improved, contributing to effective lignin removal during the bleaching stage. However, excessive radical activity under severe conditions may also cause limited degradation of carbohydrate components, highlighting the importance of controlling bleaching parameters such as temperature, alkali concentration, and oxygen pressure. Overall, the results demonstrate that oxygen bleaching is an efficient and environmentally favorable method for lignin removal when optimized to balance delignification and fiber preservation.

Spectral Datas

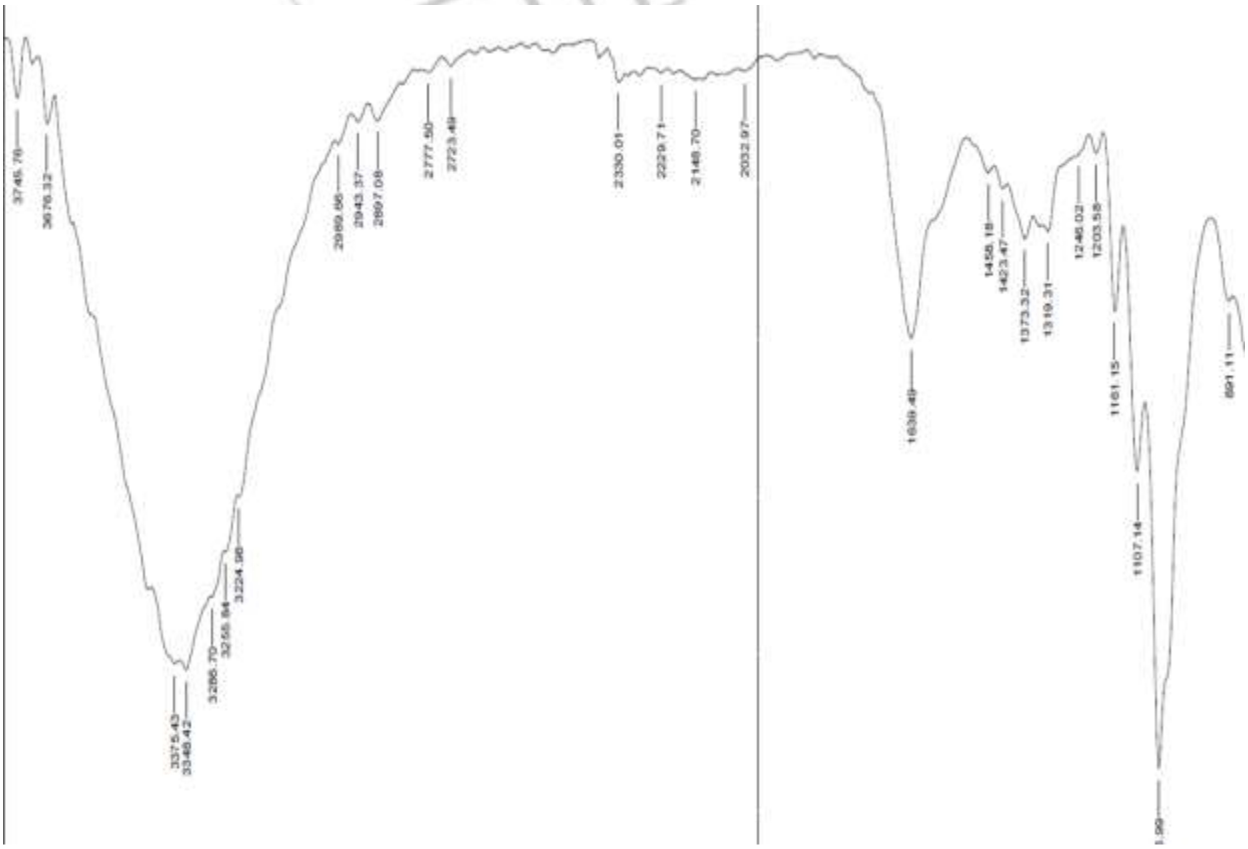


Figure 5 FTIR Band Assignments for Unbleached to Bleached pulp

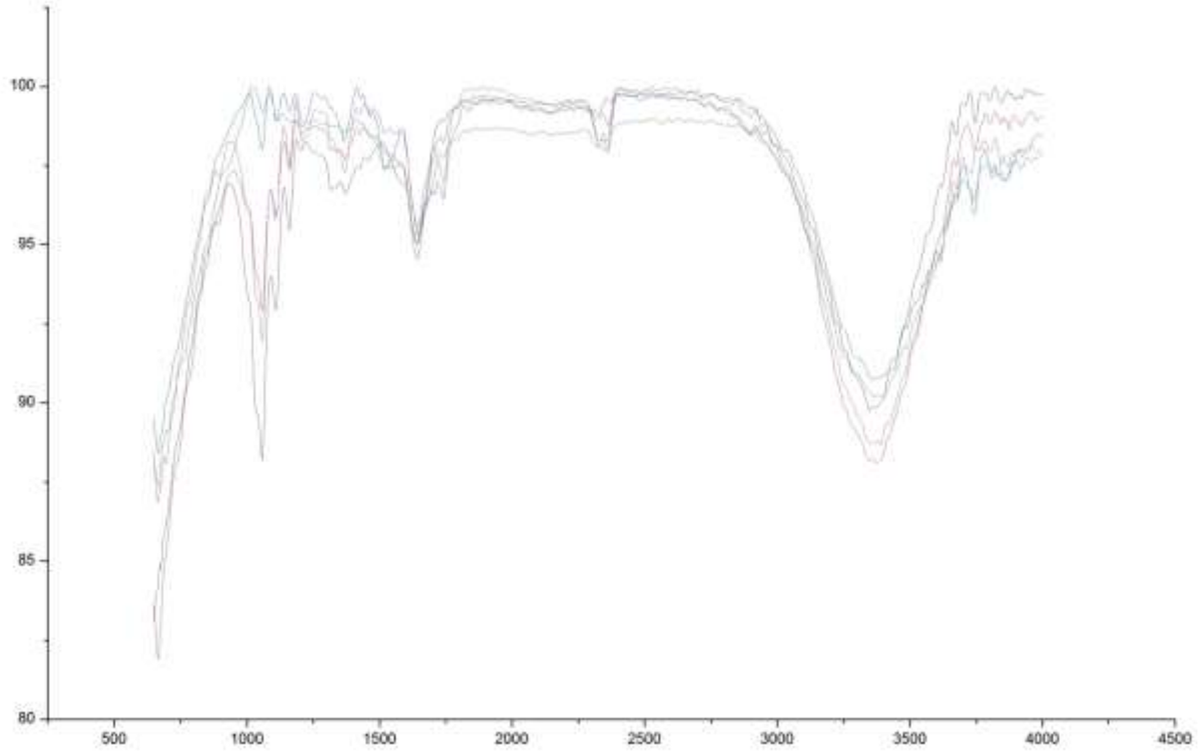


Figure 6 FTIR Band Assignments for Unbleached to Bleached pulp

FTIR band assignments of unbleached Hardwood pulp bands are based on comparative analysis of spectra of elementary carbohydrates. The FTIR spectral signatures of cellulosic fibres are represented in Fig.1. As per observations, the spectral impressions are explicit in the high frequency region of FTIR spectra and exhibit unique spectra in the finger print region. The region between 1450 – 900cm^{-1}, known as finger print region, is also the most significant region in resolving the complexity of cellulose (Socrates, 1980).

In this spectrum, the broad peak 3375-3345 cm^{-1} is assigned for O-H stretching vibration of cellulose. This is due to the chips are cooked with 165°C during cooking process and it is formed as cellulose fiber. The weak peak at 3000-2900 cm-1 is presented due to CH_3 symmetric stretching vibration of Ketones.

In the FTIR spectra of unbleached hardwood pulp, a broad band appeared in the region around 3348 - 3375 cm^{-1} is due to the asymmetric and symmetric O-H stretching. Weak bands arise around 2900 cm^{-1} is of asymmetric C-H stretching. IR Absorption of symmetric CH_2 stretching band is appeared around 2900 cm^{-1} is due to the aromatic methoxyl and methylene groups in lignin, the disappearance of this band occurs, after the removal of lignin. Sharp but medium transmittance bands in the 1639 cm^{-1} are due to the stretching vibration of conjugated C=O of xylans and the bending vibration of adsorbed water. The band 1604 cm^{-1} due to lignin is not found after the cooking process. Band appeared in 1516 cm^{-1} in Eucalyptus wood are due to aromatic skeletal vibration of lignin, the disappearance of these bands ensure the removal of lignin.The C H symmetric deformation vibration is noticed in the region of 1369 cm^{1} and CH_2 wagging is noticed around 1319 cm^{1} of cellulose. The region from 1230 1250 cm^{1} is remarkable with the presence of lignin and hemicellulose, may occur due to the in plane deformation of C OH in polysaccharides. The removal of lignin is witnessed by the presence of the band at 1207 cm^{1} in wood pulp due to C O stretching. A sharp weak band around 1160 cm^{1} depicts the asymmetric stretching of C O C and ring breathing of C C of cellulose. It is also observed that lignin also has C O ester group stretching vibration in this region. A band around 1107 cm^{1} is for C O C stretching vibration of glycosidic bond which combines a carbohydrate molecule to another group of same or to other group.

VII. CONCLUSION

The Kraft pulping process stands as a dominant force in global pulp manufacturing, prized for its efficiency in chemical recovery and its capacity to process a variety of wood types, both softwood and hardwood. The process hinges on the alkaline method, utilizing white liquor—a carefully balanced mixture of NaOH and Na2S—to effectively cook wood chips in digesters. This sophisticated process not only delignifies wood, breaking it down into fibers, but also allows for the recovery of about 90% of the pulping chemicals, significantly enhancing its economic viability.

The Kraft process involves a complex interplay of chemical reactions and physical conditions. Effective delignification, the removal of lignin from the wood, is crucial and is achieved through the action of hydroxyl and hydrosulfide ions. These ions facilitate the cleavage of ether links in phenolic units, leading to the dissolution and removal of lignin. Temperature plays a vital role in this process, with specific ranges required to optimize delignification while preventing carbohydrate degradation and maintaining fiber strength.

The optimization of chemical concentrations, particularly NaOH and Na2S, is critical for achieving a balance between reaction rate, pulp quality, and yield. While a higher percentage of sodium sulfide can darken the pulp, it also offers benefits such as increased wood penetration, uniform cooking, reduced cooking time, and enhanced yield and strength. The control of pH is equally important, influencing the effectiveness of the chemical reactions and the quality of the final pulp.

The washing stage is another key component in the Kraft pulping process. Rotary vacuum washers are commonly employed to separate the spent chemicals, known as black liquor, from the pulp. The efficiency of this washing process is vital for both the recovery of chemicals and the quality of the pulp. Factors such as fiber characteristics, shower characteristics, sheet formation, and operating factors like dilution factor and stock temperature all play a role in the effectiveness of the washing stage.

Oxygen delignification is an important step in modern Kraft pulping, serving as a bridge between the cooking stage and final bleaching. This process uses oxygen and alkali to remove residual lignin, reducing the need for chlorinated chemicals in subsequent bleaching stages. The environmental benefits of oxygen delignification are significant, as it reduces the generation of harmful organic halide compounds and lowers BOD, COD, and color in effluent. However, the process requires careful control of temperature, pressure, and pH to prevent carbohydrate degradation and maintain pulp strength.

Chlorine dioxide bleaching is another crucial stage in the Kraft pulping process, particularly for producing ECF (elemental chlorine-free) pulp. This bleaching agent is favored for its selectivity, reacting with lignin without significantly degrading cellulose fibers, thus preserving pulp yield and strength. The effectiveness of chlorine dioxide bleaching is influenced by factors such as pH, retention time, temperature, and consistency.

Alkaline extraction is essential for removing chlorinated lignin products formed during the bleaching process. This stage involves the use of caustic soda, often in conjunction with oxygen and hydrogen peroxide, to solubilize and remove these products. The efficiency of alkaline extraction depends on factors such as reaction time, consistency, temperature, and the amount of caustic applied.

Hydrogen peroxide bleaching is another important bleaching method, particularly for producing TCF (total chlorine-free) pulp. This bleaching agent is valued for its ease of use, lower production costs, and environmental friendliness. The effectiveness of hydrogen peroxide bleaching is influenced by pH, temperature, and consistency.

In conclusion, the Kraft pulping process is a complex and highly optimized sequence of chemical and physical processes. Each stage, from cooking to washing and bleaching, plays a critical role in the overall efficiency, economic viability, and environmental impact of the process. The ongoing research and development in this field continue to refine the process, pushing towards greater efficiency, higher pulp quality, and more sustainable practices.

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Variation In Physico-Mechanical Properties Of Market Samples Of Euca Wood

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Abstract

Wood is a naturally occurring, renewable and anisotropic material whose properties are strongly influenced by its chemical composition and cellular structure. The present study investigates the variation in physico-mechanical properties of market samples of *Euca* wood (*Dalbergia sissoo*), a highly valued timber species widely used in construction, furniture, and joinery applications. Wood primarily consists of cellulose, hemicelluloses, lignin, and minor extractives, which collectively govern its strength and performance characteristics. Owing to its favorable strength-to-weight ratio, elasticity, durability, and workability, *Euca* wood is often considered comparable to, and in some cases superior to, teak. However, limited systematic studies are available on the variability of its physical and mechanical properties across different market sources. In this investigation, selected market samples of *Euca* wood were evaluated for key physical properties, including density and moisture-related characteristics, as well as mechanical properties such as tensile, compressive, bending, shear strength, and cleavage resistance. The observed variations in properties are attributed to differences in growth conditions, anatomical structure, and material heterogeneity. The findings provide valuable scientific data for the effective utilization of *Euca* wood as an alternative to over-exploited premium timbers, thereby supporting sustainable resource management and appropriate end-use selection.

Key words Euca wood, Dalbergia sissoo, Physico-mechanical properties, Mechanical properties, Timber utilization

I. INTRODUCTION

Wood has been used as a versatile construction and engineering material for thousands of years due to its unique chemical composition, cellular structure, and favorable strength-to-weight ratio. It is primarily composed of cellulose, hemicelluloses, lignin, and minor extractives, which together determine its physical and mechanical behavior. Owing to its anisotropic nature, wood exhibits different properties in different directions, influencing its resistance to mechanical stresses such as tension, compression, bending, and shear. Understanding these properties is essential for the effective and economical utilization of timber.

Dalbergia sissoo **(Euca)**, a deciduous tree of the family Fabaceae, is widely distributed in the subtropical and tropical regions of India, particularly in riverine and agroforestry systems. The timber of Euca is known for its high strength, elasticity, durability, and excellent workability, with properties comparable to or even superior to teak. Due to its aesthetic appeal and mechanical performance, it is extensively used for furniture, doors, windows, and other constructional applications.

With increasing demand for wood products and growing pressure on forest resources, Euca wood offers a promising alternative to overexploited premium timbers such as teak and sal. However, limited scientific information is available on the variation in physical and mechanical properties of market samples of ***Dalbergia sissoo***. Therefore, the present study aims to evaluate these variations to support appropriate end-use selection and promote the sustainable and efficient utilization of Euca wood.

II. MATERIALS AND METHODS

The present investigation entitled 'Variation in physico-mechanical properties of market samples of Eucalyptus wood was carried out. The strength testing of the samples was carried out in the and laboratory analysis of the collected samples was done in the laboratory of the department at the industry located at Cauvery river region.

i) Moisture content (%)

Fresh weight of the standard samples was recorded just after they were cut from logs of Euca wood procured from different sites. After initial weighing, the samples were oven dried at 102±1^{0}C till constant weight. This weight of samples was recorded as oven dried weight (g). The moisture per cent of the samples was calculated by using the formula given by Desch and Dinwoodie (1996).

Moisture content (%) = $\left\{\frac{Mi-Mo}{Mo}\right\} x1$

Where,

M_i = Initial weight of sample (g)

M_o = Oven dried weight of sample (g)

Since, the teak wood samples were already seasoned and was not taken as control for comparison of moisture content.

Wooden samples soaked in water for maximum absorption

Weighing of wood samples after oven drying

Plate 1- Determination of specific gravity of wood samples

Figure 1 Determination of specific gravity of wood samples

ii) Specific gravity

Specific gravity of the market samples was determined by the maximum moisture content method (Smith, 1954). Wood samples were prepared from the disc which was cut from the base of log for each sample. These samples were submerged in distilled water till saturation (Plate 1). The weight of the samples at this point was recorded as weight at maximum moisture content level. These samples were then oven dried at 102±1^{0}C until a constant weight was attained.

iii) Fibre length and diameter

It was determined by macerating the shavings of wood in Jeffery's solution (10 per cent chromic acid and 10 per cent nitric acid) for 48 hours (Pandey *et al.*, 1968). Thereafter, the samples were thoroughly washed, stained with safranine, mildly tapped for the separation of fibres and mounted with 10 per cent glycerin. The measurement was taken with the help of ocular micrometer of 15X fitted in the eyepiece of microscope with 4X magnification objective lens which was standardized with the help of stage micrometer.

2.1 EXPERIMENT : To study mechanical properties of *Euca* wood

Observations recorded:

- Tensile strength (kN/mm^2)
- Bending strength (kN/mm^2)
- Compression strength parallel to grain (kN/mm^2)
- Compression strength perpendicular to grain (kN/mm^2)
- Compression Modulus of elasticity (kN/mm^2)
- Bending Modulus of rupture (kN/mm^2)
- Bending Modulus of elasticity (kN/mm^2)
- Tensile Modulus of elasticity (kN/mm^2)

The standard size of the specimen for conducting this test was 300 mm x 10 mm x 10 mm. The computer generated data and graph from Universal Testing Machine (UTN-10) was obtained to derive the values of maximum load, maximum displacement and breaking pattern for all the samples (Plate 2). Utmost care was taken so that each specimen faced similar type of test measures.

i) *Tensile strength (kN/mm^2)*

The standard size of the specimen taken was 300 mm x 10 mm x 10 mm which was tested for bending strength on Universal Testing Machine (UTN-10) and data were recorded (Plate 2). All care was taken such that each specimen faced similar type of test measures.

ii) *Bending strength (kN/mm^2)*

The standard size of the specimen taken was 300 mm x 20 mm x 20 mm which was tested for bending strength on Universal Testing Machine (UTN-10) and data were recorded (Plate 3). All care was taken such that each specimen faced similar type of test measures.

iii) *Compression strength parallel to grain (kN/mm^2)*

This test was conducted in the direction parallel to the grain using Universal Testing Machine (UTN-10) (Plate 3). The standard size of specimens for the compression test was 50 mm x 20 mm x 20 mm along the grain. All samples faced similar type of test measures.

iv) *Compression strength perpendicular to grain (kN/mm^2)*

The size of the specimen taken was 50 mm x 20mm x 20 mm across or perpendicular to the direction of grain and the data were recorded on Universal Testing Machine (UTN-10) (Plate 3). Proper care was taken such that each specimen faced similar type of test measures.

v) *Compression Modulus of elasticity (kN/mm^2)*

The compressive strength data and graphs perpendicular to grain were used for the determination of modulus of elasticity.

a) *Modulus of elasticity parallel to grain (kN/mm^2)*

The compressive strength data and graphs parallel to grain were used for the determination of modulus of elasticity

b) *Modulus of elasticity perpendicular to grain (kN/mm^2)*

The compressive strength data and graphs perpendicular to grain were used for the determination of modulus of elasticity

vi) *Bending modulus of rupture (kN/mm^2)*

The size of the specimen taken was 30x20x20 mm and the data were recorded on Universal Testing Machine (UTN-10). All care was taken such that each specimen faced similar type of test measures.

vii) *Bending modulus of elasticity (kN/mm^2)*

The static bending strength data and graph were used for the determination of bending modulus of elasticity.

viii) *Tensile modulus of elasticity (kN/mm^2)*

The static bending strength data and graph were used for the determination of bending modulus of elasticity.

