BAMBOO FOR PULP AND PAPER

A State of the Art Review

With Annotated Bibliography

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This report forms part of the Consultancy project "Preparation of State of the Art Reviews (STARs) along with Annotated Bibliographies on selected topics of Bamboos and Rattans".

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Bamboo Information Centre – India

OTHER STARs

1. *Dendrocalamus strictus*
2. *Bambusa bambos*
3. Management of Natural Sympodial Bamboo Stands and Plantations.
4. Collection, Conservation, Evaluation and Utilization of Rattan Germplasm.
5. Bamboos in Agroforestry Systems.

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PREFACE

Bamboo is regarded as a major resource that meets the need of common people and also as a poverty alleviator due to its multi purpose uses. As a result of this, bamboo resources are of great importance in the rural socio-economy of several tropical countries. As pulp and paper being the major commercial bamboo consuming sector, it is very necessary to have an updated information on the state of art related to its pulping processes and technologies for the optimal utilization of this valuable resource. It is in this context, for the proper management and utilization of bamboo for paper and pulp, the International Network for Bamboo and Rattan (INBAR) assigned KFRI to prepare a State of the Art Review (STAR) on Bamboos for Pulp and Paper.

The report consists of three parts. In Part I, a brief highlights of pulp and paper making principles are dealt with, which is very essential to follow the Part II, Bamboo for Pulp and Paper. An annotated bibliography, arranged alphabetically by Author's name is given in Part III.

I sincerely thank INBAR for providing financial support for preparing the report. Dr. T.K. Dhamodaran, Scientist (Wood Science), Dr. R. Gnanaharan, Research Coordinator and Shri. K. Sankara Pillai, Librarian, KFRI, authors of this report deserve special mention for preparing an excellent report.

I hope this report will equally be useful to researchers, wood, pulp and paper technologists and pulp industry and all concerned with the promotion of sustainable utilization of bamboo for pulp and paper.

Peechi
March 2003

J.K.Sharma Ph.D
Director

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Authors

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PART I. PULPING AND PAPER MAKING PRINCIPLES

1. INTRODUCTION

Pulp is the most important product of chemical conversion of ligno-cellulosic materials. In bamboo growing countries, like India, bamboo is a main raw material for producing pulp for paper and rayon. The gap between production and requirement for paper and paper products keeps increasing with the standard of living is going up. The term 'pulp' is used generically for mechanical pulps, semi-chemical and chemical pulps. Before dealing with the topic 'bamboo for pulp and paper', it is important to have a minimum understanding of different pulping processes. Part I deals primarily with an overview of early history, chemical constituents and fibre morphology of ligno-cellulosic material and the different processes available for producing pulp and paper. Part II deals specifically on the role of bamboo in the production of pulp and paper. Some of the standard terms used in pulping processes are given in Appendix 1. Part III contains the annotated bibliography.

2. EARLY HISTORY OF PULP AND PAPER PRODUCTION

The invention of paper making in about AD105 belongs to the Chinese. The first papers were made to some extent from the inner bark of paper mulberry tree and to a larger extent from bamboo (Libby 1962) [7a]. The principles behind the Chinese process of making paper during those days were almost the same as that employed today in the manufacture of hand-made papers, in so far as the mechanical operations of forming the sheets are concerned. The culms of bamboo were cut near the ground and sorted into bundles according to age. The younger the bamboo, the better the quality of the paper that was made from it. The bundles were buried under of mud and water for a period of two weeks in order to soften them. Later, they were taken out, cut into small pieces, ground in mortars with a little water and pounded to a pulp with large wooden pestles. This semi-fluid mass, after being cleansed of the coarsest parts, was transferred to a tub of water, so that the whole became of sufficient consistency to form the paper. Then, a sheet was taken up with a mould or frame, which was constructed of bamboo in small strips made smooth and round like wires, which allowed the water to drain away, leaving a sheet of felted fibres. On each side of the tub was placed a stove with an inclined top of clay. A sheet was then put on one stove by removing the edge of the mould and laying the paper flat on the stove to which it adhered. The sheet previously put on the stove was then removed and the process was repeated. A smoother paper was obtained by brushing a solution of fish glue or alum onto the sheets and polishing by rubbing them with smooth stones.

The Chinese established a paper mill at Samarkand sometime during the 6th century. In AD795 the Arabs introduced the process and developed it further in their own country. The process was introduced into Europe through the crusaders, who visited Palestine and Syria during the 12th century, and later many improvements were incorporated. France had a paper mill in Essonnes in 1189. By this time, wire had replaced the reeds for the moulds. The first paper mill in Germany was erected in 1336, and in England in 1498. The first paper mill in the United States was established in Philadelphia during 1696. In 1798, Louis Robert, a printer's helper, invented a machine that would make paper in lengths of 12- 15 meters. The invention of the 'fourdrinier' machine during the 19th century and the 'cylinder' machine during 1809 marked revolutionary changes in the art of paper making.

The first mill for producing full chemical pulp by the sulphite (soda) process was erected at Philadelphia during 1855. The invention of sulphate (kraft) pulping made a revolution in the manufacture of wood pulp and numerous kraft pulp mills were established. Pulping by the neutral sulphite semichemical process was employed for the production of corrugated board in the United States in 1925.

Up to 1890, the purpose of pulp production was exclusively to furnish the paper industry. In 1892, however, Cross and Bevan discovered the xanthation of cellulose and realized the possibility of producing a regenerated cellulose fibre, rayon. The viscose process was developed and in 1903, a Norwegian sulphite mill began to deliver bleached sulphite pulp for textile purposes to England. The expansion of viscose industry was marked with the possibility of utilizing kraft pulp produced by the prehydrolysis kraft process for dissolving grade pulp and the first mill for producing prehydrolysis kraft pulp was started in Germany in 1929.

3. CHEMICAL CONSTITUENTS AND FIBRE MORPHOLOGY

Even though any ligno-cellulosic material including bamboo can be pulped with suitable methods, information on the chemical constitution and fibre morphology is important in deciding their techno-commercial suitability as well as the method of pulping. Generally, long-fibred materials with high cellulose content, low lignin, extractives and ash contents are preferred. Fibre length influences the tearing, burst and tensile strength properties of sheets. Properties like lumen and fibre diameter as well as their ratio (flexibility coefficient) and the wall thickness are known to affect the pulp strength.

3.1. Chemical constituents

3.1.1. Cellulose

Cellulose is the most abundant form of the naturally occurring compounds of carbon. This forms the principal component of the cell wall of all woods, straws and grasses (bamboo). As it is most frequently found in fibrous form, it has got good tensile strength, and as it is insoluble in cold and hot water, it forms an important component of pulp and paper. Cellulose is a polymeric carbohydrate, a polysaccharide with repeating units of glucose. The neighbouring glucose units are joined through carbon atoms 1 and 4.

Cellulose being relatively resistant to oxidation, lignin and other colouring matters can be removed with bleaching agents without appreciable damage to the strength of pulp. The alpha or true cellulose content of a fibrous material does not affect directly its pulpability, but the higher the alpha-cellulose content of a material, the higher the yield of fully delignified, bleached chemical and semichemical pulps.

3.1.2. Hemicelluloses

When wood is freed from extractives (compounds which are soluble in cold water or in neutral organic solvents) and is then carefully freed from lignin, it yields a fibrous product termed holocellulose, which represents the sum total of cellulose and other polysaccharides; the latter are usually termed hemicelluloses (or polyoses). Pulping processes remove not only lignin (imperfectly) but also some of the less resistant hemicelluloses; so, holocellulose cannot be obtained by ordinary pulping operation.

The hemicelluloses contain mainly sugar units other than glucose (such as xylose, mannose, arabinose, rhamnose, galactose, etc.). Usually the dominant unit in the hemicelluloses is xylose, but frequently mannose units are present in appreciable amounts, especially in the case of the hemicelluloses of coniferous woods. The hemicellulose fractions which contain xylose (and uronic acid) units are often termed ‘xylans’ or more loosely ‘pentosans’. Those contain mannose units linked to each other and to glucose units have been referred as ‘mannans’.

The hemicelluloses (when freed from lignin) swell more than does cellulose and are in part dispersible in water. They have adhesive properties not shared by cellulose. Whereas cellulose is fibrous, hemicelluloses are non-fibrous. Whereas cellulose is quite insoluble in cold alkali, hemicelluloses are quite soluble in dilute caustic soda. In any chemical pulping operations, some of the initial hemicelluloses are retained in the pulp. A portion of the less resistant hemicelluloses is removed during digestion, and their degradation products are then found in the spent liquors.

In the case of pulps freed from lignin by adequate and controlled bleaching, the hemicelluloses have been shown repeatedly to contribute greatly to tensile and bursting strength and to folding endurance of the pulp sheet. Both the quantity and the type of hemicelluloses in a pulp influence the pulp properties and the type of paper that can be made from such a pulp. There are certain disadvantages also about their presence. These are undesirable for dissolving grade pulp. In the case of certain bleached pulps, these are responsible for a loss in brightness of the bleached pulp on storage or aging.

3.1.3. Lignin

Lignin is the cementing substance between fibres and tissues and is concentrated mainly in the region of the middle lamella and imparts rigidity to wood tissue. Lignin exists in wood or bamboo as branched-chain polymer molecules. The lignin may be separated from an associated wood component either by preferentially dissolving lignin or by preferentially dissolving non-lignin components. Isolated lignins, in general, are amorphous and non-crystalline, and show definite softening points at elevated temperatures. The average molecular weight is in the range of 11,000. An important property of lignin is its capacity to absorb ultra violet light. The chemical skeleton of lignin is a phenylpropane or a “$C_6 – C_3$” or a “C_9” type.

Pulping is basically and mainly a delignification process employing inorganic acids or alkalies and other compounds or organic solvents and compounds or by employing biological agents such as certain fungi which will selectively attack on lignin, causing its degradation and consequent dissolution. The amount and reactivity of lignin have a marked effect on the pulpability of the material. These differ depending upon the raw material (softwoods, hardwoods, bamboos, etc.). During most pulping reactions, components other than lignin are simultaneously removed. The character of pulp depends upon the form and amount of energy supplied for accomplishing the separation. Chemical, mechanical or a combination of the two forms of energy are utilized. In general, when chemical energy alone is supplied, completely separated fibres are obtained; whereas in mechanical and semichemical pulping (combination of mechanical and chemical processing) whole fibres, fibre bundles, damaged fibres, and fibre fragments are produced. With the various methods now available for partitioning the two forms of energy, pulps of widely diverse properties can be processed. Bleaching of pulp is also a process mainly employed for further purification of the pulp by removing the remaining portions of lignin and other colour bodies in the pulp.

3.2. Fibre morphology

Fibre dimensions indicate the suitability of a fibrous raw material for producing pulp. Generally, the average fibre length of soft woods, hardwoods and bamboos is 3.5, 1.3 and 2.7 mm respectively. It varies within and between species as well as within trees and due to different locations. The fibre length is roughly 100 times longer than its diameter.