III. RESULTS AND DISCUSSION

The results obtained from the present investigation entitled **“Variation in physico-mechanical properties of market samples of Euca wood** carried out in the Laboratory and Wood Workshop in the Department of Forest Products, College of Forestry, Dr YS Parmar University of Horticulture and Forestry during 2015-2016 and 2016-17 are presented in this chapter. The data procured from the study were subjected to appropriate statistical analysis and the results obtained are presented below under the following headings:

1) Identification and authentication of wood

2) Physical properties of wood

3) Mechanical properties of wood

4) Simple correlation coefficients

5) Multiple regression analysis

1) Identification and authentication of wood

The wooden samples collected from ten different sites were subjected to the following observations:

1.1 Colour, Texture and Odour

1.2 Anatomical studies

1.1 Colour, Texture and Odour of different Euca wood samples

Colour of the wood samples of Euca collected from different market sites was matched with RHS Colour Chart {Fan 4, sixth edition (2015)} for identification purpose (Table 1). Wooden samples procured from Chowkiwala and AP were found similar in colour when matched with Greyed Orange Group sheet number 165 (moderate brown [A] colour). Samples from TN and Sundernagar were found to be moderate brown [C] when matched with moderate brown colour from Brown Group with sheet number 200 whereas, rest of the wood samples were moderate brown [D] from same group and sheet number (Plate 4).

S.No	Sites	Colour	Texture	Odour
1	AK	Moderate brown 200[D]	Medium	Sweet
2	BK	Moderate brown 200[D]	Coarse	Sweet
3	GH	Moderate brown 200[D]	Coarse	Sweet
4	KH	Moderate brown 200[D]	Medium	Sweet
5	TN (Solan)	Moderate brown 200[C]	Medium	Sweet
6	CS	Moderate brown 165[A]	Coarse	Sweet
7	AP (1)	Moderate brown 165[A]	Medium	Sweet
8	GB	Moderate brown 200[D]	Coarse	Sweet
9	SM	Moderate brown 200[C]	Medium	Sweet
10	SS	Moderate brown 200[D]	Medium	Sweet

Table 1: Variation in Colour, Texture and Odour of Euca wood from different market locations

The texture of the Euca wood varied from coarse to medium on the basis of tangential diameter of the vessels. The odour of all the Euca wood samples collected from different market sites had sweet in smell (Table 1).

Wood is a natural and one of the most valuable raw materials with variations in properties of texture, colour, density and strength have been used for many purposes (Ates *et al.,* 2009). The importance of wood properties has been recognized throughout the history, as native people globally understood the unique properties of different tree species and used a particular tree species best suited for specific applications. Therefore, studies on wood properties help in promoting proper utilization of the wood for multiple applications.

Safdari *et al.* (2008) identified and studied the important commercial wood species *Fagus orientalis, Acer insigne, Carpinus betulus, Alnus glutinosa, Diospyros lotus, Juglan regia, Tilia rubra, Sorbus torminalis, Prunus avium, Parrotia percia, Ulmus glabra, Quercus castaneaefolia, Gledistschia caspica* and *Fraxinus excelsior* in Iran based on the texture, colour and vessel arrangement with presence or absence of tyloses. Similarly, Toong *et al.* (2014) established a predictive relationship between the material properties and anatomical characteristics of common commercial Malaysian timbers. They studied relationship of anatomical characteristics with wood texture, porosity, density, radial shrinkage, modulus of elasticity and compression parallel to grain.

Kumar *et al.* (2012) studied the qualities and attributes of sandalwood found in southern India. The sandalwood produces a characteristic odour in comparison to the other commercial trees available in that area. The sapwood of the tree has no distinct odour but the heartwood has aroma in it and is one of the finest natural materials for carving and extracting oil.

In the current work the colour, texture and odour has shown that moderate brown colour was dominant, texture varied from medium to coarse and odour with sweet in smell. These properties are very helpful in establishing the identity of wood.

2 Physical properties of wood

2.1 Moisture Content (%)

The presence of moisture in wood makes it dimensionally unstable and it also indicate the degree of porosity in wood. The data related to moisture content of wood of Euca collected from different sites are presented in Table 3. The maximum moisture content of 20.170 per cent (4.601) was observed wooden samples collected from TN site and the minimum moisture content (10.803 %) was found in sample procured from GH site.

Brough *et al.* (1986) have reported that the moisture content of wood is probably affected by the habitat. The variations in moisture content could be attributed to environmental factors (variation in climate, site quality, competition among individual trees), genetic factors and the interaction between both. They also observed that the wood is hygroscopic in nature, hence it tends to absorb water from the surrounding environment. The hygroscopicity of wood depends upon the cellular composition of wood *i.e.*, different types of cells, their cell wall thickness and lumen size. The present results are supported by the findings of Lekha (1999) in *Acacia catechu* and Kumar (1996) in *Eucalyptus teriticornis*.

2.2 Maximum Moisture Content (%)

The data pertaining to maximum moisture content of wood of Euca collected from different sites are presented in Table 3. The higher, maximum moisture content was observed in wood samples procured from TN site which was 68.326 per cent and the lower, maximum moisture content was noticed in the wood sample from AP site *i.e.* 46.995 per cent (Fig. 1).

Similar observations have been reported by Hernandez (1993) which reveals that variation in maximum moisture content of wood is attributed to the process of water sorption in the cell wall. When sorption occurs, the water molecules bound with sorption sites through hydrogen bond, primarily in free hydroxyl sites of amorphous cellulose, which occurs within cell wall and results in swelling thus, both cellular and growth ring structures affect the moisture content in wood.

2.3 Specific gravity of wood

Specific gravity is the parameter which determines the strength of wood and gives the idea of the weight, density and porosity of wood. The data obtained on specific gravity is presented in Table 3 revealed significant variation among Euca wood samples collected from different sites. The maximum specific gravity (0.644) was recorded in wood from AP site and the minimum specific gravity of 0.517 was observed in wood samples from TN site (Fig. 1).

The significant variation in the specific gravity of wood has been observed by Cox *et al.* (2001) in the wood of *Shorea acuminata, S. ovalis, S. leprosula* and *Dryobalanops aromatica*, and observed that specific gravity is heritable while Zobel and Talbert (1984) revealed that specific gravity of wood is a measure of the amount of structural material which provide support and strength and the most important wood characteristic because its knowledge allows the prediction of greater number of properties than any other trait.

Similarly, Meena *et al.* (2016) also investigated the different provenances of *Tectona grandis* wood for bark percentage, specific gravity and fibre length. The data on specific gravity and fibres length of wood exhibited significant variation in different provenances of Teak. The highest specific gravity of wood (0.655) was recorded in ORANP-7 clone and lowest specific gravity (0.552) was noticed in ORANP-6 clone.

2.4 Fibre length (mm)

The size and compactness of fibres in wood gives the level of strength and resistance of wood. They are elongated type with much lignified cell wall. The data on fibre length exhibited significant variation among Euca wood samples collected from different sites as shown in Table 4. Among the different Euca wood samples, longest fibre length was recorded in samples collected from Ghumarwin site (1.660 mm), while the shortest fibre length (0.495 mm) was noticed in samples collected from Chowkiwala site (Fig. 1). Sykes *et al.* (2006) have also reported that fibre length can be controlled genetically and is not under influence of environmental fluctuations. Wani and Khan (2010) reported significant variation in the wood anatomical features viz. fibre length, fibre wall thickness from different portions of trees of *Populus nigra*

L. Nguyen *et al.* (2009) found that the wood fibre length of *Acacia mangium* and *Acacia auriculiformis* increased from the pith to periphery in the wood. Izekor and Fuwape (2011) studied the *Tectona grandis* wood and revealed that the fibre length of the wood is greater in older wood among the group of trees. Tavares *et al.* (2011) reported that in *Eucalyptus globulus* wood, the fibre length decreased from the bottom to the top of the tree and increased from the pith to the bark.

2.5 Fibre Diameter (mm)

The data pertaining to fibre diameter of Euca wood samples collected from different sites are shown in Table 4. Among Euca wood samples, higher fibre diameter was recorded in wood samples from AP site (0.020 mm). The lowest fibre diameter (0.013 mm) was noticed in the wood samples from the sites TN and AP.

Izekor and Fuwape (2011) studied *Tectona grandis* wood and reported that the mean values of fibre diameter were 26.79, 29.47 and 32.83 µm. Fibre length, fibre diameter and cell wall thickness increased with increase in age.

2.6 Vessel Diameter (mm)

The data on vessel diameter showed significant variation among Euca wood collected from different sites as shown in Table 4. The maximum vessel diameter (0.126 mm) was recorded in wood from Ghumarwin site which was statistically at par with the sites of Sarahan (0.124 mm), Kangu (0.124 mm), Andreta (0.123 mm), TN (0.123 mm), AP (0.122 mm).

Pande and Singh (2005) observed within tree variations in the anatomical properties like vessel length, vessel diameter and wall thickness due to vertical or radial direction and location were non-significant.

3 Mechanical properties of wood

3.1 Tensile strength (kN/mm^2)

The ability of any material to resist the stretching forces is its Tensile strength. Wood when used for construction and other purposes is ought to face these forces. Hence, study of this parameter tells the ability of wood to work under such stresses. A critical analysis of the data recorded for tensile strength is presented in Table 2. Data obtained showed significant variation among samples collected from different sites. The maximum tensile strength was noticed in wood samples collected from Baroh site (0.094 kN/mm^2) which was statistically at par with samples of Galore site (0.078 kN/mm^2). The minimum tensile strength (0.030 kN/mm^2) was observed in the samples procured from site of Ghumarwin and this was statistically at par with the samples from AP (0.039 kN/mm^2) and AK (0.032 kN/mm^2) sites Sanwo (1986) found that the rate of growth has no significant influence on specific gravity and strength properties of plantation-grown teak in Nigeria. Awan *et al.* (2012) studied the tensile strength in *Eucalyptus camaldulensis* and other mechanical properties and have reported variation in properties. Verma *et al.* (2012) evaluated the tensile properties of bamboo laminae prepared from slivers, selected from different regions of bamboo culms (*Dendrocalamus strictus*) and found that these properties increased from inner to outer region for any cross section and from bottom to top.

3.2 Bending Strength (kN/mm^2)

Bending strength of wood determines its capacity to be used as a beam, pillars etc**.** The data pertaining to bending strength of Euca wood samples collected from different sites as shown in Table 2. There was no significant variation among the samples collected from different sites. The maximum bending strength (0.006 kN/mm^2) was noticed in wood samples from Baroh and Sundernagar while the minimum tensile strength (0.004 kN/mm^2) was observed in the sites, CS, AK, Galore, GH and SS. In standard Teak wood samples, a bending strength value of 0.015 kN/mm^2

was noticed.

S. No	Sites	Tensile Strength (kN/mm^2)	Bending Strength (kN/mm^2)
1	AK	0.032	0.004
2	BK	0.094	0.006
3	GH	0.078	0.004
4	KH	0.066	0.005
5	TN	0.068	0.005
6	CS	0.047	0.004
7	AP (1)	0.039	0.005
8	GB	0.030	0.004
9	SM	0.055	0.006
10	SS	0.076	0.004

Table 2: Variation in Tensile and Bending strength of Euca wood

Olufemi and Malami (2011) have also concluded that *Eucalyptus camaldulensis* had static bending strength of 0.133 kN/mm^2 and the modulus of elasticity of 15.220 kN/mm^2. Awan *et al.* (2012) studied the mechanical properties of farm-grown *Eucalyptus camaldulensis* Dehn. in comparison to conventional timbers *i.e.*, *Dalbergia sissoo* Roxb., *Acacia nilotica* Del. and *Cedrus deodara* Roxb. and have reported variable values for different species.

3.3 Compression strength perpendicular to grain (kN/mm^2)

Compressive strength of wood is the vital property in the timber utilization as it subjected to compressive forces during its utilization. The data on compression strength perpendicular to grain showed significant variation among samples of Euca wood collected from different sites as shown in Table 3. The maximum compressive strength perpendicular to grain 0.038 kN/mm^2 was noticed in wood samples from Andreta site and the minimum compressive strength perpendicular to grain was recorded in the Sundernagar site (0.022 kN/mm^2). In Teak, compressive strength of 0.034 kN/mm^2 was observed which was superior to all the Euca wood samples collected from different market sites (Fig. 2). The cellular orientation perpendicular to the grain makes the wood weaker in compression as cell layers in this direction may have variable cell types. Rahman *et al.* (2005) have reported similar results for Teak wood samples for mechanical properties. The highest ray volume showed higher specific gravity and greater compression strength irrespective of the fact that ray proportion remains the same across pith to bark. Izekor *et al.* (2010) studied the effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood aged 15, 20 and 25-year. Garau *et al.* (2008) compared the mean values obtained for branch wood with the stem wood and found that compression strength of stem wood was more than the strength of branch wood. If wood is considered as a bundle of straws bound together, then a compression parallel to grain can be thought of as a force trying to compress the straws from end to end (Rowell, 2013). Pillow and Luxford (1937) have also reported great variation in compression parallel to grain for different trees.

3.4 Compression strength parallel to grain (kN/mm^2)

The compression perpendicular to grain is a stress applied parallel to the length of the wood cells and is important for its application in sports goods. The data shown in Table 3 on compressive strength parallel to grain revealed significant variation among different Euca wood collected from the respective sites. The data showed the highest compressive strength parallel to grain in wood samples from Baroh site (0.069 kN/mm^2) which was statistically at par with the sites of Andreta (0.064 kN/mm^2), Ghumarwin (0.063 kN/mm^2) and Sundernagar (0.065 kN/mm^2) while the lowest compressive strength perpendicular to grain (0.046 kN/mm^2) was noticed in Sarahan site. Teak showed the compressive strength of 0.067 kN/mm^2 (Fig. 2). Awan *et al.* (2012) studied the mechanical properties of farm-grown *Eucalyptus camaldulensis* Dehn. in comparison to conventional timbers i.e., *Dalbergia sissoo* Roxb., *Acacia nilotica* Del. and *Cedrus deodara* Roxb. Izekor *et al*. (2010) studied the effects of density on variations in the mechanical properties of the wood from *Tectona grandis* plantation and have registered variations in strength properties.

S. No	Site	Compression perpendicular to grain (kN/mm^2)	Compression parallel to grain (kN/mm^2)
1	AK	0.038	0.064
2	BK	0.031	0.069
3	GH	0.033	0.062
4	KH	0.029	0.062
5	TN (Solan)	0.029	0.056
6	CS	0.023	0.061
7	AP (1)	0.025	0.053
8	GB	0.023	0.063
9	SM	0.022	0.065
10	SS	0.032	0.046

Table 3: Variation in Compression strength perpendicular and parallel to grain (kN/mm^2)

3.5 Modulus of Elasticity perpendicular to grain (kN/mm^2)

Elasticity of the wood means its level of retention of original size and shape. Hence, determination of wood elasticity has got great significance to find its suitability for specific uses. The data on modulus of elasticity (MOE) perpendicular to grain are presented in Table 4. The maximum value for modulus of elasticity perpendicular to grain among samples of Euca wood collected from the sites was observed for Ghumarwin site *i.e.*, 1.653 kN/mm^2 while the minimum (0.827 kN/mm^2) modulus of elasticity (MOE) was noticed in wood samples from Sarahan site. The modulus of elasticity in Teak wood samples was found 0.717 kN/mm^2 (Fig. 3).

3.6 Modulus of Elasticity parallel to grain (kN/mm^2)

The data presented in Table 4 revealed significant variations in the values of modulus of elasticity (MOE) parallel to grain. Among all the wood samples collected from different sites, the maximum modulus of elasticity parallel to grain was recorded for TN site (0.231 kN/mm^2) while the minimum modulus of elasticity (MOE) was noticed for Sarahan site (0.097 kN/mm^2). The modulus of elasticity in Teak wood samples was recorded 0.082 kN/mm^2.

S. No	**Site**	**MOE perpendicular to grain** (kN/mm^2)	**MOE parallel to grain** (kN/mm^2)
1	AK	1.247	0.107
2	BK	1.346	0.142
3	GH	0.861	0.140
4	KH	0.933	0.100
5	TN (Solan)	1.199	0.231
6	CS	0.950	0.145
7	AP (1)	0.838	0.196
8	GB	1.653	0.163
9	SM	0.948	0.152
10	SS	0.827	0.097

Table 4: Variation in Modulus of Elasticity, Compression strength parallel and perpendicular to grain (kN/mm^2)

Saravanan *et al.* (2014) carried out studies on mechanical properties using different age gradation *viz.*, three, four and five years of *Melia dubia* wood samples and found variation in each year growth. Among the age gradations five year old *M. dubia* registered maximum value for modulus of elasticity compression parallel to grain and confirmed the suitability of five year old wood as raw material for plywood, pencil and light furniture industry.

3.7 Bending Modulus of Rupture (kN/mm^2)

Modulus of Rupture (MOR) is a measure of a wood specimen strength towards rupture. It can be used to determine overall strength of wood species; unlike the modulus of elasticity, which measures the deflection of wood. The significant variation is observed in modulus of rupture among different species from different sites which can be attributed to variable cellular composition of woods. The data on modulus of rupture (MOR) are presented in Table 8. The maximum value of modulus of rupture among Euca wood samples collected from the different sites was observed for Sundernagar site (0.116 kN/mm^2 while the minimum value for modulus of rupture was noticed for Sarahan site (0.081 kN/mm^2). The maximum bending modulus of rupture (0.242 kN/mm^2) was observed in Teak wood samples collected from Solan market (Fig. 3).

Sharmin *et al.* (2015) observed that the mixed plantation wood of S*wietenia macrophylla* grown in Chittagong region showed MOE 10204 N/mm^2 and MOR 61 N/mm^2 which were relatively lower than the wood of *Tectona grandis*. Rao *et al.* (1972) in *Dalbergia sissoo* wood and Purkayastha and Kazmi (1985) in *Tectona grandis* wood also reported the similar results.

3.8 Elongation (%)

Variation in elongation (%) in wood samples of Euca wood collected from different sites may be due to the difference in alignment of the cells. The total elongation also depends upon the length of the gauge and also upon the species. The data on elongation of Euca wood collected from the different sites are presented in Table 8. The maximum value for elongation in bending test (3.867 %) was noticed in the site of TN and the minimum value was observed in Sarahan site (2.167 %). The maximum value for elongation in tension test was recorded in the Sarahan site (3.300 %) which was statistically at par with the sites of Baroh (3.000 %), Kangu (2.833 %), TN (2.867 %) and Galore (2.933 %) while the minimum value was noticed for Andreta site (1.433 %) (Fig. 3).