The fibre length influences mainly pulp strength, the tearing resistance in particular and to a lesser extent, the burst, tensile and the fold. Properties like fibre diameter and lumen diameter, if considered individually, have no appreciable influence on pulp strength, but the cell wall thickness is known to improve the paper strength. Flexibility coefficient influences tensile strength and, to some extent, the burst strength also, while the relative fibre length influences tearing resistance (Siddique and Chowdhury 1982) [352] . The Runkel ratio (cell wall thickness to lumen diameter) gives an indication of suitability of fibres for paper making (Runkel 1949). The values of Runkel ratio are classified into three groups.

Runkel Group	Runkel ratio values	Relative thickness of cell wall	Remarks for paper making
1	Less than unity	Thin	Very good
2	About equal to unity	Medium	Good
3	More than unity	Thick	Poor

Wood, bamboo and other grasses falling under Runkel group 1 and 2 are suitable for pulp and paper making, while those falling under group 3 are of poor quality for pulping.

Appendix 2. A & B gives the details of chemical analysis and fibre dimensions of some commonly used cellulose raw materials including bamboo for pulp and paper.

3.3. Characterization of pulp

An understanding of pulp properties is vital for both internal control purposes and as a means of describing the pulp grade for sale. Methods of wood analysis are thoroughly discussed in the monograph on wood chemistry (Browning 1952) [381]. Descriptions of wood and pulp analyses are found in different publications (Sieber 1951 [19a]; Merck 1957 [53]; Rydholm 1965) [70] and also in the charts brought out by the professional associations of the Pulp Industry in various countries such as the USA (TAPPI Standards), Sweden (CCA Standards), Germany (Merkblatt des Vereins der Zellstoff- und Papier-Chemiker und-Ingenieure), Scandinavia (Scan- C Standards), and by the International Committee for Cellulose Analysis (ICCA Standards).

3.3.1. Determination of residual lignin

3.3.1.1. Chlorine number and permanganate / kappa number

Determination of residual lignin in the pulp is the most important of all pulp analyses. It indicates the degree of delignification obtained by the cook and forms the basis of comparison for many of the cooking results, such as yield, screenings, pulp brightness, etc. It is based on measurement of a chemical reaction, such as chlorination or permanganate oxidation. These methods are more rapid and suitable for adoption in the mills, even though they have the drawback of giving only a relative figure for the lignin content and not an absolute value.

Chlorine numbers are obtained by measuring the chlorine which reacts with lignin in substitution and oxidation reactions. The *Roe* chlorine number indicates the grams of chlorine absorbed in 15 minutes at 20 ^{0}C by 100 gram pulp containing 55 gram water. Its correlation with the lignin content of the pulp is fairly straight-lined, with a factor of about 0.9 for sulphite and 0.8 for sulphate (kraft) pulps.

Permanganate numbers are based on the fact that lignin is rapidly oxidised by potassium permanganate. At standardized conditions the excess permanganate can be determined after a certain reaction period. A figure for the permanganate consumption can thus be obtained, which is a rapid and accurate measure of the lignin content of the pulp. ICCA Standards redefined the permanganate number as *Kappa* number and is related to the Klason lignin content by a factor of 0.13, and to the *Roe* chlorine number by a factor of 0.20 for sulphite and 0.16 for kraft pulp.

4. PROCESSES AND PRINCIPLES

4.1. Mechanical pulping

Mechanical or groundwood process is the oldest process for converting ligno-cellulosic into pulp and its invention by Keller in 1843 in Germany marked a milestone in the history of paper making. Mechanical or groundwood pulp is made either by pressing the wood against a revolving grinding stone or by passing chips through a mill, in the presence of water. The wood fibres are separated and to a considerable degree fragmented. Pulp yield is very high, amounting to nearly 90 per cent of the dry–basis weight of the wood processed. Fresh mechanical pulp is light yellow in colour; it is often bleached white for the production of papers in which the yellow colour is undesirable. It finds its greatest use for newsprint, magazine papers, certain packaging papers and absorbent papers.

Within the group of mechanical pulping processes (see Appendix 4A), modifications of the traditional grinding process include groundwood production with a preceding steaming step, application of chemicals, and grinding process under pressure. All processes aim at reducing power consumption and improving groundwood properties. The process which applies chemicals before or during grinding yields **chemigroundwood (CGW)**. Sulphite, bisulphite solutions, kraft-like liquors, sodium hydroxide, sodium bicarbonate, etc. are used for the pretreatment which results in energy savings and increased brightness of the groundwood. The use of a pressure-resistant grinding chamber at much higher temperatures yields **pressure groundwood (PGW)**. **Chemi-pressurized groundwood (CPGW)** is produced by the use of 5 per cent caustic soda and 2.5 per cent hydrogen peroxide within the pressure grinder.

Another modified mechanical pulping covers the **refiner mechanical pulping processes**. The principal characteristics of refiner mechanical pulping are the use of chips (also wafers or even sawdust) and the application of disk refiners of various types for defibration and fibrillation of the raw material. Depending on the process conditions, refiner mechanical pulping processes yield different types of pulps such as refiner mechanical pulp (RMP), chemi-refiner mechanical pulp (CRMP), pressurized refiner mechanical pulp (PRMP), and chemi-thermomechanical pulp (CTMP).

The Masonite process and the Asplund process come under the refiner mechanical pulping processes but they are principally more closely related to the production of fibreboard material. In the **Masonite process** wood is defibred by steam explosion, performed by a quick release of pressure (up to 70 bar) after a steam treatment of chips in a digester ('Mason gun') at temperatures up to 285 ^{0}C for a few seconds. The crude fibre product is further refined and screened. The **Asplund process** is the first thermomechanical process, applying steam at high temperature and disk refining under pressure; thus it forms the basic procedure of the thermomechanical pulping.

The most important industrial refiner mechanical pulping process today is the **thermomechanical pulping (TMP)**. The process involves an impregnation and preheating step of washed wood chips with saturated steam under pressure. The preheated chips are fed to the disk refiner for defibration at approximately the same temperature and pressure as in the preheating stage. The secondary refining stage is generally carried out at atmospheric pressure. Therefore, the defibred material is expanded into a cyclone where the steam is removed, and refined in one or two stages to the desired freeness. The rejects from screening and cleaning are thickened and recycled to the refining step or separately refined. The TMP process yields 91-98 per cent pulp which has a lower brightness than groundwood pulp.

In the **chemimechanical process** (CMP), mechanically destructed chips are impregnated with alkaline peroxide liquor ($NaOH/H_2O_2$) at 40-60 ^{0}C at atmospheric pressure for 1.5–2 hrs before low-consistency (5%) refining.

Air pollution problems in mechanical pulping are less significant than in chemical pulping. However, RMP, TMP and particularly CRMP and CTMP processes cause mill effluents with considerable amounts of extractives.

The world-wide increase in the application of mechanical, thermomechanical and chemimechanical pulping processes to produce pulps from non-wood fibre sources including bamboo is described extensively by Misra (1980) [521].

4.2. Chemical pulping

Chemical pulping employs chemical reagents to effect a separation of the cellulose fibres from other wood components. Wood chips are cooked with suitable chemicals in aqueous solution, usually at elevated temperatures and pressures. The objective is to dissolve the lignin and other extraneous compounds, leaving the cellulose intact and in fibrous form. This objective can be realised to a commercially satisfactory degree through the use of chemical reagents, although there is an appreciable dissolution of carbohydrate material and degradation of cellulose. Pulp yields are usually about 50 per cent of the wood weight. Because the chemical processes consume relatively large quantities of inorganic chemicals such as alkalies, paper makers devised methods for reagent chemical recovery from the spent cooking liquor; recovery has remained an integral part of chemical pulping. Environmental and economical concerns necessitated chemical recovery as a very important part of chemical pulping.

4.2.1. Alkaline pulping processes

The soda process and the sulphate(or kraft) process are the two principal alkaline pulping techniques and the basis for several modified alkaline processes, including kraft pulping after a prehydrolysis step for the production of dissolving pulp. Sodium hydroxide is the principal cooking chemical in both processes, while in sulphate pulping sodium sulphide is an additional pulping component. Both processes received their names from the regeneration chemicals used to compensate for the loss of sodium hydroxide, namely sodium carbonate (soda) and sodium sulphate, respectively.

4.2.1.1. Soda process

Soda process, the first process to manufacture chemical pulp, was invented by Hugh Burgess in 1851, employed caustic soda (sodium hydroxide) solution for cooking. The soda pulp is of relatively low strength and use of the process is limited to manufacture of filler pulps from hardwoods, which are then mixed with a stronger fibre for printing papers.

4.2.1.2. Kraft (sulphate) process

In 1884, a German chemist, Karl F. Dahl employed sodium sulphate in place of Sodium carbonate (soda ash) the chemical recovery system. This substitution produced cooking liquor that contained sodium sulphide along with caustic soda. Pulp so produced was stronger than soda pulp and was called **kraft pulp,** so named from the German and Swedish word for 'strong' and the process is termed as **kraft process**. The process is also termed as **sulphate process** because of the use of sodium sulphate (salt cake) in the chemical makeup. Sulphate, however, is not an active ingredient of the cooking liquor. The term 'sulphate process' is perhaps a misnomer, or at least misleading, as it might cause one to suspect that sulphate rather sulphide is used in the actual cooking. Almost any species of wood can be pulped by the sulphate process, which may be considered practically a universal pulping process. Resins or pitch, if present, are all readily saponified in the alkali employed and are chemically altered and dissolved in the kraft process. This material is removed from the pulp and becomes a valuable by-product. Bark and knots yield to kraft cooking, lignin is easily removed, and cellulose remains relatively stable. Kraft pulp, however, was dark in colour and was difficult to bleach. For many years, the growth of the process was slow because of its limitation to papers in which colour and brightness were unimportant. In the 1930s, with the discovery of new bleaching techniques, bleached kraft pulp became commercially important. The availability of pulp of high whiteness and the expanding demand for unbleached kraft in packaging resulted in rapid growth of the process, making kraft process the predominant wood-pulping method. Many soda mills were converted to adopt kraft process because of the greater strength of the pulp. A liquor- recovery system is always an essential part of kraft pulping. The dissolved organic constituents in the spent pulping liquors are burned for steam generation or some, like the turpentine and tall oil are recovered, and the inorganic pulping chemicals are recovered and reused.

In the kraft cooking operation, wood chips are prepared and fed to digesters. These huge cylindrical towers have a number of zones or compartments. Wood chips and cooking liquor are fed into the top and injected into successive zones of high pressure and temperature, where impregnation and cooking takes place as the chips progress downward. Additional zones wash the spent liquor from the chips. In batch cooking, after the digester is charged with chips, a mixture of "black liquor", the spent liquor from a previous cook, and "white liquor", a solution of NaOH and sodium sulphide from the chemical recovery plant, is pumped in. The digester is heated either by direct injection of steam or by the circulation of cooking liquor through a heat exchanger. After completion of the cook, the contents of the digester are blown to a blowpit by rapid opening of valve. The violence of the blow defibres the cooked chips. The spent cooking liquor is washed from the pulp; the later is then screened and sent to the bleach plant or directly to the paper mill if it is to be used unbleached. Some of the spent liquor (black liquor) is used for an admixture with white liquor to charge new cooks; the remainder is sent to the recovery plant to reconstitute cooking chemicals. The quantity of sodium present in the black liquor is such that its re-use is economically necessary.

4.2.1.3. Prehydrolysis kraft pulping

For dissolving grade pulp, the purity of kraft pulps is insufficient. Purification of kraft pulps is difficult since the impurities are rendered alkali-stable during the kraft cook. Therefore, an entirely different method has been applied to make kraft pulps of sufficient reactivity for dissolving purposes, namely **prehydrolysis** prior to kraft cooking. This consists of treatment at fairly low temperature with concentrated acids, at intermediate cooking temperature with dilute acids or high cooking temperature with water only. A considerable part of the hemicelluloses and fairly little cellulose are hydrolysed to shorter chains, part of which dissolve in the cooking liquor together with a limited fraction of acid-soluble lignin. In the subsequent kraft cook the main delignification reaction takes place. The net result of the two-stage prehydrolysis- kraft cook is therefore a high-alpha pulp of reduced yield. The yield, as well as the alphacellulose content, is very much dependent on the extent of prehydrolysis. About 87- 97 per cent alphacellulose content can be achieved by this process.

4.2.1.4. Anthraquinone as an additive in alkaline pulping

The use of anthraquinone (AQ) as an additive in the alkaline pulping processes is found to have the benefits of increased delignification rates as well as reduced alkali charges and improved pulp properties and yields. AQ acts as a redox catalyst in the liquor system.

By addition of 0.05 per cent AQ, the cooking time is reduced by 25-35 per cent and the alkali charge by 5 per cent while yields increase by 1.5-3 per cent at the same residual lignin level and comparable strength properties are obtained as in conventional kraft pulping (Goel *et al*. 1980).

4.2.1.5. Sulphite process

The **'sulphite process'** was invented during 1857 by an American chemist, B.C. Tilghman who observed the effect of sulphurous acid in softening wood. He obtained cellulose fibres by treating wood with bisulphite–sulphurous acid solutions under high temperature and pressure. The base used was calcium and later magnesium. Sodium and ammonium are also used as base, which are having advantages in liquor-recovery operations. Sulphite pulps are relatively light in colour, are easily bleached to a high-white colour, have moderately good strength properties. Sulphite pulp is almost pure cellulose and is used in fine papers.

4.2.2. Semichemical pulping

Semichemical pulping processes are characterised in principle by a chemical treatment preceded by a mechanical refining step for defibring or fibrizing. This general definition also applies to the chemimechanical processes and the high-yield chemical pulping processes such as the sulphite and kraft. It is more suitable to hardwoods.

The chemical treatment in semichemical and chemimechanical pulping can be effected with reagents like sodium sulphite, caustic soda, and kraft liquor. The sodium sulphite is usually buffered to near neutrality with sodium carbonate or bicarbonate or kraft green liquor.

The most important semichemical process is undoubtedly the **neutral sulphite semichemical (NSSC) process**. The general advantages of the NSSC process are low requirements with regard to wood quality and species, high yields, relatively low consumption of chemicals at a given residual lignin content, low capital investment and profitable small production units as compared to full chemical pulping. Besides single hardwoods and hardwood mixtures, mixtures of hardwoods and softwoods can also be pulped successfully with the NSSC process. NSSC pulping is also used for non-wood plants and residues because of the generally low lignin contents of these materials and the widely variable conditions offered by the NSSC pulping.

The principal process involves impregnation with a neutral sodium sulphite pulping liquor at about 125 ^{0}C for an hour under pressure after a short steaming of the chips at atmospheric pressure, followed by cooking at temperatures between 160 and 190 ^{0}C, depending on the cooking time, which may vary between 15 minutes and 8 hours, which again depending on the type of digester used and the desired pulp type and quality. Defibration is carried out by means of single or multi-stage refinement process using disk refiners.

The lignin content of the NSSC pulps is high as compared to those from chemical pulps, and ranges between 10 and 15 per cent. Due to the high lignin and polyoses content the NSSC pulp has low conventional strength properties. The typical NSSC pulp is normally much more rigid and stiff than kraft pulp. Therefore, it is the most typical and suitable fibre material for the production of corrugating medium.

The caustic soda in the **soda semichemical process** reacts with the lignin-carbohydrate complex to form soluble sodium lignate, and the carbohydrates are solubilized by hydrolysis. However, this lignin reaction occurs only after a major portion of the caustic soda has been consumed in neutralizing the readily available acetyl and methoxyl groups and in hemicellulose dissolution. Therefore, lignin removal is the least in alkaline semichemical pulping.

The **cold-soda or cold caustic process**, which is less important than the NSSC process, involves in principle, the treatment of chips with a sodium hydroxide solution at temperatures generally between 20 and 30 ^{0}C and a final refiner defibration. In the **cold-soda chemimechanical pulping**, the caustic soda attacks the fibre bond mainly by reaction with the acetyl and other acid groups, which are reactive even at room temperature. The most important step in the cold-soda pulping is the impregnation with alkaline liquor to reach a very fast but total penetration of the chips, causing the necessary swelling of fibres and avoiding considerable losses of polyoses. Impregnation times are between 15 and 120 minutes with generally short reaction times of 15-30 minutes in pressurized and continuous systems. The concentrations of NaOH are generally low (0.25–2.5%), but up to 10 per cent in the case of some roller mill impregnation systems. Cold-soda pulping requires little installation capital, and despite the cost of the chemicals, the processing costs are actually lower than in stone grinding, because of reduced energy consumption. In some process modifications the liquor is reused up to 20 times.

The cold-soda pulp yield ranges between 85 and 92 per cent, whereby the selectivity of lignin and polyoses dissolution is much lower than NSSC pulping. The main disadvantage of cold-soda pulps is a generally a low brightness level (40-50%), which can be effectively increased by a two-stage peroxide-hypochlorite bleaching.

As the cold-soda pulps have properties comparable to NSSC pulps, these are used as unbleached coarse grades for corrugating medium production, and as bleached grades for printing papers and newsprint in combination with groundwood pulp and chemical pulp.

In the **kraft semichemical process**, the reactions of kraft liquor are similar except thiolignin is formed and dissolved. Because of the buffering nature of the sodium sulphhydrate in the kraft liquor, attack on the hemicelluloses and cellulose is less in the kraft than in the soda process.

In the **acid sulphite and bisulphite semichemical pulping**, the delignification reaction predominates under acid conditions. As with the NSSC process, the mechanism of delignification probably involves sulphonation of the lignin of the middle lamella in the solid state, followed by hydrolysis to soluble lignosulphonic acid and carbohydrates. The hemicelluloses are less dissolved in these acid procedures than in the others.

In the **sulphite chemimechanical pulping,** the neutral or acid sodium sulphite solutions dissolve mainly carbohydrates. The relatively high temperatures employed have an important weakening effect on the fibre bond. The material from the chemical stage may be partially disintegrated and defibred through the mechanical action of digester discharging, conveying, or deliquoring. The first action in the defibring–refining machine is probably heating the fibre bond and further weakening it to the point that it will split. Temperature is an important factor in fibrizing semichemically softened fibrous material. The second action in the mechanical state is the actual disintegration of the fibre aggregates and separation into individual fibres. The third action in the fibrizing zone of the machine, which is generally superimposed on the defibring action, is the refining or processing of the individual fibres to prepare them for papermaking. This action, which largely involves fibrillation, softening, and formation of colloidal, mucilage-like surfaces, is for the purpose of stock preparation as with any other type of pulp. The actions occurring during the mechanical part of semichemical pulping may take place in one or more stages or passes. This is determined by a number of factors including the kind of fibrous material and its particle size, the degree and kind of chemical treatment, and the requirements for papermaking.

The semichemical pulps have chemical and strength properties intermediate between groundwood and full chemical pulps. The brightness of these pulps varies from 35 to 55 per cent which can be improved to 80 to 85 per cent by multi-stage bleaching. The semichemical pulps are characterized by their high lignin and hemicellulose (pentosans) contents.

4.2.2.1. High-yield chemical pulping

There is no clear border line between semichemical pulping and the so-cold **high-yield chemical pulping**, or between the resulting pulps. From a practical aspect, many high-yield chemical pulps are more or less semichemical pulps with regard to their yields (55-70% and even higher) and typical process design (disk refining after the chemical treatment).

High-yield chemical pulps are obtained in principle by modified sulphite and sulphate processes; by applying reduced charges of chemicals and / or reduced cooking time and temperature, and a refining step after cooking. **High-yield sulphite pulps** are produced by an acidic sulphite, bisulphite or alkaline sulphite process. In **high-yield acid sulphite pulping** (with calcium, magnesium or sodium bases) the reaction rate is usually decreased by cooking at lower temperatures (120-130 ^{0}C) and with lower acidity of the liquor, i.e, less sulphur dioxide, than in full chemical sulphite pulping. Common yields of unbleached pulps are between 60 and 70 per cent. High-yield acidic sulphite pulps are often produced in newsprint sulphite mills, saving up to 30 per cent of wood compared with full chemical pulps. The pulps are mainly used as newsprint furnish in mixtures with groundwood and chemical pulp. Generally the strength values (except burst strength) and the freeness are lower than those of comparable full chemical pulps.

In **high-yield bisulphite pulping**, the cooking liquor has no excess of sulphur dioxide and the maximum cooking temperature is somewhat higher than that in acidic sulphite pulping. The preferred bases are sodium and magnesium. High-yield bisulphite pulps are generally used in the same fields as acidic sulphite pulps (eg., in newsprint).

High-yield alkaline sulphite pulping, a modification of alkaline sulphite pulping, is becoming an increasingly interesting alternative to the kraft process. The cooking liquor is buffered between pH 9 and 12, containing sodium sulphite, sodium carbonate, sodium hydroxide and sodium sulphide. The yields lie around 60 per cent and the pulp is brighter than normal kraft pulp. Due to its good strength properties, the pulp is useful as linerboard.

In **high-yield kraft or sulphate pulping**, the typical karft process is modified either by reducing the charge of chemicals by about one-half or by decreasing the cooking time and temperature. The yields are generally between 55 and 65 per cent, but even up to 80 per cent are also possible. Usually high-yield kraft pulps have lower strength values and are darker than normal kraft pulps and NSSC pulps. The process is used for both hardwoods and softwoods.

A survey of different pulping procedures is given in Appendix 4.A.

4.2.3. Dissolving or Rayon grade pulping

The chain-like high molecular weight cellulose polymer can be transformed into fibres or films of desired properties by spinning, casting, rolling, or extruding, from a melt or from solution. The natural, renewable polymer cellulose frequently occurs as fibres that are too short for textile uses. It cannot however be converted directly into longer fibres or into film because it can neither be melted nor simply dissolved in a solvent owing to strong hydrogen bonding in the material. A suitable cellulose derivative must first be prepared before it is possible to form a spinning solution from which cellulose can be regenerated. The commercially used systems for this purpose are the viscose process and, to a lesser extent the cuprammonium (Bemberg) process, and the acetate process.