Okoh (2014) has studied and reported similar results while investigating physical (oven-dry density) and mechanical properties (modulus of rupture, elongation (%) modulus of elasticity and compression parallel to the grain) of four tropical hardwood species *Terminalia superba*, *Terminalia ivorensis*, *Quassi aundulata* and *Recinodendron heudelotii.*

S. No	**Sites**	**Modulus of Rupture static bending test** (kN/mm^2)	**Elongation Static Bending test (%)**	**Elongation Tension test (%)**
1	AK	0.089	2.333	1.433
2	BK	0.113	3.100	3.000
3	GH	0.098	2.367	2.933
4	KH	0.104	2.800	2.833
5	TN (Solan)	0.097	3.867	2.867
6	CS	0.084	2.267	1.820
7	AP (1)	0.099	2.800	1.600
8	GB	0.088	2.767	1.533
9	SM	0.116	3.177	2.333
10	SS	0.081	2.167	3.300
	Mean	0.097	2.764	2.365
11	Control(Teak)	0.242	3.087	2.443
	SE (d)	0.011	0.004	0.003
	CD0.05	0.024	0.008	0.006

Table 5: Variation in Bending Modulus of Rupture (kN/mm^2), Elongation (%) in tension and bending (kN/mm^2)

3.9 Tensile Modulus of Elasticity (kN/mm^2)

The data pertaining to tension modulus of elasticity of Euca wood samples collected from the different sites are presented in Table 9. The maximum value for tensile modulus of elasticity among Euca wood samples was observed for Baroh site (2.876 kN/mm^2) while the minimum value was noticed for Ghumarwin site (1.853 kN/mm^2). The maximum value was observed in the samples of teak (2.990 kN/mm^2) (Fig. 2).

S. No	**Site**	**Bending MOE** (kN/mm^2)	**Tensile MOE** (kN/mm^2)
1	AK	8.591	2.052
2	BK	8.921	2.876
3	GH	9.283	2.536
4	KH	10.369	2.246
5	TN (Solan)	6.935	2.329
6	CS	7.188	2.365
7	AP (1)	8.716	2.229
8	GB	7.891	1.853

Table 6: Variation in Tensile and Bending Modulus of Elasticity (kN/mm^2)

Saravanan *et al.* (2014) studied the mechanical properties of *Melia dubia* wood samples using different age gradation of three, four and five years. Among the age gradations, the five year old wood samples registered the maximum value of bending strength, modulus of elasticity, compression strength parallel and perpendicular to the grain.

IV. CONCLUSION

The present study on the variation in physico-mechanical properties of market samples of *Euca* wood (*Dalbergia sissoo*) revealed considerable differences among samples collected from different market sites, which can be attributed to variations in growth conditions, anatomical characteristics, and material heterogeneity. The colour of the wood samples predominantly ranged from moderate brown shades, with textures varying from medium to coarse based on vessel dimensions, while all samples exhibited a characteristic sweet odour.

Significant variation was observed in physical properties such as moisture content, specific gravity, fibre length, vessel diameter, and fibre diameter. Wood samples from the AP site recorded the highest specific gravity and fibre diameter, whereas the longest fibre length and largest vessel diameter were observed in samples from the Ghumarwin site. Mechanical properties also showed marked variability among sites. Higher tensile and bending strengths were recorded for Baroh and Sundernagar sites, while Andreta and Baroh sites exhibited superior compressive strength parallel and perpendicular to grain, respectively. The modulus of elasticity values varied notably, with Ghumarwin, TN, Baroh, and Kangu sites showing higher performance under different loading conditions.

Overall, the results indicate that *Euca* wood possesses favorable physico-mechanical properties comparable to premium timbers. Based on the comprehensive evaluation, wood samples from AP, Baroh, and Ghumarwin sites demonstrated superior performance and can be recommended for use in various structural, furniture, and construction applications. The findings of this study contribute valuable scientific information for the effective utilization and appropriate end-use selection of *Euca* wood, thereby supporting sustainable timber resource management.

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Extraction Of Hemicelluloses From Ehcas Wood Before Kraft Cooking

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Abstract

Wood – a raw material for pulp and paper industry - contains large amount of hemicelluloses, which are partly dissolved in black liquor in the chemical pulping process. Hardwood is particularly rich in hemicelluloses, i.e. pentosans. This work investigates a possibility of extraction of hemicelluloses prior to kraft cooking in order to find applications for the isolated polysaccharides and increase mill capacities. The response of the cooking process and pulp properties is analyzed. The optimal conditions for targeted 90-95% yield of wood after pre-treatment were determined to be at temperature 150 degree C, liquid-to-wood ratio 3:1 and dilute sulphuric acid charge of 0,18% on wood weight. Water pre-treatment was found to be less efficient due to the need for longer dwell times of wood chips. The degree of the extraction and the yield of the extracted hemicelluloses in combination with liquid-to- wood ratio should be sufficient to provide high concentrations of pentosans in the extraction liquor. Target Kappa number of the pulp cooked from pre-treated chips was obtained with half of the H-factor compared with the standard pulp. The yield of pulp decreased equally to the amount of the material removed in the pre-treatment stage. The limiting viscosity number was higher, than that of the standard pulp due to much lower content of low-molecular hemicelluloses and high content of cellulose. Strength properties of the pre-treated pulps were found to be surprisingly lower, than that of the standard pulp. Lower extent of the hemicelluloses removal in the pre-treatment stage gives increase in strength properties.

Key words : hemicelluloses, EHCAS, extraction, kraft cooking, pulp properties

I. INTRODUCTION

Modern market economy gives rise to high competition between industrial branches. Every enterprise invests into research increasing capacities and using raw material as fully as possible in order to increase profit. Pulp and papermaking industry is a good example of this. For many years kraft pulp mills have been increasing capacities by installing more cost effective equipment, increasing yield of pulp and reducing number of stops in the mill. Kraft mills have an intelligent system of recycling spent liquor in order to recover energy and cooking chemicals. Many plants have integrated resin departments that take care of crude tall oil soap, separated from black liquor in order to isolate and derive a great variety of products. Rising energy prices, i.e. mineral oil, influences the costs of raw material for synthesis of different chemicals. Pulp mills can be a source of valuable raw material - pentosans, which can be extracted from the wood. This work will evaluate extraction possibilities and study the influence of this process on the quality of pulp.

One idea is separating hemicelluloses, i.e. pentosans from wood chips before carrying out kraft cooking. The technology has been used in mill scale in production of dissolving pulps. Previous experiments have shown that pre-treated chips are cooked to target Kappa number with lower H-factor. [11] It means that production rate of a pulp mill might be increased to a certain extent. Extraction pre-treatment step makes it possible to obtain a solution containing a large part of hemicelluloses, which can be used for further treatment. This work carried out at Smurfit Kappa Kraftliner Piteå in cooperation with Kiram AB and Lund University is devoted to aqueous pre-treatment of EHCAS chips at elevated temperatures resulting in hydrolysing and extracting pentosans. The experiments include pre-treatment of wood chips at different temperatures, dwell time, wood-to-liquid ratios and recirculation, cooking the pre-treated chips and analysing different properties of the pulp. The aim of the work is to optimise the extraction process, analyse the effect of the process of kraft cooking and ascertain if this process can be introduced at a mill producing kraftliner in respect of the strength properties of the product.

II. PULP PRODUCTION. KRAFT COOKING

Papermaking industry is a huge industrial branch with high capacities, complicated equipment and processes influenced by a great variety of factors. Nowadays the main raw material for papermaking is wood fibres. Different wood species are used for producing fibrous material, both softwood and hardwood. All types of pulping processes can be divided into chemical, semi-chemical and mechanical. The dominating raw material in papermaking is chemical pulp. It is obtained by digesting wood chips in acidic, neutral or alkaline conditions. All the chemical pulping methods may be divided into alkaline, acid, neutral, combined and organosolv processes. Alkaline processes in their turn include kraft (sulphate) pulping, soda pulping and some other modifications such as polysulfide cooking, helping to preserve carbohydrates. Acid processes are divided into sulphite and bisulphite pulping. Kraft pulping is now dominating all over the world, because of high fibres strength and due to some drawbacks of sulphite processes such as high pollution potential and small range of raw materials suitable. An innovative method is using organic solvents, e.g. alcohols or strong organic acids. These organosolv methods are not used on industrial scale yet, but the laboratory- scale results are, though, challenging.

Kraft pulping was first used in 1884. It is a process of lignin dissolution at high temperatures and pressures that is performed by white liquor. The main cooking components of white liquor are OH □ and HS □ ions in the form of NaOH and Na S . The other components in white liquor are Na_2CO_3 , $Na_2 SO_4$, $Na_2 S_2O_3$, $Na_2 SO_3$ etc. There are several important values used to characterize white liquor. The whole amount of the components is called Total alkali. Causticity and Reduction values are used to characterise the efficiency of the chemical recovery cycle. The raw material for kraft cooking is wood, both hardwood and softwood can be used. The wood logs are chipped in a special way and fed to a digester together with white liquor.

In industry cooking is carried out batchwise or continuously. The basic processes in industrial kraft pulping are:

Feeding the chips and white liquor, Digesting, Discharge of pulp, Washing and screening

An important part of kraft cooking is recovery of the chemicals. Firstly, the expensive chemicals are recovered ready to be used again, secondly, a tremendous amount of energy is obtained to power a mill, thirdly, steam is obtained for heating purposes. If no recovery system was invented, kraft pulping would not make any profit, because the chemicals and the energy needed are much more expensive than pulp.

Black liquor is a dark viscous liquid that is separated from the pulp after a cooking process. Black liquor contains dissolved lignin and other alkali-soluble organic matter as well as inorganic components of white liquor. The properties of black liquor depend on wood species, charge and composition of cooking liquor and delignification rate. Black liquor is a fuel with quiet low combustion value compared to other fuels. Black liquor is separated from the pulp by washing. An effective washing process is one that recovers maximal amount of the liquor with the lowest dilution ratio. As long as black liquor is combusted in order to recover cooking chemicals and heat the amount of water in it should be kept at the lowest possible level. In order to increase dry solids content and decrease the amount of steam consumption multiple-effect evaporation is used. Then the thickened black liquor is combusted in a recovery boiler. The products that leave the recovery boiler are a smelt containing sodium sulphide $Na2\ S$ and sodium carbonate $Na2CO3$ and high-pressure steam produced in a reboiler heated by the flue gases of the combusted black liquor.

After the caustization the liquid phase containing NaOH and $Na2\ S$ (white liquor) is separated from the solid lime mud, clarified and goes to the cooking department. The lime mud is regenerated in a limekiln.

High-pressure steam from boiler is conventionally used in turbines to generate electricity. After the turbines steam with lower pressure is used for heating in different processes such as evaporation of black liquor, cooking and drying the paper.

Washed and screened pulp can be delivered to a paper mill, dried using pulp machines or bleached in order to increase brightness. Unbleached chemical pulps, especially kraft pulps, have a dark brown colour, which is the result of the residual lignin in the pulp. To get bright pulp as a requirement for a good printing paper surface and other related properties, the rest of the lignin has to be removed with other selective chemicals. Bleaching may be proceeded by various chemicals and in different combinations of steps.

III. WOOD AS RAW MATERIAL FOR PAPER MAKING

Wood is a natural material making up the major part of the forest biomass. Properties of wood vary depending on tree species, growing conditions (climate, type of soil, season), and age of a tree. Wood material has cellular structure. All cells can be divided into prosenchymatous and parenchymatous. Prosenchymatous cells are “dead cells” and have two functions in a tree: mechanical support and conduction of water from the roots to the crown of a tree. Compared with the amount of prosenchymatous cells wood contains only small amount of parenchymatous cells, which provide storage of nutrients and growth of a tree by division of the cells. Softwoods and hardwoods have different structure caused by different cellular composition. Softwoods have simple structure where long vertical tracheids make up 90%-95% of wood volume. These tracheids are called fibres in pulp and paper industry and provide good paper formation and strength of paper. The parenchymatous cells in softwood are short, thin-walled and contain material for nutrition. These cells are not desirable in papermaking. Hardwoods have smaller amount of fibres than softwoods (40%-75% of wood volume) and more complex cell structure. Hardwood fibres are shorter and narrower than softwood fibres and produce paper with lower strength characteristics, but smoother surface and better distribution of fibres in paper web.

Wood is an organic matter, consisting of three main chemical elements: carbon, oxygen and hydrogen. Small amount of nitrogen is also present in wood as well as ash or mineral elements. Principally wood cell wall is made up of 3 main components. They are cellulose, hemicelluloses and lignin. Cellulose and hemicelluloses are carbohydrates that differ in structure and thus possess different properties. The molecules of hemicelluloses can be made up by a variety of monomeric sugars among which hexoses are D-glucose, D-mannose and D-galactose, and pentoses are D-xylose and L-arabinose. The main distinguishing feature of hemicelluloses compared to cellulose is their relatively high accessibility to acidic or alkaline hydrolysis. This is due to their amorphous structure and much lower degree of polymerization (100-200). The average content of hemicelluloses in wood is 25%-35%. Hardwood species contain in average 1.5 times more hemicelluloses than softwood species. Some part of hemicelluloses is difficult to separate from the wood, those hemicelluloses are thought to be firmly bound to cellulosic chains. [Hemicelluloses play important role in papermaking while they promote swelling of fibres prior to grinding. If hemicelluloses are preserved in cooking process it gives higher yield of pulp.

Lignin is a branched 3-dimensional polymer that has irregular structure. The structural units of lignin are various derivatives of phenyl propane with various bonding combinations. Two main types of lignin units are guaiacyl (with one methoxyl group in phenol ring) and syringyl (with two methoxyl groups). Lignin content in wood can vary from 20% to 35%. The lignin of softwoods is mainly (almost exceptionally) guaiacyl units while hardwoods contain both guaiacyl and syringyl. Lignin is an undesirable component in papermaking. It causes aging and yellowing of paper. The main objective of chemical pulping is to remove lignin and try to preserve as much polysaccharides as possible. Wood contains some amount of extractives – substances soluble in water and organic solvents, and other organic matter such as proteins, salts of organic acids. Inorganic compounds are present in wood in very small amounts - 0.5%-0.7% of wood weight.

Hemicelluloses

As long as this investigation aims at extracting hemicelluloses from hardwood, i.e. EHCAS, more attention should be paid to the properties of the polysaccharides specific for this wood species. As stated before hemicelluloses are polymeric anhydrides of pentoses and hexoses. But in fact some uronic acids are also present, some hexuronic acids are among them: □-D-glucuronic, □-D-mannuronic and □-D-galactouronic acids. These acids can undergo decarboxylation when heated with mineral acids and convert to carbohydrateS.

Wood chips

The most common type of raw material in chemical pulping is wood chips. Wood logs are cut in a special way in a chipping machine. The logs are fed to the machine at an angle of approximately 45 □ and the shape of chips resembles a parallelepiped with an angle 45 □ to the direction of the fibres. Target chip size could be length X width X thickness = 20 X 20 X 4 mm. Accepted range of the chip length is 10-30 mm and thickness 3-7 mm, while there are no special requirements for the width. [19] The uniform size of the chips is very important in order to provide the uniform diffusion of the cooking liquor inside the chips and avoid having pulp undercooked and overcooked.

PRE-TREATMENT

In the middle of the 20th century the pre-treatment of wood was developed in order to obtain high purity dissolving pulps. The technology includes dilute acid or water pre- hydrolysis at elevated temperatures. The objective is to remove hemicelluloses as fully as possible so that pure cellulose with high degree of polymerization could be obtained. In our case full removal of hemicelluloses is not only unnecessary, but even undesirable, because they play an important role in the developing sheet-forming properties of the fibres. It is important to preserve cellulose and to extract pentosans. By now many methods of wood pre-treatment have been described in the context of total wood hydrolysis aiming at obtaining monosaccharides suitable for biological treatment.

Examples of the methods are:

- Steam explosion – lignocellulosic material is subjected to high-pressure steam treatment and the pressure is released. This produces a kind of explosion effect on the material
- Hot water pre-treatment – lignocellulosic material contacts with hot water in co-current, counter-current or flow-through mode
- Dilute acid pre-treatment – uses elevated temperatures and acid charge in treatment solution where acid acts as a hydrolysis catalyst
- Alkali pre-treatment – uses alkali charge, lower temperatures and longer dwell times compared to acid treatment .
- Steam explosion is a drastic method. It influences the structure of wood chips considerably and presumably damages fibres, which should be avoided.

Effect of hot water pre-treatment on wood:

- Accessible surface area increase
- Removal of hemicelluloses
- Slightly alters lignin structure

Dilute acids have similar effect on wood, but also alter lignin structure to a significant extent. The main advantages of hot water pre-treatment compared to dilute acid or alkali treatment is that the wood material is treated in less severe conditions. The mechanism of hot water hydrolysis lays in cleavage of O-acetyl and uronic acid substitutions that results in formation of acetic and other organic acids. This is thus a self-catalysed reaction. Further degradation of polysaccharides to monomers and derivatives is possible in the solution. Theoretically all hemicelluloses can be dissolved by water. Literature investigations show that significant amounts of lignin can be removed from EHCAS wood in the step of water pre-treatment. The amount of lignin that can be dissolved at 150 degree C and treatment time 120 minutes reaches 20% of the total amount of lignin in wood, that is about 4% of the total wood weight. Lignin dissolution can promote cooking process reducing the H-factor. On the other hand this kind of pre-treatment can cause the formation of some stable lignin forms, resistant to alkaline treatment.

Process variables

Wood is a complex material built up of the substances different in properties and bonded to each other. This bonding provides solid structure of wood and if a certain wood substance has to be removed, it makes it extremely difficult to remove this substance and to preserve the other ones. The industrial processes that are applied to remove lignin or to isolate cellulose are complex and a lot of factors have to be carefully adjusted to obtain a good result, e.g. temperature, pressure, time, liquid-to-wood ratio, chemicals charge. When isolating hemicelluloses before kraft cooking the main objective is to keep pulp properties invariable in order to provide equally high strength characteristics of paper, as they would be without the extraction pre-treatment.

The following factors can be considered in the adjustment of extraction:

Liquid-to-wood ratio

Liquid-to-wood ratio has both technological and economical aspects. On the one hand, larger amount of liquid may promote more full extraction of hemicelluloses because smaller concentrations of hemicelluloses cause less precipitation back on wood. On the other hand, economically it is more feasible to have as high concentration of hemicelluloses as possible in the extract if there is any further treatment. The higher the concentration of the substance in the solution, the less energy is needed to evaporate excess water. The process should be optimized with possibly low liquid-to-wood ratio.

Time

Time is a limiting factor if the process of hemicelluloses extraction is applied industrially. Long duration of pre-treatment step makes the process economically inefficient, it demands extremely large equipment and causes high energy consumption. The objective is to reduce dwell time to smallest possible value at adjusted temperature and wood yield.

Temperature

Temperature as well as time is a limiting factor in pulp and paper industry. In addition, high temperatures may damage cellulose chains and that will result in lower cellulose yield, lower degree of polymerisation of cellulose and as a result lower strength of the end product – paper.