The starting material for the preparation of cellulose solutions via complex formation or derivatization must be a cellulose of high purity and good processability. Refined wood pulp or the so-called d**issolving pulp** (also termed as chemical conversion pulp, alpha pulp, rayon grade pulp, etc.) is used for the manufacture of rayon, cellophane, plastics, films, explosives and other cellulose derivatives, etc. The main requirements of a dissolving pulp are good processability (especially good filterability), high-yield, and a good overall economy.

The production of dissolving pulp from materials having high silica and pentosan content is complicated. The removal of pentosans can be accomplished by conventional methods, *i.e.*, by acid hydrolysis during sulphite cooking or by acid prehydrolysis followed by kraft cooking. The difficulties with silica can be partly overcome with repeated hot and cold alkali purifications (Jame and Scheuring 1953). The general minimum requirements for a viscose dissolving pulp for producing bulk products are listed below :

Alpha-cellulose	:	>89%
Solubility in 5% NaOH	:	<5%
Extractives	:	<0.3%
Ash content	:	<0.1%
Iron	:	<12ppm
SiO_2	:	<50ppm
Calcium	:	<250ppm
Brightness	:	>90%, ISO

In 1892, C.F. Cross, E.J. Bevan and Clayton Beadle discovered that, after treatment with carbon disulphide, mercerised cellulose dissolves in dilute caustic soda to form a golden, highly viscous, solution, to which they gave the name **viscose process**.

Schweizer, in 1857 observed that cellulose is soluble in cuprammonium hydroxide- $[Cu(NH_3)_4](OH)_2$, and used this as the spinning solution for regenerated fibre production. This is known as the **cuprammonium process** for the production of regenerated cellulose (rayon). In the **acetate process** the cellulose acetate derivative dissolved in methylene chloride or acetone is used as the spinning solution.

4.2.4. Non-conventional pulping processes

The non-conventional pulping processes include well-known pulping principles, which are, however, only rarely applied commercially. Their industrial application is often limited by high costs of chemicals and special equipment requirements. However, they posses the advantage of more environmental friendliness techniques. Appendix 4B gives a survey of different non-conventional pulping procedures. Pulping via sodium-xylene sulphonate, aqueous ethanol, ketone-ammonia mixture, ethanol amine, peracetic acid, oxygen-alkali, etc., are some of the efforts to develop pollution free pulping processes. Among the various processes, some commonly referred methods are described below :

4.2.4.1. Ethanol-water pulping

Aqueous ethanol is a powerful delignifying agent. Retention of lignin is strongly dependent on pH of the cooking liquor. After distilling off the alcohol from ethanol-water black liquor, a major fraction of the solubilized lignin separates as a quasi-molten phase.

4.2.4.2. Hydrotropic pulping

Certain substances which are only slightly soluble in water become more soluble in the presence of certain salts known as hydrotropic salts. These are salts of organic acids which have a large organic group and are themselves soluble in water. It has been shown that a near-saturated aqueous solution of sodium xylen sulphonate at approximately 70 ^{0}C, will dissolve large quantities of lignin. These salts appear to act as catalysts. As they are not consumed, they can be recovered unchanged for reuse. Also they hydrolyse wood or straw at a much faster rate than the chemicals used in other processes of pulp making. In pulping with sodium xylene sulphonate, cooking could be accomplished in shorter time and at lower temperature than with other standard processes. For most woods the composition of the hydrotropic cooking solution is approximately one third salt and two thirds water; the solution is adjusted to a slightly acid pH (3.5). A typical cook, for paper bags takes 2-3 hrs. at 145 ^{0}C and 4 bar pressure. At the end of the cook, the solution is filtered from the pulp and reused half a dozen times for other cooks. The solution is then diluted with warm water (40- 60^{0}C) to a salt concentration of 8-10 per cent for precipitating the lignin. The lignin is removed by filtration and the solution is evaporated until the concentration of sodium xylenesulphonate is nearly 30 per cent; at this stage the solution can once again be used for cooking. The solution is nonscaling and noncorrosive and free from objectionable odour. The pulp is pressed to a consistency of about 40 per cent, washed free of the remaining hydrotropic salt. The properties of the pulp fall between those of an acid sulphite and an alkaline kraft pulp. The yield is 10 per cent higher and gives a high white colour in the usual bleaching processes.

4.2.4.3. Nitric acid pulping

The nitric acid pulping process consists of a two- stage pulping operation. In the first stage nitric acid is used to remove the lignin and, to a lesser degree, the pentosan and other non-cellulosic materials without damaging the cellulose fibre. The chemical reactions involved are nitration, oxidation and hydrolysis. The second stage consists of an alkaline extraction of the nitrolignin residues encrusting the cellulose fibre. I to 4 per cent sodium or ammonium hydroxide is normally used to dissolve and disperse these residues.

Although high-yield pulps (45- 52%) displaying good physical strength properties intermediate between kraft and sulphite pulps have been obtained under a wide range of pulping conditions, the high cost of the acid, which must be used in relatively large concentrations (52%) and lack of an efficient recovery system caused a bottle-neck for commercial adoption of this process on a wide scale.

4.2.4.4. Peracetic acid pulping

Lignin degradative oxidation is used in the pulping process with peracetic acid. This reagent selectively delignifies and gives pulp in high yield but requires large amounts of expensive chemicals and therefore not economical.

4.2.5. Sulphur free chemical pulping processes

Environment protection concerns led to the development of sulphur free chemical processes as alternatives to sulphite and kraft pulping. **Non-sulphur alkaline pulping** covers delignification procedures such as, two-stage soda-oxygen process, single-stage oxygen process, and the alkaline – AQ-peroxide process.

The **two-stage soda-oxygen pulping process** involves a high-yield soda cook, followed by a mechanical defibration and a concluding oxygen bleaching in alkaline medium. The cooking stage has the greatest influence on final pulp yields and properties. The yield after the cooking stage should be in the range of 60-65 per cent to reach high final yields after the bleaching procedure, and to achieve optimal refining conditions with regard to energy input and fibre protection. The yields of bleached pulps are comparable to kraft pulp yields, while the strength properties are somewhat lower. A practical aspect of this process is the fact that it can run in established kraft pulp digestion and recovery equipment with an added refining section and an oxygen bleaching plant.

In the **single-stage oxygen pulping process**, the delignification is carried out in slightly alkaline solutions (pH 7-9) of sodium hydroxide, sodium carbonate or hydrogen carbonate (also in the presence of hydrogen peroxide) at 140-150 ^{0}C and high oxygen pressures in the range of 20-40 bar. The pressure cooking is carried out at low consistency to maintain the temperature level. To avoid insufficient oxygen penetration into the wood very thin chips (< 1.5 mm) must be used. The pulps are generally obtained in high yields and good brightness, but the strength properties are usually not comparable to those of kraft pulps. Strength improvements can be obtained by sodium hydrogen carbonate pre-cooking, increasing the carbon dioxide content in the gas phase, and by addition of potassium iodide or other metal compounds as cellulose protectors (Fujii and Hannah 1978).

In the **alkaline–AQ-peroxide process**, delignification is carried out in two stages with a refining step in between. The first stage is a high-yield soda-AQ cook down to kappa numbers of 50-60. The second delignification step is performed as a medium to high consistency (>10%) hydrogen peroxide bleaching (<0.5% H_2O_2 based on wood), reducing the kappa number down to about 30. The obvious advantages of this process are: 2-5 per cent higher yields than in kraft pulping, better mechanical characteristics and higher brightness as compared to kraft and soda-AQ pulps, low AQ amounts (<0.1%), elimination of the air pollution problems of kraft pulping, and easy and low-cost substitution within the existing kraft mills by installation of a refiner section and a hydrogen peroxide bleaching tower.

Apart from the non-sulphur alkaline pulping processes, the **organosolv pulping** is a sulphur free non-alkaline process employing 1:1 mixture of alcohol (ethanol or methanol or butanol) and water or phenol and water as the cooking medium. Organosolv pulping seems to be a viable future pulping alternative because of the relatively low capital investment required for a new mill, the absence of pollution problems, and the advantage of obtaining polyoses and lignin easily and largely unchanged for further high-value utilization.

4.2.6. Bio-pulping

As microorganisms or the enzymes produced by them can break down lingo-cellulosic materials, preferential degradation of lignin by soft-rot fungi can be exploited for achieving at least partial delignification. Considerable amounts of the complex lignin molecule can be degraded or altered to bring about savings in energy inputs during pulping. The cleaving of carbon-carbon and carbon-oxygen linkages by the biological process renders the lignin molecule more accessible to subsequent action of the cook liquor. While the industrial physico-mechanical process operated under high pressure and temperature, the biological conversion process operates under much milder conditions thus resulting in energy savings.

A systematic screening of a number of white rot fungi which could act preferentially to degrade middle lamella lignin leading to defibration, led to the identification of an isolate of *Schizophyllum* *commune* (Ramaswami and Ramanathan 1989) [66]. Currently the time required after treatment is in the order of days and can be reduced with the identification of right strains and other treatment conditions. The treatment can be done either during transport or storage in the yard.

4.2.7. Effect of process variables and conditions on pulping

The end results of pulping, as measured by pulp yield and quality, are affected by the variables controlling the chemical as well as mechanical stages of the process. The physical and chemical characteristics of the fibrous material, its state of sub division, the composition of the pulping liquor, the amount of chemical applied, and the time and temperature of pulping are some of the variables affecting the chemical processing stage. An increase in temperature results in an increase in the rate of pulping and a decrease in pulping time for a given degree of delignification. Vroom (1957) [434] developed the concept of 'H factor' – a means of expressing cooking time and temperature as a single variable. The penetration of the cooking liquor into the fibrous material is an important dependent variable. The mechanical stage is affected by the properties of the materials from the chemical stage and its subdivision, the slurry consistency, the temperature, the number of passes, and the design of the machine and its elements.

Since small chips are more easily penetrated with the pulping chemical than large ones, the former are particularly favoured. It is recommended to use chips having a dimension of 20-30mm in the grain direction in full chemical pulping as against 10-13mm for semichemical pulping. Chips reduced laterally to matchstick dimensions by hammer or disk mills are used to some extent.

4.2.8. Yields of various pulping processes

A classification of pulping processes based on present- day terminology and showing the relations and overlappings with respect to yields is given below (McGovern 1962) [414]:

Sl No.	Process		Yield (%)
1	Mechanical (groundwood)	:	90-95
2	Chemigroundwood	:	85-90
3	Chemimechanical		
	- Cold-soda, sodium sulphite, bisulphite	:	85-95
4	Semichemical		
	- Neutral sulphite, bisulphite, kraft, soda	:	65-85
5	Coarse- fibre		
	- steam, mild chemical	:	70-90
6	High yield chemical		
	- kraft, sulphite	:	50-65
7	Chemical		
	- sulphate, soda, sulphite, bisulphite	:	40-50
	- pre-hydrolysis sulphate	:	35-40

4.3. Bleaching

The object of bleaching is to render the pulp whiter without excessive degradation of the cellulose. Industrial bleaching of pulps first with hypochlorite and later with chlorine, partly in combination, and with an intermediate extraction step with alkali began at the end of the 19^{th} century. The development of pulp bleaching techniques in the 20^{th} century has led to a large number of bleaching chemicals (Appendix 6A) applied in numerous and highly specific processes (Appendix 6B, C, D & E) today.

The principal aim of pulp bleaching is to increase brightness. The whiteness of pulps is generally determined by measuring the reflectance of nearly monochromatic light (457 microns) by a standard General Electric (GE) reflectance meter. A magnesium oxide plate of known reflectance is used as a standard. The brightness values are expressed as percentage of light reflected by the sample as compared with that reflected by a completely white surface. Unbleached pulps generally exhibit brightness values ranging from 25-65 GE units. The sulphite process usually gives the brightest unbleached pulps, whereas those produced by kraft, soda or semichemical processes can be quite dark. Groundwood pulps have brightness values in between 40 and 60 units.

To produce white fibres from the brown or pale yellow pulps, treatment with a bleaching agent is required. The nature of the bleaching operation depends on several factors: the type of raw material used to make the pulp, the pulping process, the degree of whiteness desired, and the purpose for which the pulp is to be used. Bleaching carries further the fibre purification accomplished in the pulping process. As the light-absorbing chromophoric component in unbleached pulps are predominantly functional groups of degraded and altered residual lignin, bleaching can be performed either by converting and stabilizing chromophoric groups without loss of substance (lignin-preserving bleaching) or by removing the lignin (lignin- removing bleaching). The traces of lignin and other coloured substances (quinone like substances formed from the phenolic groups of lignin by various oxidative processes are known to absorb visible light) are removed or converted to colourless forms by bleaching. The extraneous constituents of wood also contribute to the colour of certain pulps, especially the groundwood pulps. Along with the removal of the residual lignin and other compounds, insufficiently delignified particles (shives, bark specks) are also partly removed. Therefore, bleaching can additionally be regarded as a purification process, which is used especially in the case of dissolving pulp production to obtain a pure pulp with high alpha-cellulose content. Bleaching without delignification to brightness values above 70 is difficult to achieve. High brightness is not, of course, the only important characteristic of bleached pulps. A good paper pulp must also have good strength and good papermaking properties, and it is important that these properties are not lost in the bleaching process.

Pulp bleaching chemicals can be classified into oxidising agents (chlorine, sodium or calcium hypochlorite, chlorine dioxide, hydrogen or sodium peroxide, oxygen, etc.) and reducing agents (sodium or zinc hydrosulphite, sodium or zinc dithionite, sodium bisulphite, etc.) (Appendix 6A). Present bleaching systems permit consistencies up to 15-25 per cent.

Industrial lignin-removing processes have improved multi-stage bleaching sequences adapted to the special pulp type and combining the different oxidising and reducing abilities of the bleaching chemicals. Degraded lignin and other reaction products are extracted during intermediate alkaline washing stages. Bleaching with peroxide, oxygen or dithionite requires additional chemicals for buffering (e.g. sodium silicate), sequestering (e.g. ethylenediamine tetraacetic acid – EDTA) or stabilizing (e.g. magnesium salts).

4.3.1. Bleaching of chemical pulps

The aim of bleaching chemical pulps is to remove the residual lignin after the cooking process to obtain so-called full- bleached pulps with brightness levels above 90 per cent or semi-bleached qualities with brightness values in the range of 60-70 per cent.

4.3.1.1. Multi-stage bleaching systems

In the early days of sulphite pulp manufacture, a single-stage treatment of pulp at low consistency, using calcium hypochlorite (chlorinated lime) satisfied most requirements. Multi-stage bleaching systems have evolved for difficult to bleach pulps like the kraft in which various sequences of chemical treatment are employed depending upon the type of unbleached pulp and special requirements. Lignin-removing bleaching is predominantly carried out today in multi-stage procedures with oxidative stages combining with normally at least one alkaline extraction step. The multi stage bleaching systems are designed in order to control the process and particularly in order to limit the damage to the cellulosic fibre, since paper made from over bleached pulp does not have full strength. Apart from the high degree of whiteness or brightness attained, the consumption of bleach was much less in multi-stage bleaching.

During the normal first stage in a modern bleach plant, the unbleached pulp is chlorinated with 3–4 per cent of gaseous chlorine by rapidly mixing it with the pulp at temperature of 21- 27 ^{0}C. In the following stage, an alkaline extraction with dilute caustic soda dissolves the chlorinated compounds which are then washed out. The final stage consists of a treatment with a very alkaline hypochlorite to neutralise the solution, followed by a final wash. This sequence of bleaching is generally termed as C/ E/H (Chlorination–Extraction–Hypochlorite treatment). By the use of small amounts of chlorine dioxide in later bleaching stages, it is possible to achieve high degrees of purification and brightness without the degradation of cellulose.

The main disadvantage of the process is the extensive degradation of cellulose fibres as well as introducing high pollutants in the effluent. Further, higher brightness beyond 80 per cent is practically impossible while using hypochlorite. Alternatively, the use of chlorine dioxide can considerably reduce the use of free chlorine and the chlorination stage which has the advantages of lowering the consumption of oxidising chemicals as also sodium hydroxide at the extraction stages, improved pulp properties such as more stable brightness, improved effluent properties such as lower colour, toxicity, acidity, salinity, organic chlorides, COD and mutagenicity. The foremost advantage of using chlorine dioxide bleaching is the benefit of attaining brightness levels in excess of 85 per cent with the associated less degradation of cellulosic fibres. Practically all over the world chlorine dioxide bleaching has been in use for the last four decades.

Multi-stage bleaching involves a series of stages, each complete within itself and operating under conditions previously described. The procedure may vary from two stages to as many as ten, involving chlorination, alkali extraction, hypochlorite, chlorine dioxide, and peroxide stages. The symbols used to describe the sequences and the various sequences, in practice for the bleaching of pulps are given in Appendix 6C, D &E. Pulps of different brightness may be obtained by varying the amount of chemical added, sequence of stages, and number of stages. The sequence of operation of the various stages will depend on the type of unbleached pulp, the quality of the bleached pulp, the brightness desired, and the economics of the process.

In most commercial processes chlorination is still the first bleaching step, and is also called the pre-bleaching stage. Chlorine converts the residual lignin in water- and alkali-soluble degradation products, and is therefore generally followed by an alkaline extraction step to remove those components.

4.3.1.2. Substitution for chlorine

As chlorination causes the largest number of environmental problems with the bleach plant effluents, many attempts have been made to replace chlorine or to reduce the amounts of chlorine used or the chlorinated products in the effluents. This can be accomplished by cooking the pulps down to low kappa numbers, thus reducing the chlorinated organic load in the effluents, or by replacing part of chlorinated lignin fragments. Replacing chlorine altogether by peroxide or oxygen bleaching enables processing of effluents with few problems with regard to environmental protection.

Hypochlorite can be used in a single-stage bleaching or in the first stage of multi- stage bleaching, but is mostly applied after chlorination and extraction (C-E-H). As hypochlorite has a severe degrading effect on cellulose in the neutral pH range at very low kappa numbers it must always be applied under alkaline conditions.

Pulp and paper industry is rated to be one of the highly polluting (in top 20s) industries. Use of chlorine can release organochlorines, including the carcinogenic dioxin that can enter the food chain. Most developing countries aim to achieve a total organochlorine (TOCL) level of 0.1 kg per tonne of paper produced. Hence, there is an increasing trend worldwide to reduce the use of both elemental chlorine and chemicals containing chlorine. Two bleaching processes, which are increasingly being adopted by the western countries are **elemental chlorine free (ECF) bleaching** and **total chlorine free (TCF) bleaching**. As a first step towards adopting more environmentally friendly methods, the ECF bleaching comprising the replacement of the more dangerous elemental chlorine with chlorine dioxide is considered and is gradually displacing chlorine in the first stage of multi-stage bleaching, whereas formerly it was used in the final stages. This development is the result of several advantages of chlorine dioxide such as higher brightness, improved strength properties, lower chemical consumption and substantial decrease in the BOD of the effluents. Chlorine dioxide bleaching is generally performed at low to medium consistency at pH values of 3-5, and at low temperatures in the first stage or at about 70 ^{0}C in intermediate or final stages for 3-5 hrs. The use of hydrogen and sodium peroxide as the bleaching agents (especially for mechanical pulps) is a solution to introduce the TCF bleaching.

Peroxides, apart from their application in bleaching mechanical pulps, are also established today in several industrial bleaching sequences for chemical pulps. They are mainly used in the latter stages in combination with chlorine dioxide yielding increased brightness values and stability. More recently the traditional sodium hydroxide extraction (E) is sometimes replaced by an alkaline peroxide stage (P or P/E) combining bleaching and extraction in one stage, and resulting in a brightness gain without an additional stage. By increasing the application of hydrogen peroxide, the amounts of chlorine bleaching chemicals are reduced resulting in decreased chlorine load of the effluents. Limitations are still the high price of peroxides and the necessary additives for stabilization. Peroxide bleaching is usually performed at medium-to-high consistency at 60-80 ^{0}C for 2-4 hrs.

4.3.1.2.1. Oxygen bleaching

Oxygen bleaching (or oxygen delignification) is another eco-friendly bleaching process. As oxidation is the essential reaction in lignin-removing bleaching, it is quite reasonable to aim at using oxygen as the cheapest oxidising agent for bleaching. In principle, oxygen bleaching is a gas-phase process at pressures usually between 4 and 8 bar in alkaline medium, performed at high consistencies of 20-30 per cent and temperatures of 90-140 ^{0}C, depending on the alkali used. But as it is not a selective lignin- degrading chemical, pulps cannot be bleached to high brightness exclusively with oxygen without considerable attack on the polysaccharides, resulting in rather poor strength properties. Thus the common practice in mill-scale bleaching today is to remove about one–half of the residual lignin in unbleached pulps by oxygen, and to finish with conventional multi stage bleaching sequences such as C-(EO)-H-D, D-C-(EO)-D, O-C-D-E, O-C-E-D-E-D or O-D-E-D, etc. The conventional bleach plants employing sequences such as C-E-H-H will have to do only marginal changes in their industry to incorporate the D-C-(EO)-D process so that pulps of high brightness can be produced at considerably and relatively low cost. The Kamyr, Sund, Beloit Rauma, etc. have equipments for the needful modifications (Goel *et al*. 1989) [5]. More than 16 plants throughout the world are employing this process, the first having been founded in South Africa in 1970. The main practical advantage of oxygen bleaching is the fact that the effluents from the oxygen step can be processed within the normal kraft recovery system. In the context of increasing air and water pollution from the traditional bleaching systems, oxygen bleaching has proven its potential as the more environmentally friendly system.

4.3.2. Colour reduction in the effluent

Some of the technological changes as suggested by Mall *et al*. (1989) [52], for reducing toxicity and colour of the effluents are: elimination or minimum use of sulphur containing pulping processes and chlorine containing bleaching processes; extended delignification; modification of bleaching sequences which includes elimination of caustic extraction stage which is the major contributor of colour; use of oxygen bleaching, chlorine dioxide bleaching; use of anthraquinone and lower sulphur high-yield pulping processes; total recycle concept, and reduction in bleached pulp brightness level.