H-factor

H-factor is a value that depends on temperature and time and is used in kraft pulping process to estimate the degree of delignification. An H-factor of 1 estimates the pulping effect of 1 hour at 100 degree C. In our investigation H-factor is used as a tool of estimating time needed for equal extraction effect at different temperatures.

pH

Hemicelluloses are extracted from the wood as a result of the hydrolysis and dissolution processes. Hydrolysis of hemicelluloses is an acid catalysed reaction where glycosidic bonds are broken down in presence of water. The reaction may be carried out adding some acid. However, hydrolysis of acetyl groups of hemicelluloses develops acidity even when wood is treated with pure water at elevated temperatures. The pH of the extract can go down to 3-4. It is worth mentioning, that the acidity of the solution does not directly influence the rate of extraction, but the acidity developed within the chips does. In case of using pre-hydrolysis of chips before kraft cooking using hot water is favourable, owing to ability of cellulose to hydrolyze in acidic conditions together with hemicelluloses. Mild treatment with small amount of acid can be acceptable. Work of Springer and Harris showed, though, that diluted sulphuric acid (i.e. 0.4% H_2SO_4) is more selective to xylan than water. At 85%-86% extraction of xylan only 6% of glucan leaves wood after dilute acid treatment at 170 degree C, while for hot water treatment this value increases to 13% of glucan. This means that mild acid treatment may be even favourable for xylan removal and glucan preservation.

Recycling

Recycling of the extract is economically desirable. The process is supposed to be introduced in a continuous pulping line. It makes it easy to recycle and recycling economises water. On the other hand, any extraction into a solution that is rich in extracted substance is limited. Applying high temperatures to a wood–rich solution mixture may cause precipitation of hemicelluloses extracted in previous stages and prevent new substance from dissolving. Optimisation of recycling includes finding best recycling ratio, which provides both high resulting concentration of dissolved substance and high yield of this substance from the wood.

Pre-steaming

If hemicelluloses extraction step were introduced in a pulp mill, pre-steaming process would normally forego it. It is used to remove as much air from wood pores as possible and to replace it with liquid. This is done due to high resistance of air to the diffusion of liquid, which has negative effect on pulping process.

Another advantage of pre-steaming is that the chips are heated before entering the digester or impregnation vessel.

EQUIPMENT AND PROCEDURES

3.1 Extraction and cooking

Extractions of the hemicelluloses and kraft cooking of cellulose were carried out in a cooking laboratory at Smurfit Kappa Kraftliner Piteå. The set of equipment consists of six autoclaves, pre-steaming equipment, a glycol bath and washing equipment. Autoclave showed in the figure 1 is a vertical cylindrical vessel made from stainless steel. An inlet in the bottom is used for pre-steaming. A lid with a mesh and an adjustable outlet for liquid is fastened to an autoclave with nuts and makes the vessel waterproof.

Figure 1 - Autoclave

Glycol bath (Figure 2) is a large vessel with an electric heater, glycol circulation pump and a rotating shaft. The shaft has two vertical disks with special housings for the autoclaves, which are installed at an angel of approximately 25□ to the shaft (Figure 3). All six autoclaves can be run simultaneously. The bath can be charged with a lesser number of the autoclaves, but balance should be maintained. When the shaft is rotating the autoclaves are immersed into glycol in turns. At the same time mixing occurs inside the autoclaves. The glycol bath has a range of working temperatures between 80degree C and 170degree C.

Figure 2 - Glycol bath

Figure 3 - Autoclave in the glycol bath

Pre-steaming equipment (Figure 4) consists of a metal support for autoclaves with a rotating holder and a steaming system connected to a steam generator. The hoses are designed to be connected to the bottom inlets of the autoclaves. Steam passes through the autoclaves and leaves the vessels through the top outlets.

Figure 4 - Pre-steaming equipment

3.1.1 Extraction procedure

Raw material for all the experiments was EHCAS chips from Smurfit Kappa Kraftliner Piteå. These chips are obtained in ordinary industrial chipping process and are used at the mill to produce bleachable pulp for bleached layers of top-liner board. The chips were kept in a freezer and then conditioned at room temperature in order to simulate real industrial conditions. Chips with determined dry matter content are weighed and loaded to the autoclaves. Then an amount of water, calculated considering the amount of water in the loaded chips, is also weighed and loaded to the autoclaves. The autoclaves are then tightly closed and placed into the heated glycol bath and the rotation is started. Calculation of H-factor is started when the contents of the autoclaves is heated up. When the process is completed, the autoclaves are taken out from the bath and cooled down instantly. When the autoclaves are cooled down the extract is separated from the chips, pH is measured, chips are weighed and dry matter content and yield are determined. If pre-steaming has to be carried out then the chips are loaded into autoclaves, the autoclaves ate weighed, turned upside down and connected to the steaming system. The steam goes through the autoclaves top-down. The procedure lasts 10 minutes. Then the autoclaves are weighed again and the amount of condensate is calculated. This figure is used to maintain liquid-to-wood ratio. The needed amount of water is added and the extraction procedure goes on as described above.

3.1.2 Cooking procedure

Chips with determined dry matter content are weighed and loaded to an autoclave. The amount of white liquor and water to be added is determined.

Effective alkali charge was considered to be 21%. White liquor that was used had the following properties (Table 1):

roperty	alue
otal alkali, g/l	65.5
ffective alkali, g/l	17.5
aOH, g/l	2.1
a$_2$S, g/l	0.6
a$_2$CO$_3$, g/l	2.6
ulfidity, g/l	5.5

Table 1 - White liquor properties

The amount of water that is necessary to maintain liquid-to-wood ratio 3.5 is calculated taking into consideration amount of water in chips and in white liquor. When the autoclaves are charged with both chips and white liquor they are closed and placed into the glycol bath heated up to 80 degree C. The autoclaves are heated up to 120 degree C with the rate of 1 degree C per minute and the temperature of 120 degree C is kept constant for 20 minutes. After that period the autoclaves are heated further up to 160 degree C with the same rate. The temperature curve is showed in the picture 3.5. When H-factor reaches the target value the process is stopped and the autoclaves are cooled down rapidly with cold water. Black liquor is collected from the autoclaves and pulp or chips are taken out and washed. Washing is carried out in cylindrical vessels with wire bottoms. The showers, installed over the vessels supply hot water for washing. It should be mentioned that washing efficiency is very high due to long treatment time and sufficient amount of wash water. Thus, the pH of the liquid contained by fibres may be considered equal to the pH of the water used in further beating and sheet forming.

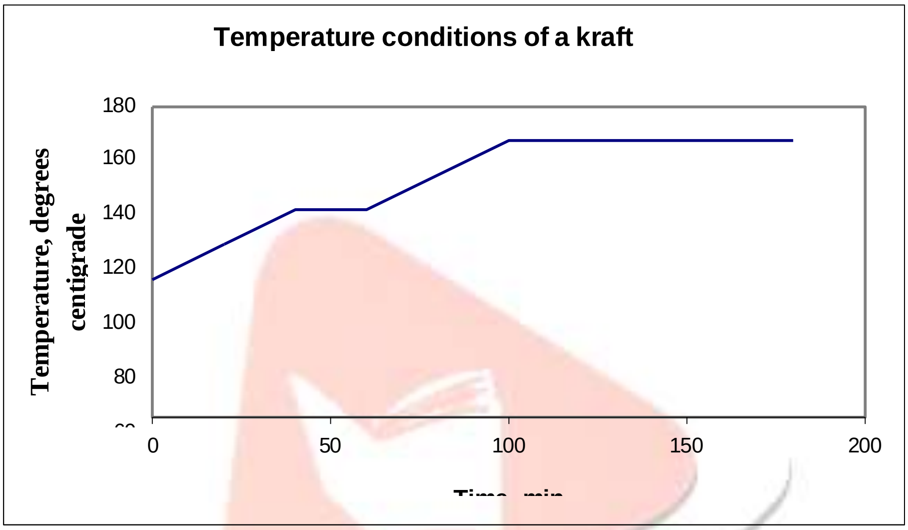

Figure 5 – Cooking conditions of a kraft cook

Laboratory kraft cook is not followed by pressure release, which causes defibration of cooked chips and is widely used in industry. In order to separate fibres the laboratory defibrator is used. The defibrator has two horizontal steel disks, one of those is rotating and the other is fixed. The surfaces of the disks have special patterns (edges) and the clearance between the disks can be adjusted. The chips with sufficient amount of water are fed manually at the top of defibrator. Obtained pulp is then centrifuged in order to remove excess of water and homogenized in a special mixing device.

3.2 Black liquor analysis

The analysis of black liquor in this case is measuring of residual alkali content in black liquor after kraft cooking. The principle lies in the titration of diluted black liquor with hydrochloric acid. [SCAN N 33-94]

3.3 Pulp analysis

3.3.1 Determination of residual lignin content

To estimate "residual lignin" content in pulp permanganate or Kappa number is traditionally used. Lignin in pulp can be easily oxidized by potassium permanganate. Permanganate method measures the amount of 0,1 N potassium permanganate consumed by 1 g of moisture-free pulp in the period of time 10 minutes.

3.3.2 Determination of limiting viscosity

Limiting viscosity number is a value for estimation of the degree of polymerization (DP) of pulp. The principle of the method lies in measuring efflux time of the pulp dissolved in cupri-ethylenediamine solution through a capillary-tube viscometer at specified concentration at 25 degree C [ISO 5351]. Higher DP of pulp gives higher viscosities of the solutions and therefore longer efflux times.

3.4 Pulp beating and determination of beating degree

Beating of pulp was performed in a PFI mill [ISO 5264-2]. The advantage of this kind of equipment is the small amount of pulp needed for the beating procedure. PFI mill consists principally of a roll with bars, housing with smooth surface and a loading device to provide the pressure. Both roll and housing rotate in the same direction, but at different peripheral speeds, beating is thus provided by the shear force. The pulp in amount of 30 g and concentration of 10% is placed in the gap between the roll and the housing and is spread evenly on the wall of the housing. The number of the revolutions of the PFI mill is counted and used to control the process.

Drainability or beating degree of pulp can be determined using Schopper-Riegler method. [ISO 5267-1] The principle lies in estimating water drainage rate. The Schopper-Riegler device is a vessel with cylindrical top and conical bottom part. A wire separates the two parts. The conical part has two outlets. One of them is placed axially directly in the bottom, while the other outlet is shifted to a side. The suspension of 2 g of pulp and 1000 ml of water is let to drain through a wire. The volume of water that leaves the vessel through the side outlet is measured. The higher drainage rate, the more water leaves the vessel through the side outlet, the lower the value of beating degree. The method that was used to determine beating degree at Smurfit Kappa Kraftliner Piteå differs from standard and the measurements are expressed as modified Schopper-Riegler degrees. The difference in this method compared to the ISO standard is a larger diameter of the bottom outlet of the Schopper-Riegler device. The value of beating degree measured as modified Schopper-Riegler degrees is more sensitive to low- beaten pulps.

3.5 Sheets preparation

Laboratory sheets are prepared in a laboratory sheet former, where pulp suspension is drained through a wire. The sheet former is connected to a vacuum system to provide better water removal. After formation the sheets are separated from the wire and pressed with dry filter paper on one side of a sheet and a smooth metal plate on the other with pressure of 0.30 MPa for totally 7 minutes. After pressing the sheets are dried on the metal plates at temperature t=23 degree C and relative humidity RH=50% and conditioned. The target basis weight of the sheets was chosen to be 100 g/m^2. It should be mentioned that laboratory sheet forming system does not have short circulation of white water that is collected under the wire in industrial papermaking process and reused for dilution of pulp suspension. In this case the fibre balance is maintained and fines are delivered back to the paper web. This provides better structure of the web. In laboratory sheet forming procedure the fines, which go through the wire are lost with the water.

3.6 Physical and mechanical properties of the sheets

A number of standard tests were carried out on the prepared sheets. The basic dimensional and structural properties include basis weight, thickness, density and porosity. Roughness and brightness are among the surface properties. Basic strength properties of pulp or paper include tensile, bursting, tear and compression tests. The definitions of the properties and testing methods are included in the “Results and discussion” part due to their high relevance to the analysis of the results.

IV. RESULTS AND DISCUSSION

4.1 Extraction

A number of the experiments were carried out in order to find optimal conditions for the extraction of hemicelluloses from EHCAS wood chips. The estimated target yield of wood after extraction was set to 89-92%.

4.1.1. Initial trials

The first experiments were based on initial trials (Ergin Kulenovic, KIRAM AB, Lund). [11] The experiments in Lund were carried out in Büchi Glas Uster manufactured polyclave. It was reported that a 20 minutes treatment with pure water at 150 degree C gives wood yield of 89.5%. The results of the autoclave extraction in the cooking laboratory at Smurfit Kappa Kraftliner Piteå gave results, different from the ones obtained at Lund University by KIRAM AB.

Temperature of experiment, °C	Dwell time, min	Yield of wood,%	H-factor	Liquid-to-wood ratio	pH after extraction
150	20	98.4	50	3:1	4.62
		99.6		4:1	4.80
		99.5		6:1	4.98
155		99.7	89	3:1	4.46
		98.5		4:1	4.62
		98.7		6:1	4.71

Table 4.1 Extraction with pure hot water at 150* degree C *and 155* degree C *with the dwell time 20 minutes.

Table 4.1 shows that the treatment of EHCAS chips at 150 degree C and 155 degree C does not give expected results and yields very low amount of extracted hemicelluloses in the range of 0.5 – 1.5% of dry wood weight. A relation between yield of wood and liquid-to-wood ratio is not possible to determine based on these trials due to the high error expectancy in such a small yield range. The errors might be caused by uneven distribution of moisture in chips and weighing inaccuracy. The pH measurements (Table 4.1) show that the acidity was developed during the extraction processes, but the values of pH are quite high, it means that the concentration of acids in the solution is extremely low.

4.1.2. Improved extraction

In the next set of the experiments the severity of extraction conditions was increased. Four parameters were varied: time and temperature (within the same H-factor value), H- factor and liquid-to-wood ratio. This set of trials showed that it is possible to reach target wood yield with more severe conditions.

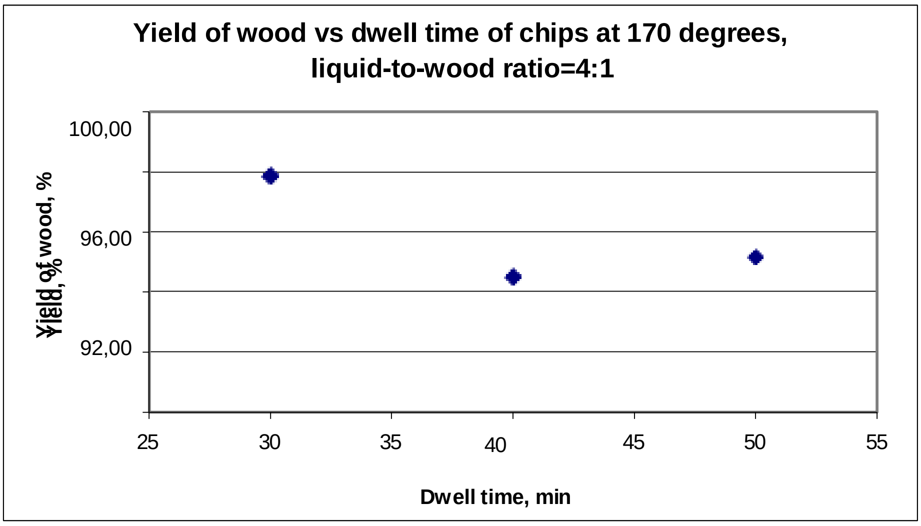

***Figure 4.1.1 - The yield of wood after the hot water pre-treatment of wood chips at 170* degree C *and the liquid-to-wood ratio 4:1 for different dwell times of the chips*.**

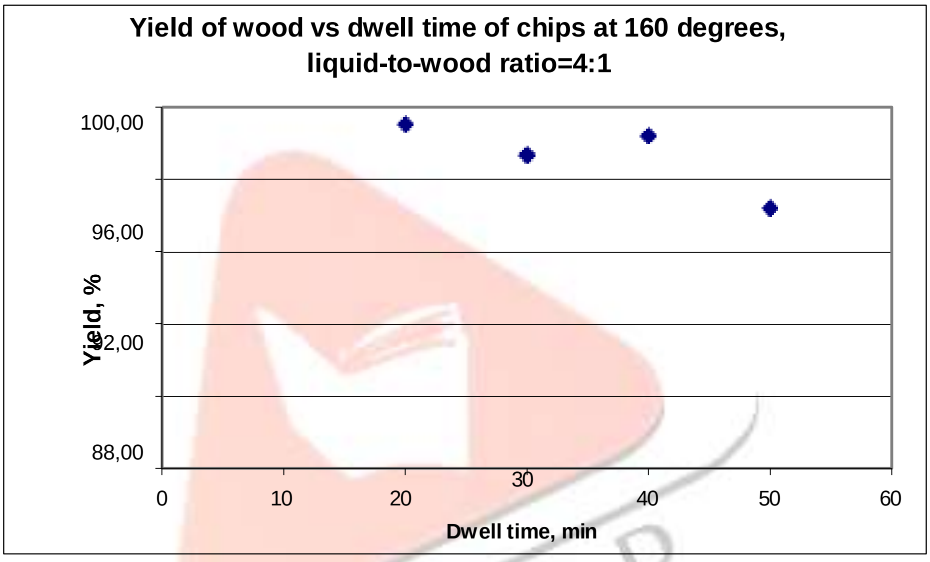

Figure 4.1.2 – The yield of wood after the hot water pre-treatment of wood chips at 160 degree C *and the liquid-to-wood ratio 4:1 for different dwell times of the chips*.

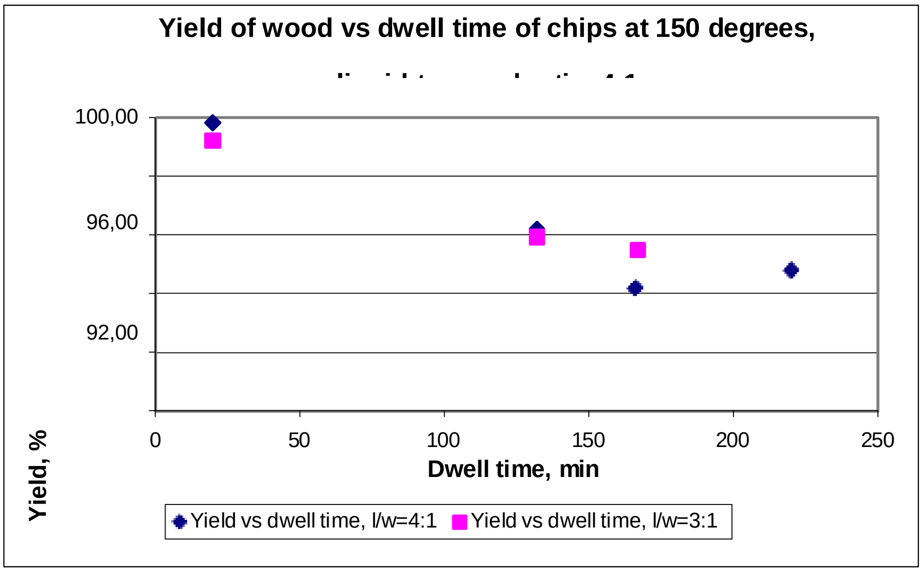

Figure 4.1.3 – The yield of wood after the hot water pre-treatment of wood chips at 150 degree C *and the liquid-to-wood ratio 4:1 and 3:1 for different dwell times of the chips*.