4.3.3. Bio-bleaching

Microorganisms or enzymes can cause modification of the lignin in the pulp rendering it more accessible to the bleaching agents, thus the application of biotechnology in bleaching can reduce the consumption of bleaching chemicals which can further help to reduce the effluent pollution and associated toxicity problems. After the alkaline extraction stage, unbleached kraft hardwood pulps have been treated with xylanases of *Escherichia coli* clone to yield pulps which are bright and have a kappa number 54 per cent lower than the corresponding control samples (Jurasck *et al*. 1987) [493a]. In addition, the viscosity of pulps was also higher compared to the control. Begasse CTMP and CMP pulps on treatment with a crude enzyme extract resulted in 2-6 unit improvement in brightness (Ramaswami and Ramanathan 1989) [66]. There is still scope to improve its performance by purification of the enzyme and identification of the optimal treatment conditions like temperature and pH. The use of bio-catalysts can accelerate the rate of reaction as well as can have control over the products formed and thus the formation of undesirable side products can be controlled. In fermenters where the enzyme cellulase has been used, it has been found that 50-90 per cent of the enzymes are free in the solution and can be directly reused again (Eriksson and Kirk 1985) [503].

4.4. Recovery of pulping chemicals

The regeneration of black liquor to fresh white liquor is an integrated and economically necessary part of the pulping process, especially in the sulphate and the soda process. The importance of the recovery line within the process may be seen from the fact that more than 25 per cent of the investment capital for a new kraft mill is used for the chemical recovery (Harris 1974) [43]. The chemical recovery cycle covers four main aspects: recovery of pulping chemicals, reduction of water-pollution by burning the organic matter in the spent liquor, generation of process heat, and recovery of valuable by-products. The principal steps of the recovery line are: evaporation of the black liquor, incineration of the concentrated liquor, causticizing the furnace smelt, and regeneration of the lime.

4.5. **Paper Manufacture**

4.5.1. Stock preparation – Beating / Refining

.The tendency of cellulose fibres to bond together when dried from a water suspension provides the essence of paper making technology. Paper manufacture is largely a mechanical operation, although the chemical and physicochemical aspects are all important in determining the final sheet properties.

Unmodified cellulose fibres, as obtained from pulping and bleaching operations, are generally unsuited for paper making. These must first be refined; refining or **beating** operation is conducted mechanically in beaters or refiners. The entire operation is called **stock preparation**. Fibres are abraded and fibrillated by the knife-edges or bars in the beater or refiner. Mechanical squeezing and pounding of cellulose fibre permits water to penetrate its structure, causing swelling of the fibre and making it flexible. During refining or beating, the pulp fibres are separated, crushed, frayed, fibrillated, and cut. They imbibe water and swell, become more flexible and more pliable. Their capacity to bond with one another on drying is greatly enhanced, partly through modification of the fibre surfaces and partly because of the creation of new surface area. Papers made from lightly beaten stocks are typically of low density, soft and porous; whereas papers from highly beaten stocks are dense, hard and much stronger. With given pulps, final paper properties are largely controlled through the type and extent of refining action employed.

4.5.2. Sizing

Sizing has been described as the treatment given to paper to prevent aqueous solutions, such as ink, from soaking into it. A typical sizing solution consists of a rosin soap dispersion mixed with the stock in an amount of 1-5 per cent of fibre. Since there is no affinity between rosin soap and fibre, it is necessary to use a coupling agent, normally alum (aluminium sulphate). The acidity of alum precipitates the rosin dispersion, and the positively charged aluminium ions and aluminium hydroxide flocs (masses of finally suspended particles) attach the size firmly to the negatively charged fibre surface.

Paper intended for writing or printing usually contains white pigments or **fillers** to increase brightness, opacity and surface smoothness, and to improve ink receptivity. Clay (aluminium silicate), often referred as kaolin or china clay, is commonly used. Another pigment used as filler is titanium dioxide, which being expensive, is often used in admixture with others. Calcium carbonate is also used as paper filler for printing and magazine stocks and for the filling of cigarette paper, to which it contributes good burning properties. Because of its reactivity with acid, calcium carbonate cannot be used in systems containing alum. Other fillers such as zinc oxide, zinc sulphide, hydrated silica, calcium sulphate, hydrated alumina, talc, barium sulphate and asbestos are also in use as fillers in paper coatings. The amount of filler used may vary from 1- 10 per cent of the fibre.

The most common way to impart colour to paper is to add soluble dyes or coloured pigments to the paper stock. Other **additives** such as wet-strength agents (organic resins), deflocculating agents and deformers are also incorporated as needed in the stock. To increase the dry strength of paper, the materials most commonly used are starch, polyacrylamide resins, and natural gums such as locust bean gum and guar gum.

4.5.3. Paper sheet formation by machines

The term **paper** is traditionally applied to a matted or felted sheet of cellulose fibres, formed on a fine wire screen from a dilute water suspension, and bonded together as the wire removed and the sheet is dried. The word, paper, is derived from the name of the reedy plant *papyrus*, which grows abundantly along the Nile River in Egypt.

The continuous paper machine converts a very dilute aqueous suspension of fibres and other ingredients into a dry sheet of paper at varying speeds. The **fourdrinier machine** is one of the two major sheet forming devices in widespread use. It consists in essence of a continuously moving wire belt or screen, to which the dilute pulp slurry is fed and from which the wet, formed sheet is removed continuously. The second major type of paper machine, the **cylinder machine**, differs from the fourdrinier only in the forming part. Here, in place of the moving wire, one or a series of rotary cylindrical filters are used.

Many grades of paper receive some type of treatment after formation and drying in order to enhance certain desirable characteristics. Such operations carried out on the paper machine are called **machine converting operations**. Machine **calendaring** is one of the most common converting operations where the sheet is passed through the nips formed by a series of steel rolls, one held on top of the other. **Surface or tub sizing** is another common converting operation, particularly in the manufacture of writing papers. **Machine coating** is practised for book and magazine papers to improve their surface for better reproduction of printed images. A coating mix is applied to one or both surfaces of the dry sheets by any of several means. The coating is often clay, contained in a high- solids aqueous suspension, which includes suitable adhesives and other ingredients. The sheet must be redried after the coating applications. The finished paper is wound on a large roll at the paper machine.

4.5.4. Paper properties

Used in a wide variety of forms, paper and paperboard are characterised by a wide range of properties. Weight or substance per unit area, called **basis weight**, is a fundamental property of paper and paperboard products. The term **ream weight** commonly signifies the weight of a lot or batch of paper. The **calliper** (thickness) of paper or paperboard is measured by placing a single sheet under a study pressure of 0.5 to 0.6 bar between two circular and parallel plane surfaces, the smaller of which has an area of 1.6 cm^2. The density or specific gravity of paper is calculated from the basis weight and calliper and may vary over wide limits. Most common papers are in the density range of 0.5- 0.7g/cc.

The strength of paper is determined by the following factors in combination: the strength of individual fibres of the stock; the average length of the fibre; the inter-fibre bonding ability (which is enhanced by beating/refining action); and the structure and formation of the sheet. Resistance to rupture when subjected to various stresses is an important property in practically all grades of paper. **Tensile strength** is the greatest longitudinal stress a piece of paper can bear without tearing apart. According to end-use situations, the wet and dry tensile strengths need to be specified separately. The stress is expressed as force per unit width of a test specimen. Since, the weight of the paper and the width of the test specimen affect the force of rupture, a conventional method of comparing inherent paper strength is the **breaking length,** the length of a paper strip in meters that would be just self-supporting. This value varies from 500 m for extremely soft and weak tissue to about 8,000 m for strong kraft bag paper, and to about 14,000 m for sheets of paper made under ideal conditions. One of the oldest and most widely used strength tests for paper and paperboard is the bursting test, or Mullen test. **Bursting strength** is defined as the hydrostatic pressure necessary to cause rupture in a circular area of a given diameter. Other strength tests for which standard methods exist are the **tearing strength** and **folding endurance**. Explanation of some general terms used in describing pulp strength properties is given in Appendix 1B.

The most important **optical properties** of paper are **brightness, colour, opacity** and **gloss**. The term brightness has come to mean the degree to which white or near-white paper and paperboard reflect the light of the blue end of the spectrum. This reflectance is measured by an instrument that illuminates paper at an angle of incidence of 45^0 and a wavelength of 457 microns. Opacity is one of the most desired properties of printing and writing papers. Satisfactory performance of such paper requires that there be little or no 'show-through' of images from one side of the sheet to the other. Satisfactory opacity in printing papers requires that white mineral pigments be incorporated with the paper stock or applied as a coating. The terms gloss, glare, finish and smoothness are used in describing surface characteristics of paper. Gloss refers to surface lustre and connotes a generally pleasing aspect. Calendaring and coating are important paper-treating methods that affect gloss. Gloss of paper is determined by measuring per cent reflectance at a low angle of incidence, 15^0 (75^0 from the perpendicular). **Glare** refers for a more intense reflection and a more unpleasant effect. The broad term **finish,** refers to the general surface characteristics of the sheet. **Smoothness** refers to the absence of surface irregularities under either visual or use conditions.

4.5.5. Paper products

The products of the paper industry are extremely varied. New applications for paper involved converted products. For this, more complex converting operations take place subsequent to the paper machine operations and are called **off-machine converting**. **Supercalendaring, embossing, coating, waxing, laminating, impregnating, saturating, corrugating** and **printing** are but a few of the common operations. Papers, often coated, waxed, resin-impregnated, or combined with other foils and films, are used for food packaging. Speciality papers incorporate the use of glass and other mineral fibres. Polyethylene–coated paper is crease-resistant and is flexible at temperatures ranging from 20 to 85 ^{0}C, which is used for bags, carton, box and bag liners as well as for disposable diapers, bibs and bed sheets. A great variety of technical and industrial papers have been developed for use in the manufacture of disposable vacuum bags, engine gaskets, cap liners, wet-cell batteries, and many other special-purpose products. The applications of paper are limited only by man's ingenuity.

4.5.6. Paper grades

There are several hundred grades of paper and paperboard, distinguished from one another by differences in their properties, in the raw materials from which they are made, or in the process by which they are manufactured. An extensive list of grades of paper is given by American Paper and Pulp Association (1951) [23] and Labarre (1952) [50].

The specific properties of the various grades of paper produced by varying many factors including type of pulp, degree of bleaching and purification, thickness of the wet web, degree of pressing in water removal, degree of pressing in drying and calendaring operations, and kind and quantity of chemical additives. A brief description of the various grades of paper is given in Appendix 9A.

PART II. BAMBOO FOR PULP AND PAPER

5. BAMBOOS : DISTRIBUTION, UTILIZATION, STORAGE AND ECONOMICS

5.1. About bamboos

Bamboo grows in India, Burma, Thailand, Indonesia, China, Japan, the Philippines, Australia, South Africa, South America and southern North America. It is a grass of several genera and species. Bamboo provides the highest biomass per unit area. There are two types of bamboos: sympodial or clump forming, as in *Bambusa*; monopodial or single clump distributed laterally, as in *Melocanna*. Bamboo grows as high as 40 m with diameter up to 30 cm. The growth rate is tremendous; in 1-2 months of the first year full length is achieved (growth rate is about 15 to 120 cm per day in some species!) (Martin 1996) [107a] and culm maturation through lignification takes place during the next two to three years.

Bamboo clumps die off after flowering, which occurs from cycles varying between 50 and 60 years depending on the species. Estimates of total global revenue generated from bamboo and its products – including the value of bamboo used by traditional communities and employment generated by them – range between US $ 4.5 and 7.0 billion.

5.2. Distribution of bamboos

Sharma (1982) [121] describes the distribution of bamboos in countries like China, Japan, Korea, besides that of South and Southeast Asia. A total of 1250 species of bamboos from 75 genera are reported from these countries. Occurrence of more than 50 species of bamboos is reported from Vietnam (Anonymous 1971). Recently, Ohrnberger (1999) [114] has brought out information on bamboos of the world and their distribution.

Gamble (1896) [94] is one of the oldest records available on bamboos of India. Singh and Guha (1981) [429] reviewed the various bamboos occurring in India, including their pulping, bleaching, beating properties and the properties of paper made from these. The upgraded list of distribution of bamboos in India is provided by ICFRE (1991) [100] and Moulik (1997) [111]. A compendium of 128 species of bamboos from 18 genera occurring in India have been brought out by Seethalakshmi and Kumar (1998) [118]. The two most widely distributed genera in India are *Bambusa* and *Dendrocalamus*.

5.3. History of pulp production from bamboos

Bamboo, "the green gold of the forest", around 10 million tonnes of which are produced annually in the world, is not expensive, long-fibered, easy to transport and therefore is an important raw material for the pulp and paper industry. Sumg (1967) [20] described the pulp characteristics and technology for the manufacture of bamboo paper in the 17th century China. Bourdillon (1899) [138], and later Sindall (1909) [192] and Vincent (1911) [205] described the use of bamboo for pulp and paper. It was India that took the lead in using bamboo in mechanized paper production. In 1912, the Titaghur Paper Mill in India started utilizing bamboo as a raw material in a limited scale. In 1918, the India Paper and Pulp Company Limited., Naihat produced paper made completely from bamboo. The pulp industry accounts for about half of India's bamboo consumption (mostly *Dendrocalamus strictus* and *Bambusa bambos*). India uses about 3 million tonnes of bamboo per year in pulp manufacture and China about 1 million tonnes. China is set to increase the use of bamboo for paper pulp manufacture to a target of 5 million tonnes per year. The use of bamboo for pulp is reported to have decreased in India due to lack of raw material (INBAR 1977) [158].

Pearson (1912) [186] and Raitt (1912) [231] provided the history of work carried out at the Forest Research Institute, Dehra Dun, India which pioneered and laid a strong foundation for utilizing bamboo for pulp and paper. The general conditions necessary for establishment of a paper mill, manufacturing cost, etc. were provided by them. Bhargava and Singh (1941 [137] and 1942) [26] established the suitability of bamboo as a raw material in the kraft process which was a major milestone in the pulp industry in India. Since then, many periodic reviews of the work carried out at the Forest Research Institute, Dehra Dun, India have appeared (Bhargava 1946 [136]; Singh and Mukherjea 1965 [79]; Tewari 1993) [124]. Tissot (1970) [198] reviewed the status of bamboo as a raw material in the Indian paper industry and the problems encountered in producing pulp and paper from bamboo (mainly *Dendrocalamus strictus*). In comparison to wood, bamboo can be pulped by the kraft and 2-stage alkali processes with less chemical and power (Stevens 1958 [80]; INBAR 1977) [158]. Only minor differences are found between pulps of 21 Indian bamboo species. The bamboo fibres are shorter than that of conifers but longer than that of hardwoods and narrower than that of wood fibres used in paper making.

An yield of 8 tonnes per ha per year of dry matter (4.0 tonnes of cellulose) was reported (Anonymous, 1955) from the Congo grown small bamboo, *Oxytenanthera abyssinica*. Hodge (1957) [99] described the economic future of bamboos in America. The reported annual yield per ha of bamboo cellulosic material was six times greater than that of southern pine. Belvin (1957) [25] reported the potential of bamboo plantations in the USA. Istas (1958) [44] reported that the short, fine and stiff fibred dwarf bamboos of Belgian Congo (*Sasa paniculata, S. variabilis, Arundinaria nitida* and *A. simonii*) were unsuitable for pulping whereas the larger species, *Bambusa vulgaris* (with average fibre length around 2.7 mm) from Congo gave promising results. Istas and Raekelboom (1962) [160] reported an yield of 50 tonnes per ha of *Bambusa vulgaris* from Congo which also provided best paper making pulps. They suggested a cutting cycle of 2 years. Mooney (1959) [110] reported an yield of 5 tonnes air-dry culms per acre (12.5 tonnes/ ha) with a 4-year cutting cycle for *Oxytenanthera abyssinica.* Breitenbach (1961) described the status of bamboo as a source of cellulose in Ethiopia. An area of about 1 million ha was reported to be under the bamboo species, *Oxytenanthera abyssinica*. An area of 10,000 ha of bamboo plantation, managed on a 5-year coppice rotation, would keep a pulp mill supplied permanently with raw material. FPRDI (1962) [148] discussed the merits of bamboo as a raw material for pulp and paper making and outlined the commercial possibilities of certain economically and technically suitable Philippine species such as *Gigantochloa levis, G. aspera, Schizostachyum lumampao, Bambusa blumeana*, *Bambusa vulgaris* and *B. vulgaris* var. s*triata*. Ono (1962) [12] reported the results of a survey of bamboo forests in Indonesia and Burma (Myanmer) and discussed the scientific techniques of bamboo pulping industry.

It was reported by Matsui (1963) [178] that about 70 per cent of the forest undergrowth in Japan was composed of Sasa bamboos. The larger species, *Sasa kurilensis,* was reported to provide an yield of 50-60 tonnes per ha when clear cut. Nelson (1966) [61] reported that *Sinarundinaria murielae,* three *Phyllostachys* spp., two *Arundinaria* spp. and *Oxytenanthera abyssinica* were promising species for planting in the southeast and the Pacific coast of the USA. The prospects of bamboo for pulp and paper and board making in India were reported by Guha (1961a [96] & b) [395]. Factors which limit the actual selection of raw material for large scale paper manufacture were enumerated by him. Chandrasekharan (1968) [476] reported that bamboo only was used commercially in India for dissolving grade pulp.

McGrovern (1967) [180] compared bamboo with southern hardwoods and southern pines in the USA with regard to yield (in India and Japan), density, chemical composition, fibre dimensions, conditions for kraft pulping and bleaching and pulp properties. Razzaque *et al*. (1981) [233] suggested a 12 month cutting cycle for bamboos for pulping. Adkoli (1992) [131] made an assessment of the availability of bamboo for the production of pulp and paper in India. Availability of wastelands for bamboo plantations, investments and efforts needed to raise such plantations were also discussed by him.. The three main species of bamboos, *Dendrocalamus strictus*, *Bambusa arundinacea (B. bambos)* and *Melocanna baccifera* are reported to constitute 83 per cent of the total growing stock. Nomura (1999) [183] described the role of bamboo in pulping in Myanmar.

El Bassam and Jakob (1996) [146] reported that generally bamboos produced about 7 tonnes dry matter/ha per year. Cellulose content of more than 40 per cent emphasizes the suitability of bamboo as a raw material for pulp and paper production. The pulp yield from bamboos varies from 40-50 per cent.

Even though China is number one in bamboo production in the world, information on the utilization of bamboo for pulping in China is scanty. There was a mass movement in China during 1958 for setting up small paper mills in order to solve the problem of shortage of paper and board in the country. As many as 4200 small plants exist in China, out of which 4000 mills produce less than 10,000 tonnes per annum (Rao 1989) [17]. The total bamboo and reed pulp production in China recorded in 1986 was 820,000 tonnes, which forms 9.2 per cent of the total pulp production in the country. Tang (1999) [21] describes the current situation and future developments on the utilization of bamboos for pulp and paper in China.

5.4. Decay while storage and control measures

Bamboo for pulp and paper manufacture is usually stored outdoors for up to a year. Because of lack of any toxic constituents, bamboo forms a ready food source for a variety of organisms. The presence of large amounts of starch makes bamboo highly susceptible to attack by staining fungi and powder–post beetles (Beeson 1941 [541]; Gardner 1945 [546]; Mathew and Nair 1990) [158]. It was found that the lignin content of bamboo chips subjected to fungal attack did not vary appreciably from that of healthy bamboo. The bleached pulp from decayed bamboo was more yellower.

Strength properties of pulp from decayed chips were appreciably reduced and this was due to the perforations or bore holes and erosion marks in the cell-walls, as observed by anatomical studies of the fibres from healthy and fungal attacked bamboos (Guha *et al*. 1958) [547]. Decay, mainly attributable to white-rotters, results in loss of wood substance and pulp yield, reduced pulp strength and increased consumption of bleaching chemicals because of the high content of residual lignin in the pulp. Bamboo attacked by brown-rot fungi was unsuitable for pulping, as the pulp yield was very low compared to healthy bamboo and the permanganate number was so high that the pulp was unbleachable. Fungal attack increases pulping costs, owing to increased alkali demands (because of acidic nature of fungi) and higher bleach consumption (Singh 1977) [566].

Sheets made from decayed and stained bamboo pulp from *Bambusa tulda* were found to have low strength. There was no appreciable difference in the yield of unbleached pulp from healthy bamboo and bamboo attacked by stain fungi, but the yield of unbleached pulp from bamboo attacked by decay fungi was low. The strength properties of pulp from bamboo attacked by decay fungi were lower than those made from bamboo attacked by stain fungi; which in turn were slightly lower than those made from healthy bamboo (Guha *et al*. 1958 [547]; Guha 1960 [152]; Bakshi *et al*. 1960) [539]. It is not advisable to store bamboos for long periods in warm and humid areas or under conditions favourable for decay. However, if bamboos have to be stored for long periods, storage should be under water or with suitable prophylactic treatment (which should not interfere with pulping) to prevent decay.

Different studies have been reported on flowered bamboo (Bhargava 1945 [136]; Bakshi *et al*. 1968 [540]; Kala 1973 [221]; Dhoundiyal *et al*. 1973) [144]. Flowered bamboo culms are more resistant to beetle attack, may be due to starch depletion. Flowered bamboo, if in sound condition, is equally good for pulping and bleaching.

When *Bambusa polymorpha* and *Cephalostachyum pergracile* were stored for 12 months in piles in the open or submerged in a natural pond, deterioration through stain and rot fungi was severe in the piles kept in the open but negligible in the bamboo kept under water. Neither duration nor method of storage had a great effect on chemical composition and sulphate pulp yields, but some strength properties of the pulp decreased about equally in both methods during storage. Brightness and response to bleaching were better in pulp from water-stored bamboo; this was also confirmed in a limited bleaching trial on mechanical pulp from *B. polymorpha* (Mai-Aung *et al*. 1969) [557].