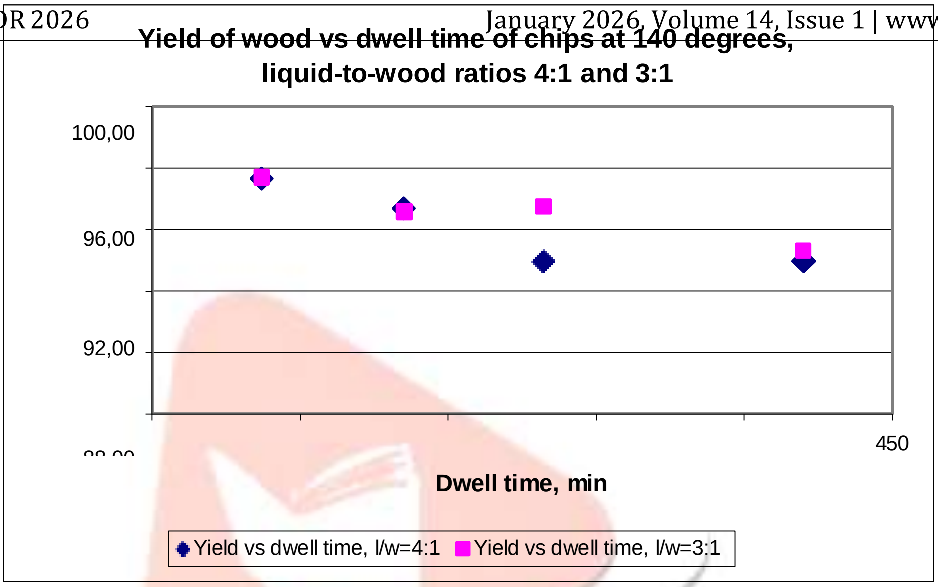

Figure 4.1.4 – The yield of wood after hot water pre-treatment of wood chips at 140 degree C *and liquid-to-wood ratio 4:1 and 3:1 for different dwell times of the chips*.

The figures 4.1.1-4 show the relation between the time and the yield of wood after the pre-treatment at different temperatures. It is logical that the yield of wood decreases with the increased treatment time and the process is more intensive at higher temperatures. The target yield can be reached 8 times faster at 170 degree C, than at 140 degree C. It corresponds with the empirical law that rising temperature by 10 degree C gives double increase in the reaction rate.

The trials have showed that it is possible to reach 90% of wood yield as a result of pure hot water pre-hydrolysis. But the conditions of these trials are not feasible in pulp production process. It is either too long time or too high temperature. Furthermore, high temperature can have destructive effect on fibres, particularly at low pH.

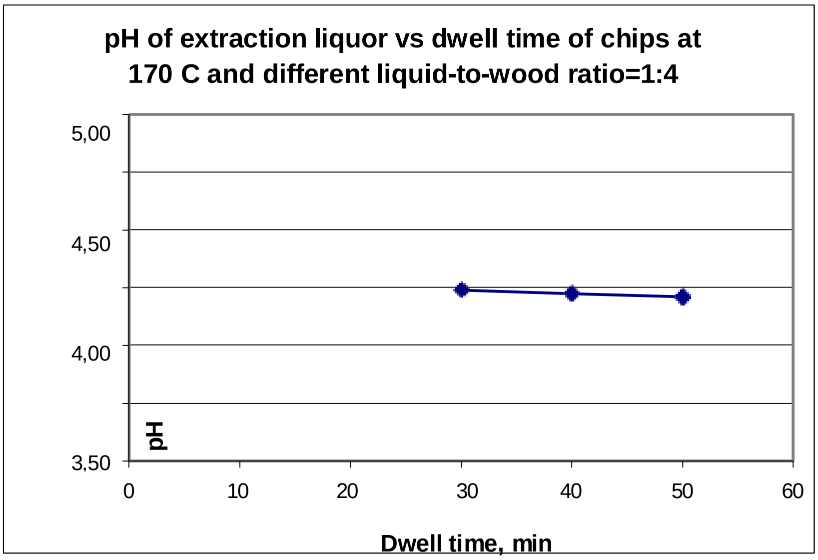

Figure 4.1.5 - The pH of the extraction liquor after the hot water pre-treatment of wood chips at 170 degree C *and the liquid-to-wood ratio 4:1 for different dwell times of the chips*

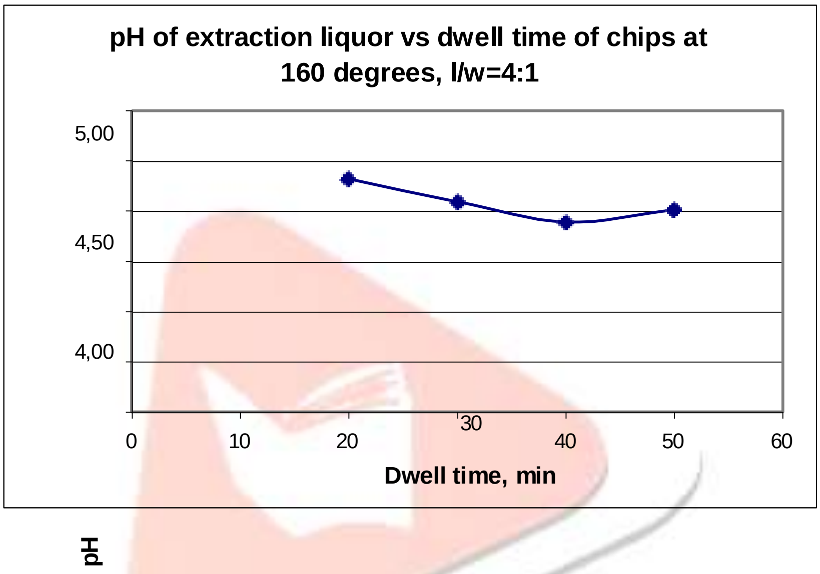

Figure 4.1.6 – The pH of the extraction liquor after the hot water pre-treatment of wood chips at 160 degree C and the liquid-to-wood ratio 4:1 for different dwell times of the chips.

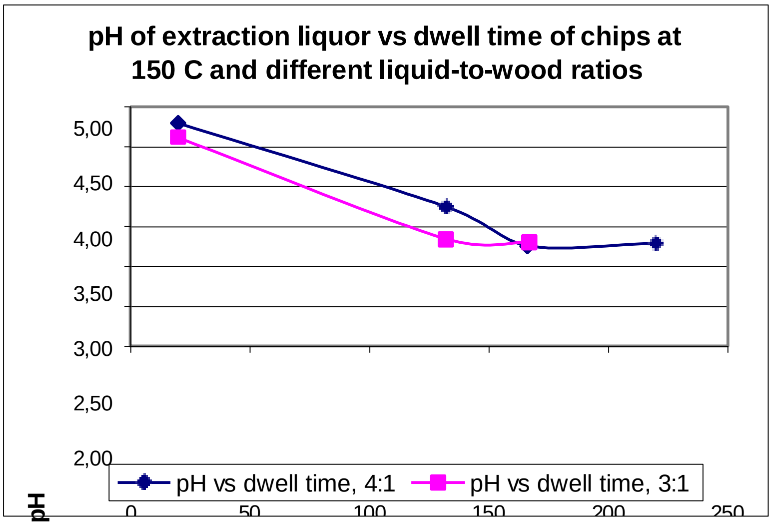

Figure 4.1.7 – The pH of extraction liquor after hot water pre-treatment of wood chips at 150 degree C and liquid-to-wood ratios 4:1, 3:1 for different dwell times of chips.

4.1.3. Comparison of the extracts and the chips after treatment

Visual comparison of extraction liquors rich and poor in hemicelluloses indicates large amount of the substance by rich orange colour and high opacity, while the liquor poor in hemicelluloses is light yellow and is comparatively clear (Figure 4.1.16).

Figure 4.1.16 - Extraction liquors. 166 minutes (left) and 20 minutes (right) treatment at 150 **degree C**.

Visual examination of the fresh, mildly treated and deeply treated chips shows that deeply treated chips (about 90% yield of wood) are very dark, it indicates that the process of wood structure degradation has started, at the same time mildly treated chips differ from fresh chips very slightly (Figures 4.1.17a-c). The deeply pre-treated chips become very easily broken down along the fibres direction and produce much more fine material, i.e. separate fibres during extraction process, while mildly treated chips stay solid and intact.

igure 4.1.17a – Fresh chips. ry matter content 57%.	*igure 4.1.17b - Chips after hort pre-treatment at 150°. ood yield 99%. Dry matter ontent 43%.*	*igure 4.1.17c - Chips after eep pre-treatment at 50***degree C.** *Wood yield 88%. ry matter content 37%.*

Examination of the extract shows that after the settling some solid phase can be observed. The solid phase contains small parts of fibres and brownish powder-like substance resembling lignin. According to Rutowski and Wandelt [8] some lignin can be extracted from the wood in water pre-treatment process as well as hemicelluloses. This indicates that delignification starts in the extraction step and the H-factor needed to cook the pulp to a certain Kappa number might be lower, than for standard cooking.

4.1.4. Liquor analysis

High-pressure liquid chromatography was carried out at Luleå University of Technology in order to determine the composition of the extracts. A 90% wood yield extract sample was taken for the procedure. HPLC showed that the extract contains relatively small amount of glucose (Table 4.2). These results prove that in the extraction process cellulose is dissolved to a very small extent, taking into consideration the fact that hemicelluloses also contain some amount of glucose units. Figure 4.1.18 shows that the extract contains large amount of oligo- and polymeric xylose, as well as monomeric. This result is quite expectable as EHCAS wood contains up to 24% of xylan. The concentration of xylose in the solution is quite high. It is favourable for the further treatment of the liquor.

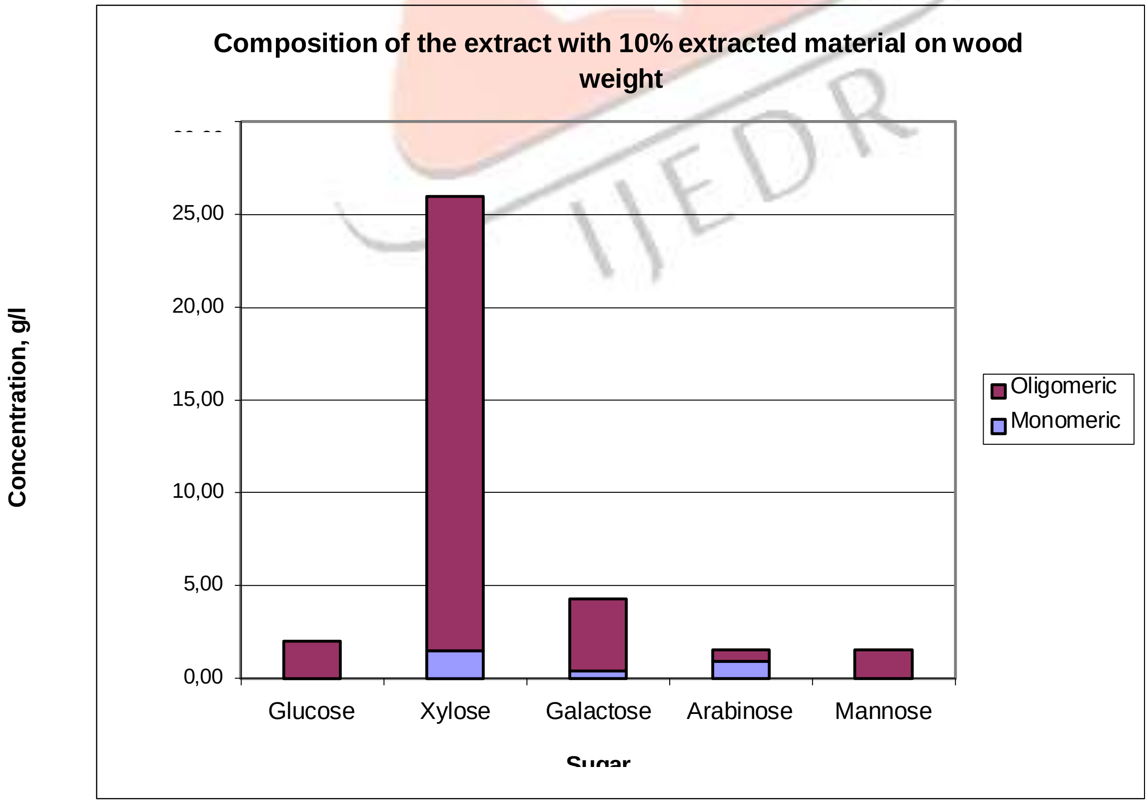

Figure 4.1.18 - Composition of the extract with 10% extracted material on wood weight. (Luleå University of Technology, Christian Andersson, David Hodge)

4.2 Cooking

4.2.1 Cooking the chips with 5%-6% extracted material

Two extracted chips samples were chosen for the first set of cooking (appendix 2). Those were:

- 94.9% wood yield chips extracted with pure hot water at 150 degree C for 130 minutes;
- 94.1% wood yield chips extracted with diluted sulphuric acid with acid charge of 0.37% on dry wood (initial pH=1.78) at 150 degree C for 85 minutes.

Figure 4.2.1 shows the relation between pulp yield after kraft cooking and the H- factor. Two different values of yield for each pulp sample should be taken into consideration. One of them is yield of pulp calculated on extracted wood weight. It indicates the loss of the material of the wood during cooking process. The other one – yield of pulp calculated on total wood weight shows the total loss of the material of the wood starting with extraction and finishing with cooking. One can see that both yields for acid pre-treated chips are significantly lower than those of water pre-treated.

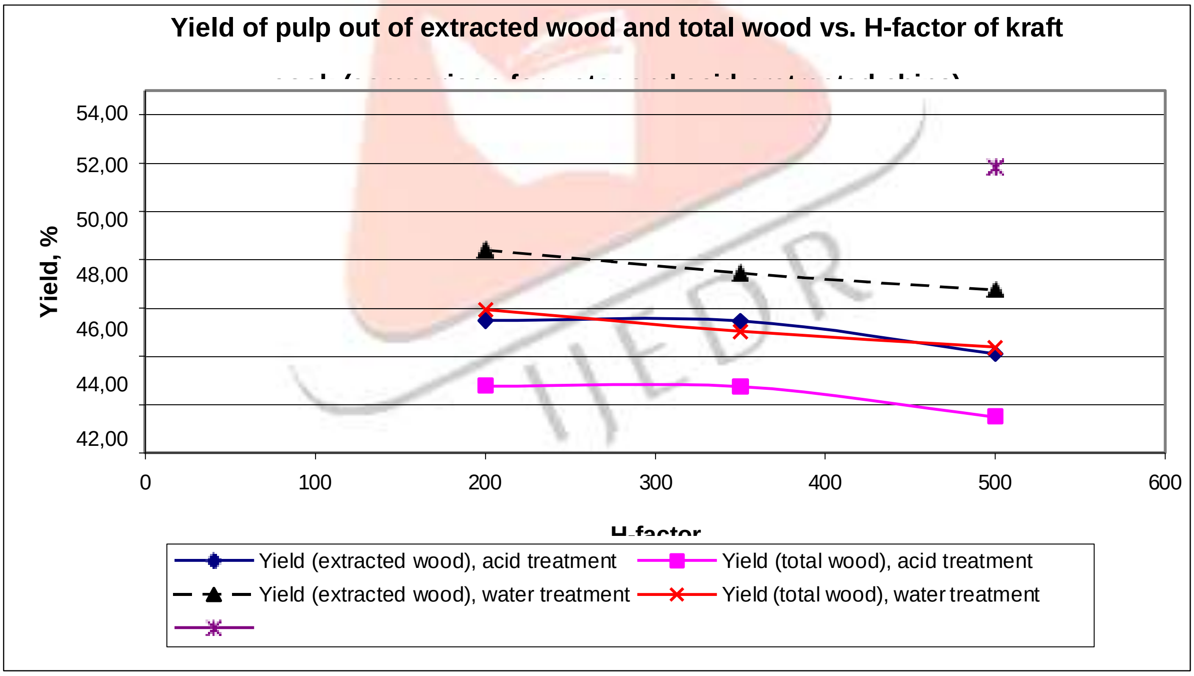

Figure 4.2.1 – The yield of pulp out of the extracted wood and total wood vs. the H-factor of kraft cook (cooking the 95% yield water extracted chips and the 94% yield acid extracted chips, 0.37 % sulphuric acid on dry wood)

According to the data a conclusion can be made that extracted chips yield less pulp after kraft cooking compared to the yield after standard cooking to the same Kappa number (50% - 52%). Relatively high yield of standard pulp can be explained by the precipitation of a part of the dissolved hemicelluloses back to the fibres in the end of the cook. This phenomenon depends on the conditions of a cook. The concentration of the dissolved hemicelluloses in the cooking liquor plays an important role in the process and governs the amount of the hemicelluloses that precipitate on the fibres. In the case of the removal of some amount of the hemicelluloses their concentration in the liquor becomes lower than that of a standard cook. In addition, some hemicelluloses may stay intact after kraft cooking but removed in the extraction process. Small amount of amorphous cellulose is presumably dissolved in acidic environment together with hemicelluloses and lignin in the extraction process. This process may also be a reason for lower yield of the pretreated pulp.

V. CONCLUSIONS

An integral investigation has been carried out in order to analyse the effect of different conditions on the extraction of hemicelluloses prior to kraft cooking, to optimise the process and to see the response of cooking process and pulp properties after the extraction. Extraction experiments showed that it is possible to extract significant amount of hemicelluloses from wood at different temperatures in the range of 140 degree C – 170 degree C with corresponding dwell times higher for lower temperatures. The optimal temperature for industrial application was selected to be 150 degree C, which is acceptable in industrial conditions, provides comparatively low dwell times of wood chips for obtaining certain wood yield after the extraction and has presumably less destructive effect on the fibres than higher temperatures. Optimal liquid-to-wood ratio of the process is 3:1, as long as it economizes fresh water and provides higher concentration of hemicelluloses in the liquor, which is good in the case of further treatment of the liquor. Liquor recycling showed, that the extraction into a rich solution is limited and the rate of extraction is smaller with higher initial concentration of the substance in the liquor. Both pure water and dilute sulphuric acid treatment of wood was investigated. In the case of water treatment acidity is developed by cleavage of O-acetyl and uronic acid substitutions in hemicelluloses that results in formation of acetic and other organic acids. Addition of small amount of sulphuric acid (0.18% on wood weight) increases the rate of extraction and does not have significant negative influence on the pulp properties compared with water pre- treated pulp.

Cooking trials showed that much lower H-factor is needed to reach the same Kappa number, than in the case of cooking fresh chips. At the same time the yield of pulp is much lower compared to the standard pulp, which is caused by the removal of the substance on the stage prior to cooking. Viscosity tests gave logical results showing that pre-treated pulp, containing small amount of low-molecular hemicelluloses, has higher average molecular weight, than standard pulp. Pulp beating curves obtained in laboratory beating process show that the standard pulp is beaten easier than the pre-treated. This difference is mainly caused by lower content of hemicelluloses in the pre-treated pulp and thus limited swelling of fibre wall and hindered alteration of the fibre wall.

Pulp strength is the most important attribute of the whole investigation, as the process should be optimised for a kraftliner mill. The tests showed that the strength of the pulps with 10% extracted hemicelluloses is on average by 50% lower than that of the standard pulp. The reason for this is low flexibility of the fibres caused by low content of hemicelluloses and thus less effective beating. As a consequence of this the contact area of the fibres is smaller and less hydrogen bonds are formed. In addition, fibre strength is reduced in the extraction and beating processes to some extent. The strength of the pulp with only 5% extracted hemicelluloses is higher than that of the pulp with 10% extracted material but still lower by 25% compared with the strength of the standard pulp.

Conclusions can be made, that extraction of hemicelluloses prior to kraft cooking can increase the capacity of a kraft mill (i.e. decreases dwell time of the chips in a digester), but reduces the yield of pulp, which means higher consumption of wood and thus higher cost for production. The strength of the obtained pre-treated pulp is not acceptable for producing kraftliner, owing to very high strength demands. It might though be useful in paper production, where light scattering at high brightness is needed. To fully understand the properties the pulp should be bleached and tested. Further research can be also aimed at varying chips size, e.g. producing thinner chips in order to overcome the limitation of diffusion and thus decrease the severity of the pre-treatment, at using other treatment methods, e.g. alkali extraction of hemicelluloses. The project might be applied in production of paper grades different from kraftliner, e.g. high brightness printing paper.

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Exploring Alternatives To Hardwood In Paper Production Using Chemi-Biological Pulp (CBP) And Deinked Pulp (DIP)

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Abstract

The production of paper using chemical bagasse pulp and deinked pulp (DIP), without the incorporation of hardwood fibers, represents a sustainable alternative to conventional wood-based papermaking. This study investigates the utilization of bagasse, a by-product of the sugarcane industry, and deinked pulp obtained from recycled paper as primary raw materials for paper production. Chemical pulping of bagasse involves alkaline or sulfate-based treatments to effectively degrade lignin and liberate cellulose fibers, yielding a pulp suitable for papermaking applications. The deinking process removes printing inks, fillers, and other contaminants from recovered paper, thereby improving fiber cleanliness and recyclability. The combined use of chemical bagasse pulp and DIP is evaluated for its ability to produce paper with mechanical strength, opacity, and printability comparable to conventional hardwood-based paper. This approach significantly reduces reliance on forest resources and supports circular economy principles through the efficient reuse of wastepaper. The findings demonstrate that paper produced from these alternative fiber sources can meet industrial and commercial quality requirements while promoting environmental sustainability in the paper manufacturing sector.

Key words: Chemical bagasse pulp, Deinked pulp (DIP), Sustainable paper production, Alternative fiber sources, Hardwood-free papermaking

I. INTRODUCTION

The paper manufacturing industry relies heavily on lignocellulosic raw materials, particularly hardwood and softwood fibers, to meet the growing global demand for paper and paperboard products. However, increasing pressure on forest resources, rising raw material costs, and environmental concerns have accelerated the search for sustainable and alternative fiber sources. In this context, non-wood pulps and recycled fibers have gained considerable attention as viable substitutes for conventional hardwood pulp in paper production. Chemi-biological pulp (CBP) represents an emerging alternative that combines mild chemical treatment with biological processes to partially remove lignin while preserving fiber integrity. This approach reduces chemical consumption, energy requirements, and environmental impact compared to conventional chemical pulping methods. CBP fibers exhibit favorable bonding characteristics and adequate strength properties, making them suitable for blending with other pulps in various paper grades. Deinked pulp (DIP), derived from recovered paper waste, is another important alternative fiber source that supports circular economy principles. Through processes such as pulping, screening, flotation, and washing, printing inks and contaminants are removed to produce usable recycled fibers. DIP reduces dependence on virgin fibers, lowers solid waste generation, and significantly decreases water and energy consumption in paper manufacturing. This paper examines the fundamental processes involved in paper manufacturing with an emphasis on raw material selection, pulp preparation, and processing techniques relevant to CBP and DIP utilization. The study highlights key stages such as wood chipping, pulping methods, digestion systems, and washing processes, providing insight into how alternative fiber sources can effectively replace or supplement hardwood pulp in sustainable paper production.

II. PROCESS INVOLVED IN PAPER MANUFACTURING

2.1-RAW MATERIAL

The chief raw material of the paper are natural fibrous material like wood(20%) and bagasse (80%) in the pure form gives the best quality paper. wood pulp composed of long and strong cellulose fibers is the most wanted raw material for the paper industry. Some hardwood like beech (Fagus grandifolia), sugar maple (Acer saccharum), and brich (Betula lutea) also furnish wood pulp. Other raw materials of minor importance are textile fibers of jute and hemp, wastes of textile industry, the esparto grass, paper mulberry, papyrus, and a number of other plants and fibrous material. Low grade papers, straw board, card board, paste board, etc. are produced from the fibrous stem of wheat, rye, barely, rice, oats, and other grasses. Hardwood are used as an ideal raw material for corrugated cases as well as printing and writing paper. Softwoods offer longer fibers (average 3mm compared with 1mm for hardwoods) and continue to be used for papers requiring the highest strength characteristics. Chemically pure cellulose consists of long ribbon like molecules made up of smaller glucose units. Papers and boards are used in contact with food in many different ways, either directly or indirectly, and either singly or laminated with other materials such as plastic or metal foil.

2.2-PULP MILL

A "pulp mill" in the paper industry is a manufacturing facility that converts wood chips or other plant fibers into a fibrous slurry called "pulp," which is the primary raw material used to produce paper at a separate paper mill; essentially, a pulp mill breaks down wood into its individual cellulose fibers by separating them from the lignin that binds them together, creating a thick, watery mixture ready for further processing into paper.

2.3-WOOD CHIPPING

Wood chipper is used in paper mill to produce chips from pulpwood so that cooking chemicals penetrate the wood quickly, completely and uniformly during manufacturing of chemical pulp or mechanical pulp. The process from pulpwood to chips is known as chipping process. The sizes of the good quality chips can be 5/8 to 5/4 inch long and 3-6 mm thickness.

WOOD CHIPS

Wood chips used in pulp mills are small, engineered pieces of wood cut from logs and wood pieces left over from the manufacture of solidwood products such as lumber and plywood. The target dimensions of a chip are usually 4–6 mm thick, 15–20 mm in length and width. This is the size range that will allow most batch and continuous chemical and mechanical pulping systems to reduce the wood uniformly to individual fibers and fiber bundles. There is no ‘perfect chip’ since wood variability does not allow consistently making the same chip over and over. There is an ideal chip size distribution that matches the needs of the mill’s digester(s). This article will describe the process of making chips that meets the specifications of pulp mills. The basic chip production processes are:

- debarking of logs increases pulp yield and cleanliness
- chipping of logs and wood products residuals makes small particles (called chips) in as uniform size distribution as possible
- chip screening removes fines and oversize chips to improve pulping uniformity
- prevention of contamination of chip flows with metal, rocks and especially, plastic
- chip transportation and storage systems receive, store, convey, and meter chips without damaging them
- quality control programs monitor chip production and deliveries [2].

Figure.1 WOOD CHIPS

2.4-TYPES OF WOOD CHIPPER

- Disc chipper
- Drum chipper

DISC CHIPPER

The disc chipper consists of steel disc, spout and chopping blades or knives. The knives are mount on the disc. The number of knives may be 4, 8 or 12. The older chipper had 4-knifes which was lower capacity and produce more waste. Therefore, comes in multi-knives chipper containing 8, 10 and 12 knives which are higher capacity and produce less waste and quality chips. All of them have almost same function. The spout of the chipper may be rectangular or oval shaped. The rectangular shape spout produces more uniform chipper. Usually, the logs are fed to the disc by a sloping spout so that they remain at an angle. After some hours the knives may be changing for sharpening. This process consumes huge energy but produces uniform woodchips. When the disc spins, then the blades cut the pulpwood into chips. The sizes of the chipper depend on disc diameter, number of knives, spout etc.

DRUM CHIPPER

The drum chipper consists of large steel drum and blades or knives. The drum is parallel to the hopper. It has some drawback. For example, it creates large uneven chips and has safety issue. But it is more energy efficient compare to disc type chipper. It produces more productive chips. After the wood chipper, the chips are passing through screens for separate acceptable sizes chips from fine and oversized chips. The chips should be free of dirts, sand, mud, stone and other foreign materials. Hence the chips are wash after screen section. Then they are sent to storage tank with conveyor belts or pipe line for storage like silos. The outside storage has some disadvantages. The surfaces chips can contaminant with air borne pollutant.

2.5 Mechanical Pulping

Mechanical pulping produces pulp by applying mechanical energy through grinding or refining to separate fibers. Most of the lignin remains in the pulp resulting in high yields (90–98%) but lower strength brightness and durability. This type of pulp is mainly used for low-grade products such as newsprint magazines and economical packaging papers.

Types of Mechanical Pulping

Mechanical pulping includes groundwood pulping refiner mechanical pulping (RMP) thermomechanical pulping (TMP) and chemi-thermomechanical pulping. In TMP wood chips are steamed before refining which reduces fiber damage and improves strength. These processes require high electrical energy for operation.

Chemical Pulping

Chemical pulping separates fibers by dissolving lignin using chemical reagents producing stronger and more flexible fibers with higher cellulose purity. The pulp contains longer intact fibers and is suitable for high-strength and specialty paper products.

Kraft Process

The kraft process uses an alkaline solution of sodium hydroxide and sodium sulfide to remove lignin from wood chips. The dissolved lignin forms black liquor which is processed for energy generation and chemical recovery making the process efficient and widely used.

Semichemical Pulping

Semichemical pulping combines mild chemical treatment with mechanical refining to partially remove lignin. It produces pulp with moderate strength and yield and is commonly used for corrugating medium and packaging applications.

2.6 Digester

A pulp digester is a large vessel used in chemical pulping to cook raw materials such as wood grass and other fibrous materials. It is used in both kraft and sulfite pulping processes. Digesters are made of carbon steel composite steel or dual-phase stainless steel depending on whether alkaline or acidic pulping is used. Digesters are classified into batch and continuous types. Batch digesters may be vertical or spherical and are heated with steam. Vertical digesters have larger capacity and are fixed units while spherical digesters have smaller capacity and rotate during operation. Continuous digesters include tube and vertical types and are equipped with automatic control systems. They are suitable for caustic soda sulfate and semichemical pulping methods.

2.7 Washing

Pulp washing is an essential step in paper pulp production that separates pulp fibers from black liquor and removes dissolved lignin and other impurities formed during cooking. Effective washing improves pulp purity and prepares it for bleaching and further processing. During washing concentrated waste liquor is extracted and sent for chemical recovery and wastewater treatment. Pulp washing methods include single-stage multi-stage and multi-stage countercurrent washing. Among these methods multi-stage countercurrent washing is considered the most efficient.

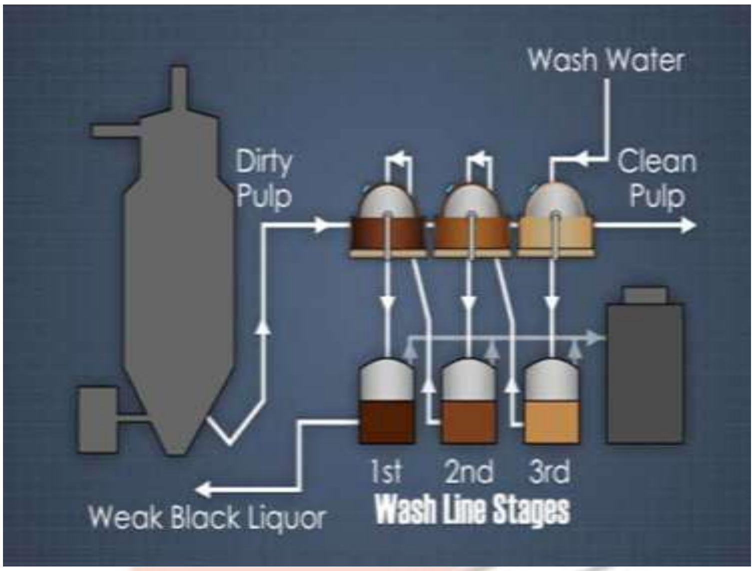


Figure 2 WASHING

Technical Principle of Pulp Washing Process

During chemical pulping nearly 50% of the plant fiber material dissolves into the cooking liquor forming waste liquor. In unwashed pulp most of this waste liquor exists freely between fibers accounting for about 70–80% while 15–20% remains inside fiber cell channels and only about 5% is trapped within the fiber wall. Therefore pulp washing mainly involves filtration diffusion and extrusion processes. Filtration removes free liquor while diffusion allows liquor trapped inside fibers to move outward making both processes interdependent.

2.8 Oxygen Delignification

Oxygen delignification is a well-established bleaching stage used in elemental chlorine free and total chlorine free pulp production. It acts as a linking step between cooking and final bleaching where oxygen and alkali are used to remove residual lignin from cooked pulp. The process operates at high temperature and pressure and is commonly performed at medium pulp consistency due to easier operation and control. Oxygen delignification is environmentally friendly cost effective and can be operated in single or multiple stages. With a single-stage oxygen delignification process about 30–50% of lignin and colored substances can be removed from unbleached pulp. In extended stages lignin removal can reach 60–70%. After oxygen delignification lignin content is reduced from about 3–5% to approximately 1.5–2% corresponding to a kappa number of about 8–10.

Figure 3 OXYGEN DELIGNIFICATION

Operating Parameters of Oxygen Delignification

Temperature and Pressure

Oxygen is a weakly reactive oxidant and therefore oxygen delignification requires elevated temperatures between 80 °C and 120 °C and pressures of 6 to 8 bar to achieve an acceptable reaction rate. Temperatures above 120 °C lead to excessive degradation of carbohydrates which negatively affects pulp quality.

Role of NaOH and pH

The amount of sodium hydroxide and pH level play a critical role in oxygen delignification efficiency. The pH should be maintained above 10 and is most effective around 12. Poor oxygen bubble distribution reduces delignification efficiency while excessive alkali dosage results in loss of pulp yield and strength.

Function of Magnesium Sulfate

Transition metals such as manganese copper and iron present in pulp catalyze peroxide decomposition and accelerate carbohydrate degradation. Magnesium sulfate is added to suppress these reactions and to protect pulp viscosity which otherwise decreases during oxygen delignification.

Advantages of Oxygen Delignification

Environmental Benefits

Oxygen delignification is an environmentally friendly process that reduces the requirement for chlorinated bleaching chemicals in subsequent stages. This lowers the formation of toxic organic halides and results in reduced BOD COD and color in effluents. All effluents from this stage are recycled to the recovery boiler which minimizes wastewater discharge.

Economic Benefits

This process significantly reduces the consumption of expensive bleaching chemicals in later stages. Although capital investment is high the operating cost of oxygen is low. Recycling of spent chemicals to the recovery boiler further reduces wastewater treatment costs while maintaining pulp yield strength and cleanliness.

Disadvantages of Oxygen Delignification

Oxygen delignification is less selective than other bleaching agents due to free radical reactions which can degrade polysaccharides. This leads to reduced pulp viscosity and fiber strength. Additionally oxygen is a weak oxidant and therefore requires high alkali concentration elevated temperature and pressure which can negatively impact pulp quality if not carefully controlled.

2.9 Bleaching Process

Bleaching improves pulp brightness printability and liquid absorption while reducing dark colored contaminants. It contributes significantly to production cost and environmental impact and therefore requires careful optimization. Bleaching affects not only brightness but also fiber strength and durability. Bleaching chemicals are classified as oxidative and reductive agents. Oxidative chemicals remove lignin while reductive agents improve brightness. Alkali is used to dissolve oxidized lignin. Modern bleaching systems operate in multiple stages with controlled temperature chemical dosage and pH. A typical bleaching sequence includes oxygen delignification followed by chlorine dioxide and alkaline extraction stages. The commonly used sequence is O–D–EOP–D where oxygen reduces lignin load chlorine dioxide removes residual lignin and EOP enhances lignin removal and brightness.

2.10 Paper Machine Section

The mill operates two paper machines PM#1 and PM#2. PM#1 is a twin wire former producing newsprint of 49 GSM and also printing and writing paper in the range of 40 to 80 GSM. PM#2 is designed for high quality paper with online measurement of basis weight moisture and ash content. The finishing section includes automatic reel handling wrapping and cutting systems. The sheeting unit consists of cutting and guillotine machines with a combined capacity of 180 tonnes per day ensuring efficient conversion and packaging.

2.11 Soda Recovery Plant

The soda recovery plant recovers cooking chemicals from black liquor generated during pulping. Brown pulp washing separates dissolved organic matter and chemicals producing weak black liquor which is concentrated in evaporators to high solids content. Concentrated black liquor is fired in the recovery boiler where organic matter burns to generate heat and steam for power generation. Inorganic chemicals form smelt which is dissolved to produce green liquor and later converted to white liquor through causticizing. White liquor is reused in pulping while lime mud produced during causticizing is reburned in lime kilns to regenerate lime. This closed-loop system ensures chemical recovery energy efficiency and environmental compliance.

Importance of Soda Recovery Plant

The soda recovery plant is essential for economic and environmental sustainability in the paper industry. It enables reuse of key chemicals reduces raw material consumption minimizes effluent discharge and generates energy thereby significantly lowering overall production cost.

III. RESEARCH AND DEVELOPMENT / QUALITY CONTROL

The company adopted and developed the innovation technology of manufacturing newsprint using mechanical bagasse pulp and its endower is to perfect and hardness the bagasse pulping technology. The in-house research laboratory facility of the company is recognised by the department of scientific and Industrial research New Delhi. The Company has a full pledged quality control assurance department which ensures highest quality standards of the products.

Specific study of R&D includes

- Environmental bleaching technology
- Pulping studies for improving pulp yield
- Bio technology studies
- Improvement of mechanical bagasse pulp quality
- Printing studies

The R&D department has sophisticated state of the art instruments.

QUALITY CONTROL

The quality control function in many paper mills is now undergoing with some changes. The old approach to quality consisted of setting up of a quality control department, making spot checks on incoming material, alone end of the plant performing some in process tests and finally conducting evaluation of the finished product. Some statistical analysis was included if such specialized talent was available. The competitive market of the future will demand much more. In progressive mill the classical quality control function just described is beginning to be replaced by the concept of total quality management. This involves the orderly co-ordination of all functions that relate to product quality even to seemingly unrelated areas such as purchasing, engineering and accounting shipping and warehousing. If starts with a management commitment to a total quality effort that impacts every phase of the company. The function of the quality control department is to measure quality keep the score and measure the performance. The responsibility for quality lies with everyone in the production system.

IV. EXPERIMENTAL METHODS

4.1 Raw Materials

Hardwood Pulp
Hardwood pulp is obtained from deciduous trees such as oak, maple, and birch. It consists of short thick fibers, producing smooth and dense paper. Hardwood pulp is commonly used for printing, writing, and fine paper products .

Chemical Bagasse Pulp (CBP)
CBP is derived from chemically treated bagasse, the fibrous residue of sugarcane. It contains approximately 50% cellulose, 25% hemicellulose, and 25% lignin. Cellulose provides strength, hemicellulose binds fibers, and lignin adds rigidity. CBP is suitable for papermaking and helps reduce reliance on wood .

Deinked Pulp (DIP)
DIP is recycled paper processed to remove inks and contaminants. It is widely used in newsprint, toilet tissue, and office papers. DIP has shorter fibers, lower brightness, and may contain dirt particles, requiring additional treatment to enhance strength .

4.2 Apparatus Required

Weighing balance, disintegrator, sheet former, rapid dryer, pneumatic press, Beakers (400 mL, 2000 mL), pipette, nickel spatula, measuring jar, glass rod, Stainless steel cutting sheets, blotter, silica crucible, Brightness tester, micrometer, tear strength tester, tensile tester, burst tester, CSF tester

4.3 Chemicals Required

Anionic Trash Catcher (ATC)
ATC captures anions in pulp, improving filler retention and machine performance. It reduces steam usage, extends blanket life, and is compatible with starch or polyacrylamide. Applicable in copy, newsprint, coated, and kraft papers .

Cationic Starch
Cationic starch enhances paper sheet strength, retention, drainage, opacity, stiffness, and brightness. It allows higher filler content and recycled fibers while reducing dusting and web breaks.

Alkyl Ketene Dimer (AKD)
AKD is a reactive sizing agent used in neutral or alkaline papermaking to impart hydrophobicity. It forms ester bonds with cellulose hydroxyl groups, improving water resistance .

Precipitated Calcium Carbonate (PCC)
PCC improves paper brightness, whiteness, opacity, and smoothness. It enhances print quality by reducing ink absorption and is widely used in coated papers and packaging .

Methylene Blue Dye
Used as a colorant to impart blue shade and can act as a sizing agent to improve strength and smoothness.

Methylene Violet Dye
Used to add violet color to specialty papers. Binds strongly to cellulose fibers ensuring uniform coloration.

Retention and Drainage Aid (RDA)
Improves fiber, filler, and additive retention during papermaking while optimizing water drainage, enhancing efficiency and cost-effectiveness.

Cationic Polyacrylamide (CPAM)
A water-soluble polymer with flocculation properties. It improves fiber retention and drainage. CPAM is hydrophilic, insoluble in organic solvents, and effective in papermaking and wastewater treatment

4.4-PREPARATION PROCESS

4.4.1-DETERMINATION OF CONSISTENCY OF PULPS - CONSISTENCY

Consistency is defined by the total content of dry solids in the pulp slurry, the slurry being made of water, fibers, fines and fillers .

Total Consistency (%) = dry weight of sample / total weight of sample x 100

In other words consistency is the amount of gm of OD (Oven dry) pulp in 100ml or 100gm of pulp slurry or as such pulp.

a) DETERMINE THE CONSISTENCY OF HARDWOOD PULP

Approximately 12.31 g and 13.28 gm of hardwood pulp is taken in a separate beakers and make them into pulp slurry then the pulp slurry is filtered. And the filtered pulp slurry is put into press and put into the rapid dryer. Finally the weight of the consistency pads is noted and the average is calculated.

SAMPLE-1

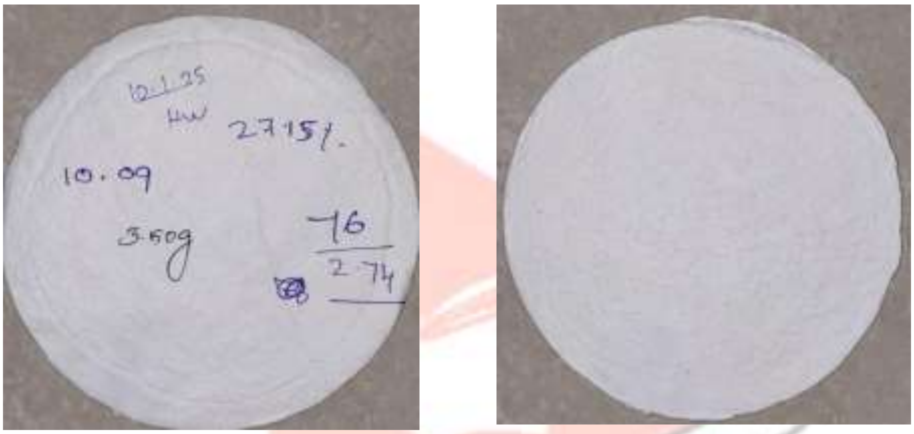
Initial weight of HW pulp = 12.31 g

Weight of consistency pad = 3.2 g

$$\text{Consistency (\%)} = \frac{3.2}{12.31} \times 100$$

Consistency (%) = 27.2 %

SAMPLE-2



Consistency pad - Hardwood sample-2

Initial weight of HW pulp = 10.09 g

Weight of consistency pad = 3.50 g

$$\text{Consistency (\%)} = \frac{3.50}{10.09} \times 100$$

Consistency (%) =27.15 %

AVERAGE

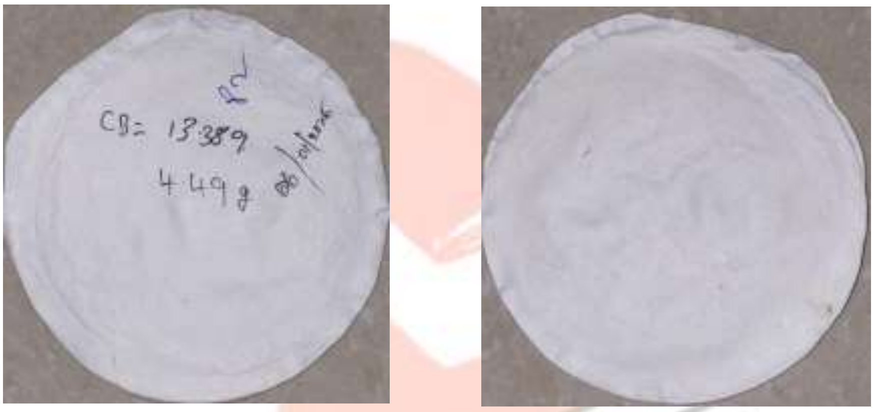
$$\text{Average} = \frac{27.2 + 27.15}{2}$$

$$= \frac{54.35}{2}$$

Consistency of Hardwood pulp (%) = 27.17 %

b) DETERMINE THE CONSISTENCY OF CHEMICAL BAGASSE PULP (CBP)

SAMPLE-1



Consistency pad - Chemical bagasse sample-1

Initial weight of CB pulp = 13.38 g

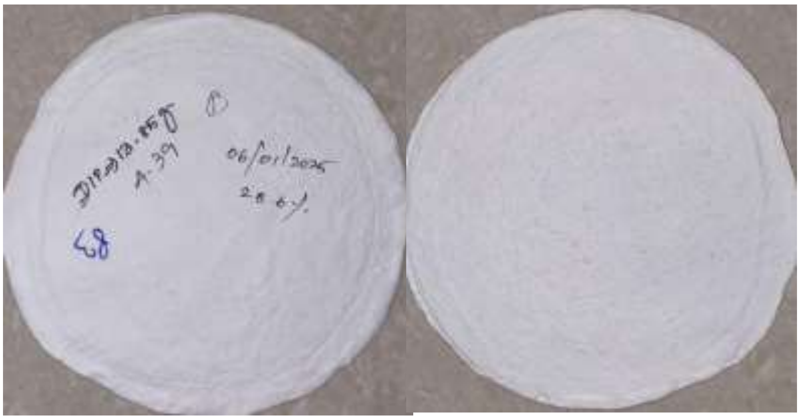
Weight of consistency pad = 3.67 g

Consistency (%) = $\frac{3.67}{13.38} \times 100$

Consistency (%) = 27.42 %

c) DETERMINE THE CONSISTENCY OF DEINKED PULP (DIP)

SAMPLE-1



Consistency pad - Deinked pulp sample-1

Initial weight of DIP pulp = 13.85 g

Weight of consistency pad = 3.56 g

Consistency (%) = $\frac{3.56}{13.85} \times 100$

Consistency (%) = 25.70 %

SAMPLE-2

Consistency pad - Deinked pulp sample-2

Initial weight of DIP pulp = 13.25 g

Weight of consistency pad = 3.39g

$$\text{Consistency (\%)} = \frac{3.39}{13.25} \times 100$$

Consistency (%) = 25.58 %

AVERAGE

Average = 25.70 + 25.58

2

= 51.28

2

Consistency of chemical bagasse pulp = 25.64 %

4.5-CONVENTIONAL

For batch process **30 g OD** pulp should be taken

BATCH-I

4.5.1-CONVENTIONAL FOR HARD WOOD (100 %)

$$\text{HWP } 100\% = \frac{100}{100} \times 30$$

$$= 30 \text{ g (OD)}$$

$$\text{Weight of Hardwood As such pulp} = \frac{100}{consistency\,\%} \times OD\ weight$$

$$= \frac{100}{27.17} \times 30$$

Weight of Hardwood as such pulp =110.4 g

4.5.2-CONVENTIONAL FOR CHEMICAL BAGASSE (100 %)

$$\text{CBP } 100\ \% = \frac{100}{100} \times 30$$

$$= 30 \text{ g (OD)}$$

$$\text{Weight of CBP As such pulp} = \frac{100}{consistency\ \%} \times OD\ weight$$

$$= \frac{100}{27.6} \times 30$$

Weight of CBP as such pulp = 108.6 g

4.5.3-CONVENTIONAL FOR DEINKED PULP (100%)

$$\text{DIP } 100\% = \frac{100}{100} \times 30$$

$$= 30 \text{ g (OD)}$$

$$\text{Weight of DIP As such pulp} = \frac{100}{consistency\ \%} \times OD\ weight$$

$$= \frac{100}{25.6} \times 30$$

Weight of DIP as such pulp = 117 g

BATCH-II

4.5.4-BLANK (HWP-15%, CBP-55%, DIP-30%)

CONVENTIONAL FOR BLANK

Hardwood pulp-15%

$$\text{HWP } 15\% = \frac{15}{100} \times 30$$

$$= 4.5\text{g (OD)}$$

$$\text{Weight of Hardwood As such pulp} = \frac{100}{consistency\ \%} \times OD\ weight$$

$$= \frac{100}{27.17} \times 4.5$$

Weight of Hardwood as such pulp =16.5 g

Chemical bagasse pulp-55%

$$\text{CBP } 55\% = \frac{55}{100} \times 30$$

$$= 16.5\text{g (OD)}$$

$$\text{Weight of CBP As such pulp} = \frac{100}{consistency\,\%} \times OD\ weight$$

$$= \frac{100}{27.6} \times 16.5$$

Weight of CBP as such pulp = 59.7 g

Deinked pulp-30%

$$\text{DIP } 30\% = \frac{30}{100} \times 30$$

$$= 9\text{ g (OD)}$$

$$\text{Weight of DIP As such pulp} = \frac{100}{consistency\,\%} \times OD\ weight$$

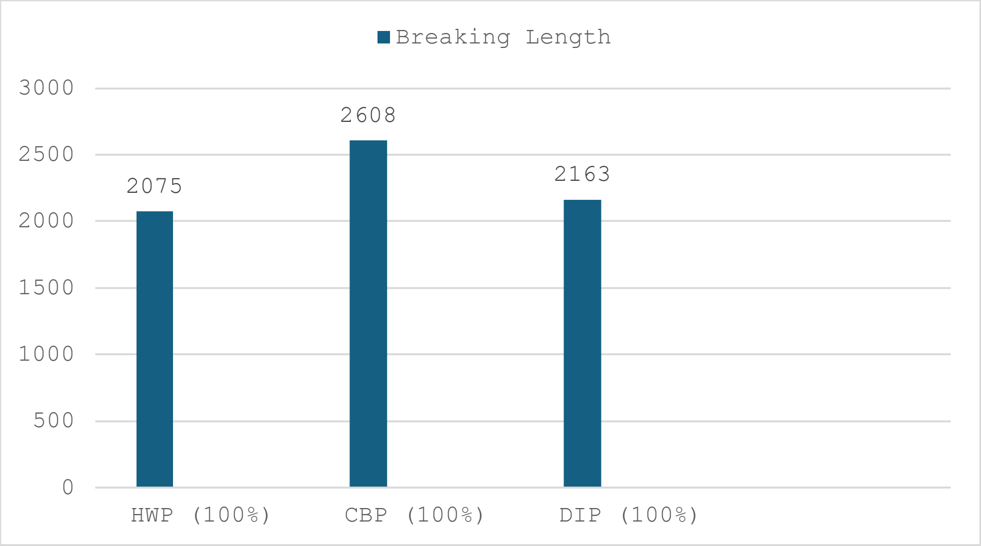
$$= \frac{100}{25.6} \times 9$$

Weight of DIP as such pulp = 35.15 g

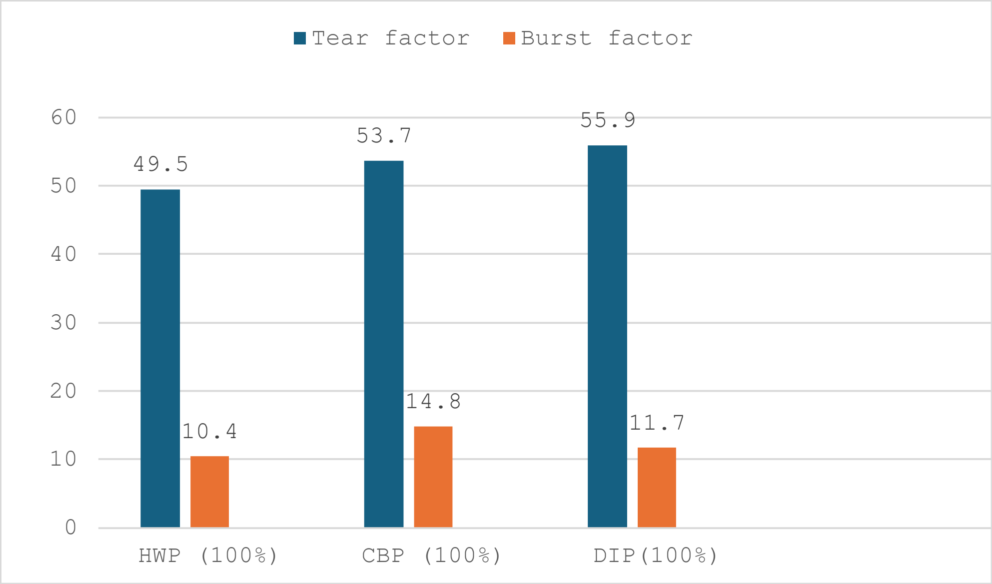
V. RESULTS & DISCUSSION

S.N0	PARAMETERS	HARDWOOD (100%)	CHEMICAL BAGASSE PULP (100%)	DEINKED PULP (100%)
1	GSM (g/m²)	62.7	59.5	62.3
2	MOISTURE (%)	7.9	8.8	8.9
3	CALIPER (mic)	113	100	114
4	BULK (cc/g)	1.8	1.7	1.8
5	TENSILE INDEX (Nm/g)	20.3	25.6	21.2
6	BREAKING LENGTH (m)	2075	2608	2163
7	STRECH (%)	1.8	2.1	2.3
8	TEAR INDEX (mNm²/g)	4.9	5.3	5.5
9	TEAR FACTOR	49.5	53.7	55.9
10	BURST INDEX (Kpa.m²/g)	1.02	1.5	1.1
11	BURST FACTOR	10.4	14.8	11.7
12	BRIGHTNESS (ISO)	84.5	82.4	86.5

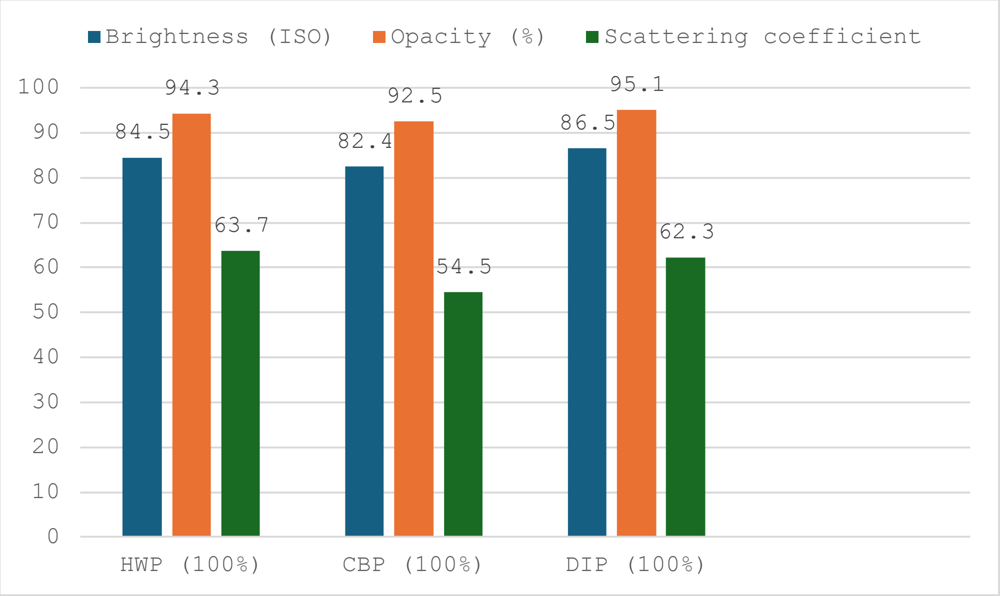
13	**OPACITY (%)**	**94.3**	**92.5**	**95.1**
14	**SCATTERING COEFFICIENT (m²/kg)**	**63.7**	**54.5**	**62.3**
15	**YELLOWNESS (%)**	**-7.5**	**-7.9**	**-9.8**
16	**ASH (%)**	**14.5**	**13.1**	**14.7**
17	**FPAR**	**89.9**	**85.07**	**86.6**
18	**CSF**	**398**	**349**	**293**



The Breaking length of Chemical bagasse pulp (100%) is relatively high compared to Hardwood pulp (100%) and Deinked pulp (100%)



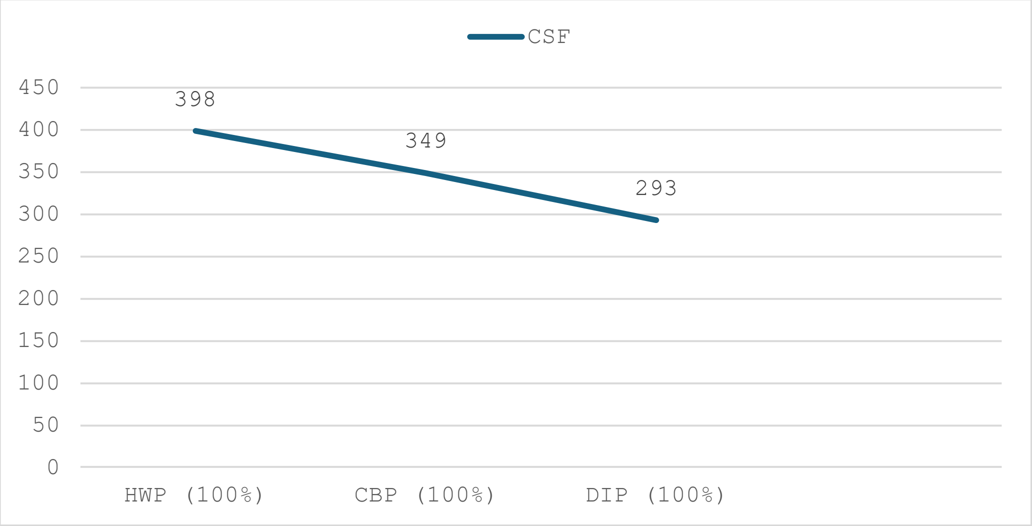
The Tear factor of Deinked pulp (100%) is greater than the Hardwood pulp (100%) Chemical bagasse pulp (100%). And the burst factor of Chemical bagasse pulp (100%) is greater than the others.



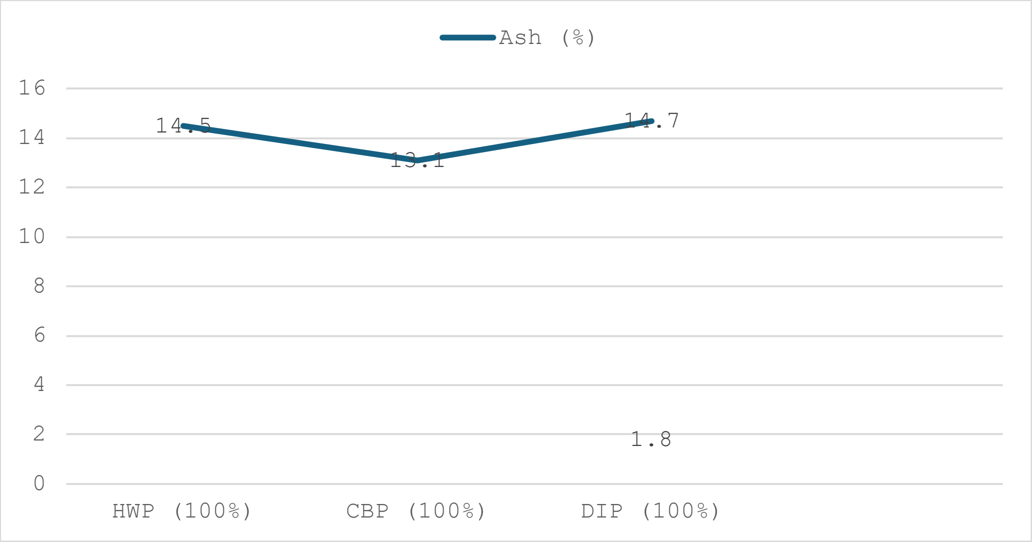
The brightness of the hand sheet of Deinked pulp (100%) is little much of hand sheets of others.

Comparing the opacity of the hand sheets of Hardwood pulp (100%) and Deinked pulps (100%) are comparatively same and the Chemical bagasse pulp is less than of the two.

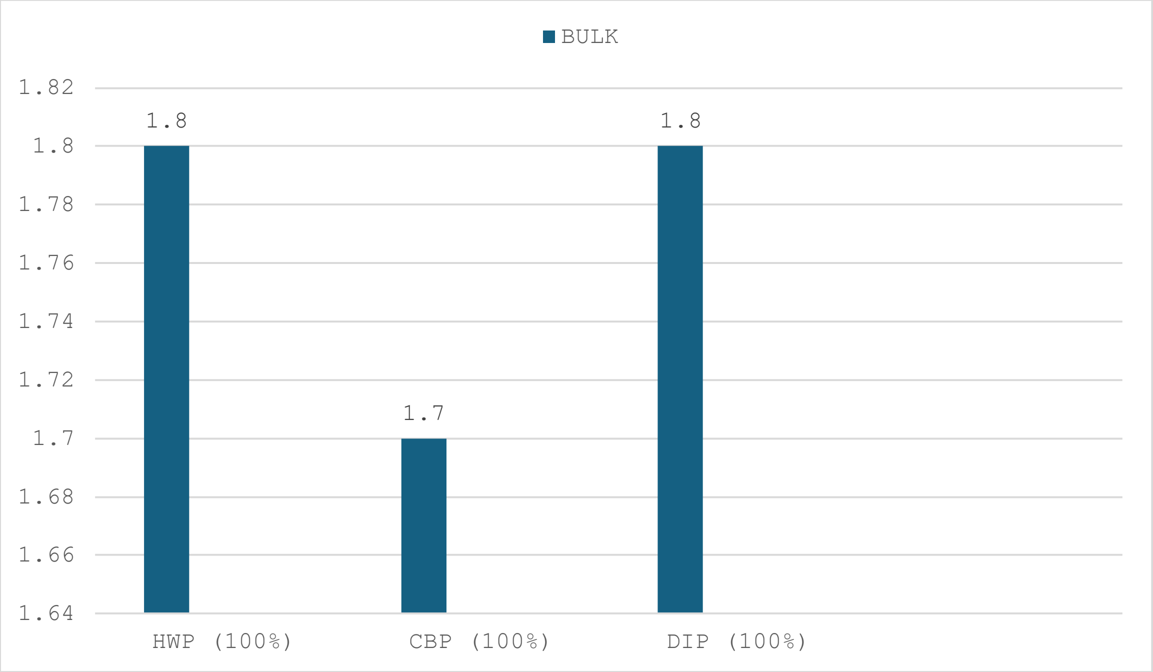
The Hard wood and Deinked pulp's hand sheet scattering coefficient is comparatively higher than the hand sheets of Chemical bagasse pulp.



The CSF (Canadian Standard Freeness) value of Hardwood pulp (100%) is much greater than of Deinked pulp (100%) and comparatively higher than the Chemical bagasse pulp (100%).

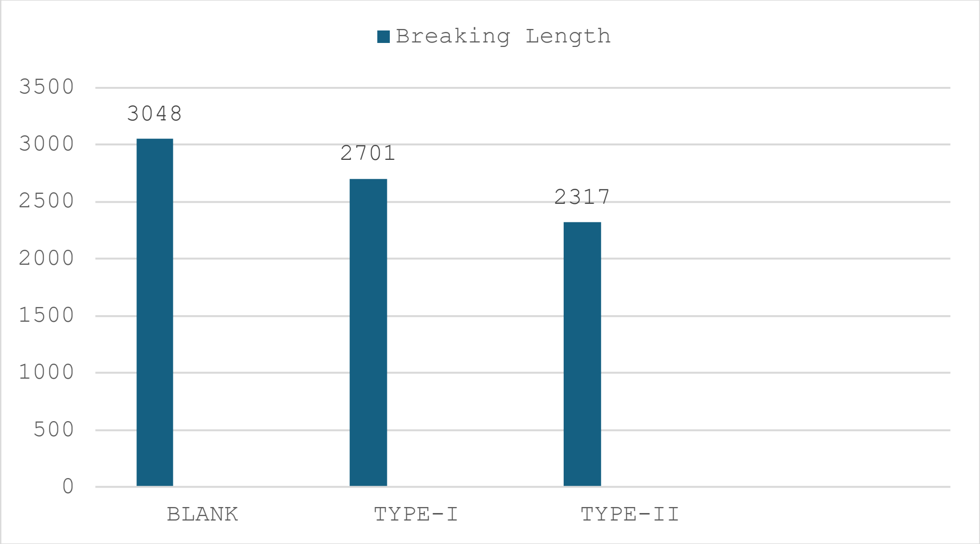


The Ash percentage of Hardwood and Deinked pulp's are slightly attain our required 15% Ash percentage, but the Ash percentage of Chemical bagasse pulp is comparatively low than the others.

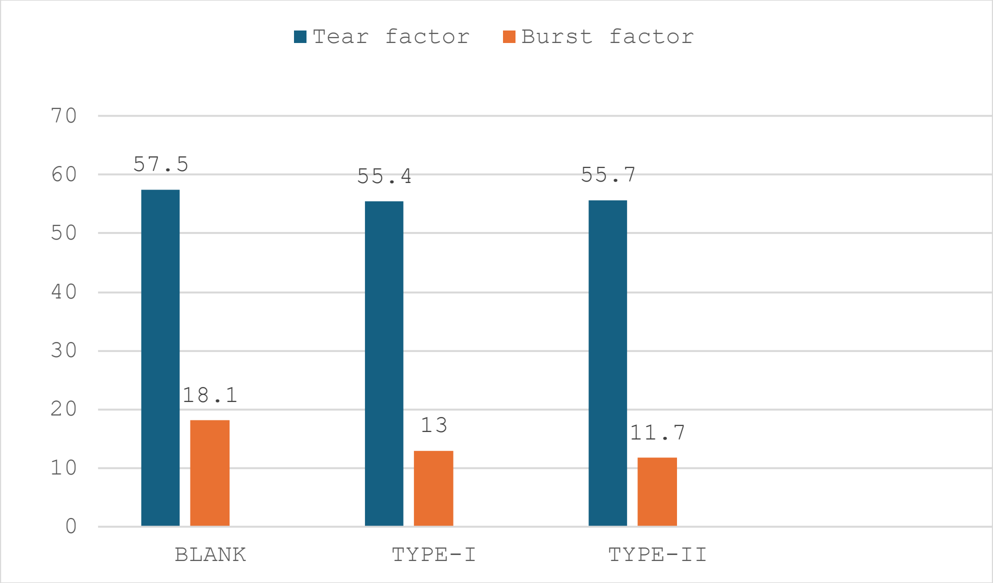


The Bulk of Hardwood pulp (100%) and Deinked pulp (100%) are equal and the Bulk of Chemical bagasse pulp (100%) is low compared to others.

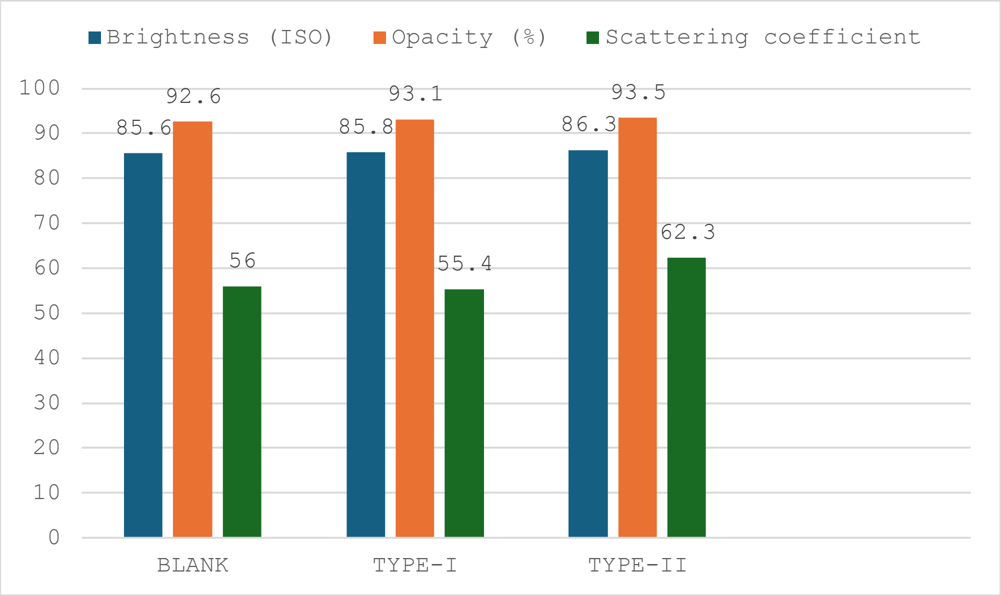
S.N0	PARAMETERS	BLANK	TYPE-I	TYPE-II
1	GSM (g/m²)	58.7	61	60.5
2	MOISTURE (%)	8.6	8.5	8.1
3	CALIPER (mic)	97	102	105.7
4	BULK (cc/g)	1.6	1.6	1.7
5	TENSILE INDEX (Nm/g)	29.9	26.2	22.72
6	BREAKING LENGTH (m)	3048	2701	2317
7	STRECH (%)	3.1	2.3	2.1
8	TEAR INDEX (mNm²/g)	5.6	5.4	5.5
9	TEAR FACTOR	57.5	55.4	55.7
10	BURST INDEX (Kpa.m²/g)	1.8	1.3	1.3
11	BURST FACTOR	18.1	13	12.8
12	BRIGHTNESS (ISO)	85.6	85.8	86.3
13	OPACITY (%)	92.6	93.1	93.5
14	SCATTERING COEFFICIENT (m²/kg)	56	55.4	56
15	YELLOWNESS (%)	-9.4	-9.2	-9.9
16	ASH (%)	12.04	13.6	14.5
17	FPAR	74	86	90.3
18	CSF	321	321	371



The Breaking length of Blank is relatively high compared to Type-I and the Breaking Length of Type-II is less than of Blank and Type-I.



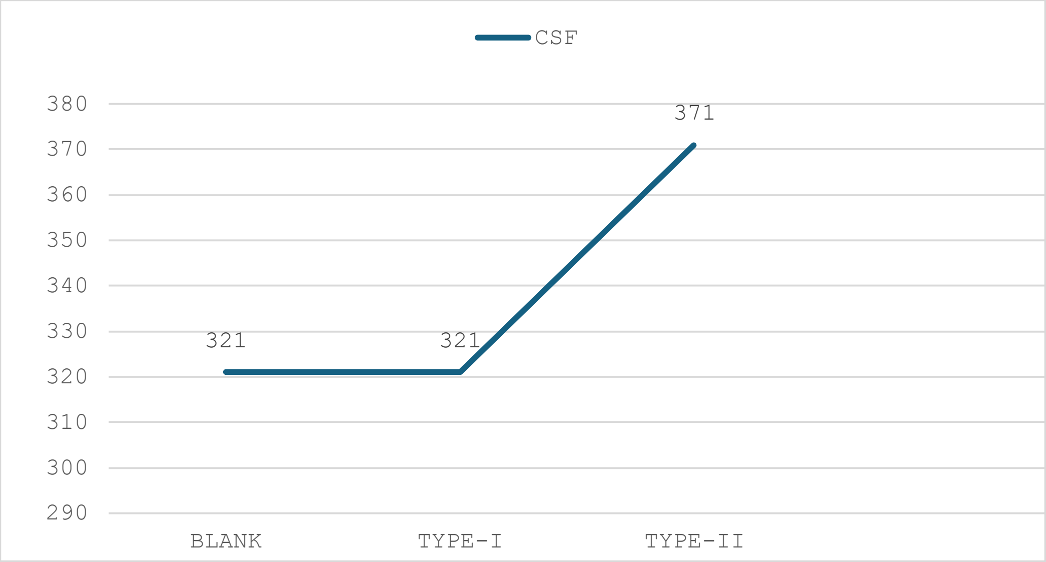
The Tear factor of Type-I and Type-II are slightly equal and the Tear factor of Blank is higher than of those two types. And the burst factor of Blank is much greater than Type-I and Type-II



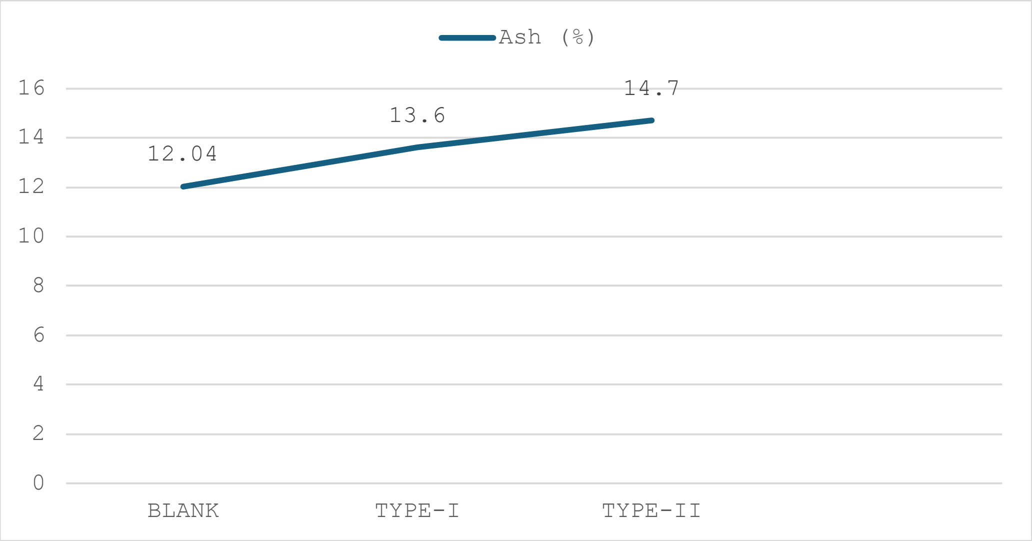
The brightness of Blank, Type-I and Type-II are comparatively same to each others.

Comparing the opacity of Type-II is less than of Blank and Type-I.

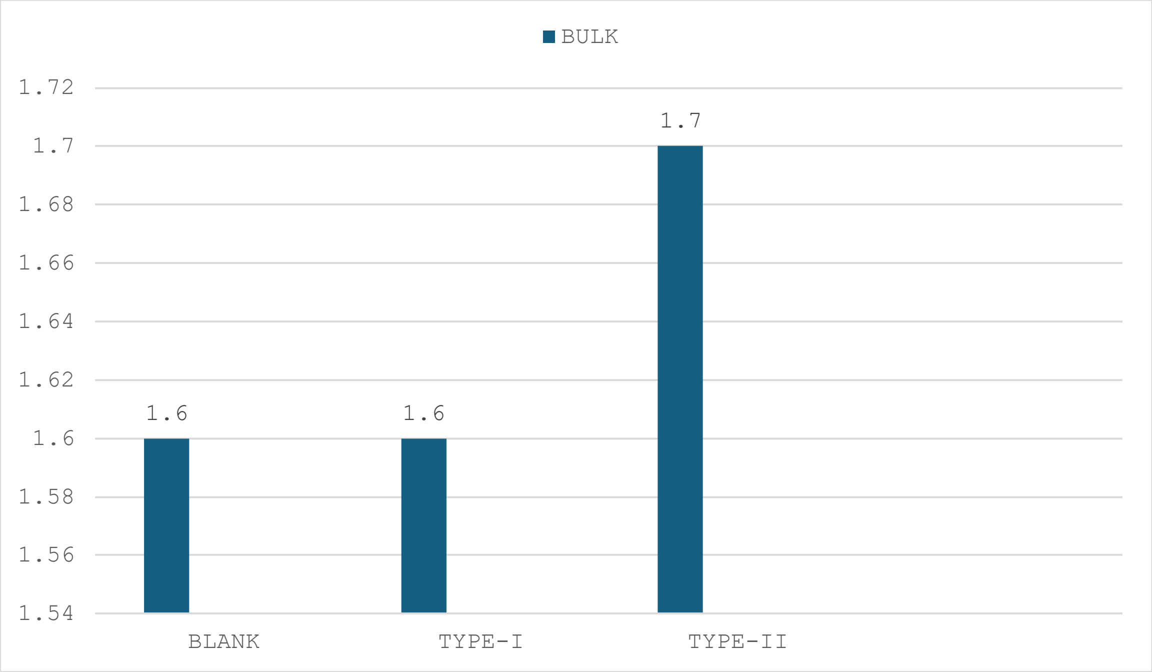
The scattering coefficient of Type-II have higher scattering coefficient values compared To Blank and Type-II.



The CSF (Canadian Standard Freeness) value of Type-II have high CSF value and Blank and Type-I have same CSF values.



The Ash percentage of Type-I is slightly attain our required 15% Ash percentage, but the Ash percentage of Blank and Type-II have low Ash Percentage.



The Bulk of Blank, Type-I and Type-II are successfully obtained the required values.

V. CONCLUSION

This study clearly indicates that manufacturing of paper using Chemical bagasse pulp and Deinked pulp in the replacement of hardwood pulp. This type of paper is eco-friendly by using agricultural waste and recycled papers. The eco-friendly papers manufactured by Chemical bagasse pulp and Deinked pulp is subjected to test for their optical properties like Brightness, Opacity, Scattering coefficient and Yellowness. The optical properties of these eco-friendly papers successfully obtained the required parameters. The **Bulk (1.6 cc/g)** is obtained successfully. The physical properties like Tensile strength, Tear Strength, Burst strength are tested and the physical properties are increased by changing the proportional of the additives. The Breaking length is low, which lacks the runnability of paper on paper machine, rolling and printing. The Breaking length can be increased by changing the proportional of additives like Filler, starch, AKD and RDA.

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