Purushotham (1970) [561] suggested measures for protection of bamboo against fungal and insect attack at felling and stacking sites. Prophylactic treatment of the raw material while storing outdoors reduced the wood substance loss by 28-30 per cent and pulp yield loss by about 30 per cent (Guha and Chandra 1979) [542]. Kumar *et al*. (1980) [555] reviewed the work done on storage losses and the adverse effect of inadequate protection on strength of paper sheets, bleach consumption and brightness and loss in digester capacity utilization. Possible ways of using effective chemicals for overcoming these problems were also described.

For long-term storage of bamboos in the open, it is recommended that the stacks are put-up on specially prepared ground (above a 10 cm layer of boiler ash and powdered lime sludge containing about 2% BHC) to prevent termite attack. The stacks should be profusely treated during different stages of stack forming and may be covered with treated bamboo mats or thatched grass (Kumar *et al*. 1994) [554]. Treatments must be done in such a way that chemical pollution of the environment is avoided. Stacking methods and treatments depend on the incidences of both fungal and insect attack. For reed bamboos, vertical stacking results in a small gain in pulp yield over horizontal stacking because the former suffers less fungal damage. Monthly treatment with borax – boric acid results in a substantial gain (Gnanaharan *et al*. 1982) [560]. A pest management strategy using minimal application of pesticide is recommended by Nair *et al*. (1983) [560].

Prophylactic treatment with a mixture of sodium pentachlorophenate (NaPCP), boric acid and borax effected a saving of nearly 60 per cent in terms of pulp yield, in green material over a storage period of one year. Treatments should be repeated after 4-6 months, immediately after the monsoons (Kumar *et al*. 1985) [553]. Storing of bamboo (*Bambusa vulgaris*) for relatively long periods (4 months) should be avoided. Air-drying facilitates processing without reducing pulp quality quality (Vivone and Gomide 1985) [474].

Maheshwari *et al*. (1988) [175] described the efficient management of bamboo storage for reducing the cost of paper production. They also described the aspects of optimum inventory of bamboo at different places of storage, proper selection of site for storage, layout of stacks in the yard in compliance with the insurance rules and easy approach for transport system, design of stacks, prevention of fire hazards, preservation of raw materials, etc.

Singh *et al*. (1988) [237] described the problem of decay on storage and its effect on pulp properties. Fungal and borer attacks influence the pulp yield and cause appreciable decrease in strength properties of paper. Prophylactic treatment of bamboos with 2.5 per cent solution of boric acid, borax and sodium pentachlorophenate (1:1:0.5) can effect considerable savings in wood raw materials. Laboratory screening tests on fungicides/insecticides revealed several formulations suitable for field applications (Kumar and Dobriyal 1990) [552]. While advanced fungal attack produces unbleachable pulps, borer attack in epidemic stages reduces the entire stack to powder causing 20-40 per cent volumetric loss. Termites also attack bamboo stacks, which in the absence of adequate protection can suffer losses up to a level of one metre from the ground during one year of storage. Protected bamboos remain sound during storage (Kumar *et al*. 1990) [551].

Apart from the chemical methods of protecting bamboos, some traditional (non-chemical) methods of preservation are also in practice, which include felling bamboos during low sugar content season (August and December - as the sugar content will be higher in spring than in winter); felling bamboos at maturity when sugar content is low (as the sugar content varies with age); post–harvest transpiration of bamboo culms (by keeping culms upright against trees for few days; parenchyma cells in plants continue to live for some time even after felling and during this period the stored food materials are utilized and thus the sugar/starch content in bamboos is lowered), and storing under water for a period of 4-12 weeks (which helps to reduce the starch/sugar content by leaching) (Kumar *et al*. 1994) [554]. It is reported that bamboos harvested during summer are more rapidly deteriorated than those harvested in the rainy season (Liese 1980) [168a]. Kirkpatrick and Simmonds (1958) [549] made an attempt to correlate the natural durability of bamboo with the time of harvesting based on the phases of the moon. But this aspect was never proved beyond doubt and hence remains as a controversial subject.

5.5. Economics of bamboo plantation

Because of the high quality of pulp that can be obtained from bamboo and because of its availability in large quantity at a reasonable price, bamboo was used extensively as raw material in paper industry. In 1950, about 225,000 tonnes of bamboo was used in this industry in India (FRI 1951). The increasingly important role played by bamboo in the development of Indian pulp and paper industry is illustrated by Podder (1959) [14]. From a consumption of 5,830 tonnes in 1924 in India, it rose to 4,50,000 tonnes in 1959. According to the report of Government of India (GOI 1961), bamboo to the level of 70 per cent was used as raw material in pulp industry in 1958–'59. In India, bamboo forests occupy about 10 million ha, roughly about 31 per cent of the total forest area of the country. Average yield of bamboo is 10-15 tonnes per ha per year. With a production of 3.23 million tonnes of bamboo a year, India is second only to China.

The economics of industrial plantations of *Bambusa bambos* (Syn. *B. bambos*), one of the prime/dominant bamboo species in India was described by Bhat (1970) [86]. He determined the standing cost of production of raw material for pulping by raising *B. bambos* as an under-storey crop in the deciduous forests of India, taking into account the establishment and cultural costs. The average physiological life cycle of this bamboo is reported to be 42 years, of which 2 years are spent in nursery. The remaining 40 years can be fixed as the rotation for this species, and the regular cutting cycle begins at around 10 years from planting. Shanmughavel (1995) [190] discussed the and economic aspects (costs and returns from a 6-year-old plantation) of *Bambusa bambos* and suggested that this is an ideal species for commercial plantations.

Kandelaki (1976) [103] described the investigations in Soviet Georgia on the technical and economic feasibility of utilizing home-grown bamboos as raw material in the pulp and paper industry. Selective harvesting of a high yielding plantation of *Phyllostachys edulis* of 3-year- old culms yielded 52.73 tonnes per ha per year (as against 4.5 tonnes per ha per year for a fir plantation and 5.5 tonnes per ha per year for alder). The cost of 1 tonne of bamboo was calculated at 11.77 rubles against 44 rubles for conifer pulpwood grown in Georgia. The pay-back period for a *P. edulis* plantation was 7 years from establishment.

Specific techniques of economic analyses, *ie*, benefit–cost analysis, marginal analysis, budgeting and market research, were suggested by McCormac (1985) [108] viz-a-viz specific bamboo resources and development objectives. Wu and Xu (1987) [240] described the world level economic benefit of paper making with bamboo(Singh 1989) [77] projected the estimated demand for paper and paperboard in India for 2000 and the requirement of bamboo. Xie *et al*. (1999) [242] developed a stand model of pure and mixed plantation of Moso bamboo (*Phyllostachys pubescens*) for pulp. A model for calculating new culm yield of pure Moso bamboo stands was established based on the non-linear relationship between culm yield, and bamboo stand density and culm age components. The best high yield structure for pure Moso stands will have a stand density of 3000 culms per ha and will produce a culm yield of 31.1 tonnes per ha every two years. In mixed Moso and broad leaved tree stands, the most important structural factor influencing productivity was the bamboo and tree density ratio, and the second most important factor was the bamboo standing density. A bamboo standing density of 2100 culms per ha mixed stand will produce 22.8 tonnes per ha of culms every two years. Yang *et al*. (1999) [129] determined the productivity of Moso bamboo stands by habitat and management, with significant differences found between different management regimes, site qualities or status of the original bamboo stand. Yuan *et al*. (1999) [130] suggested a 3-use management system (bamboo shoots, young bamboo for pulping and mature bamboo for wood purpose) for Moso bamboos in China. The new management system was more successful than the usual management for 2-uses (shoot and wood). Detailed data on comparative yield and their economics were provided by them.

6. CHEMICAL COMPOSITION

Information on the **chemical composition** of bamboo is important as far as its utilization for pulping is concerned. Holocellulose (also called hemicelluloses) is the main component contributing to the strength of paper made from bamboo. The high cellulose content and a yield of 40-50 per cent pulp make bamboo an ideal raw material for manufacture of paper. From the angle of paper production, the average chemical composition of bamboo (on OD weight basis) is :

Holocellulose	61 - 71%
Lignin	20 - 30%
Pentosans	16 - 21%
Silica	0.5-4.0%
Ash	1.0-9.0%

The solubility in different solvents are :

Cold water	1.6- 4.6%
Hot water	3.1- 7.0%
Alcohol-benzene	0.3- 7.8%
1% NaOH	15 - 39%

Apart from the high cellulose content, the other factors like high lignin, pentosans and silica contents as well as higher solubilities are not in favour of ideal pulping conditions. But, since it contains higher cellulose content, bamboo is a preferred raw material for pulping.

Bhargava (1945) [136] provided data on the proximate chemical analysis of 10 bamboo species. In *Dendrocalamus strictus*, it was found that the proximate chemical composition varied with locality and also due to flowering.

Bamboo pulps from *Ochlandra abyssinica* and *Oxytenanthera abyssinica* have high alpha-**cellulose** content (Monteiro 1949 [306]; Seabra 1954) [189]. Numerous reports are available on the **chemical composition** of different species of bamboos grown in different countries [for example, Istas and Hontoy (1952) [219] and Istas *et al*. (1956) [159] on the Belgian Congo species *Sasa japonica, S. kurilensis, Bambusa hoffii, B. vulgaris, Gigantochloa aspera* and *Ochlandra travancorica*; Monsalud and Tamolang (1962) [8] on some Philippine species; Tono (1963) [261] on some Japanese bamboos; Nair (1970) [9], Maheshwari *et al*. (1976) [171, 227], Azzini (1976) [366], Bhola (1976) [218], Kandelaki (1977) [103], Guha *et al*. (1980) [452], Karim *et al*. (1994) [407] on the Indian species *Dendrocalamus strictus*, *Bambusa bambos*, *Oxytenanthera monostigma*, *Bambusa vulgaris*, *Bambusa tulda*, *Phyllostachys* spp. and *Melocanna baccifera*; Ku (1971) [165] on Taiwan bamboos including *Bambusa beecheyana* Munro.

var. *pubescens*; Razzaque *et al*. (1981) [233] on the Bangladesh bamboo species *Melocanna baccifera, Oxytenanthera nigrociliata*, *Dendrocalamus longispathus*, *Bambusa tulda* and *Neohouzeaua dullooa*; Xia (1989) [241] on eight Chinese species]. Proximate chemical composition of the two most important Indian bamboos, *viz*., *Dendrocalamus strictus* and *Bambusa bambos* is given in Appendix 3A. No appreciable change in the chemical composition of 3- to 36-month-old Bangladesh bamboos was observed indicating that the bamboo probably attains maturity within its first year of growth (Razzaque *et al*. 1981) [233]. Sekyere (1994) [234] reported that *Bambusa vulgaris* from Ghana had a cellulose content of 61.2 per cent and lignin content of 26.8 per cent indicating its suitability for making good quality pulps. Appendix 3A gives the chemical composition of the two most important Indian bamboo species, *Dendrocalamus strictus* and *Bambusa bambos*.

The **within culm variation of the chemical constituents** is also reported to be significant. In *Bambusa vulgaris*, the basal portion is reported to have the lowest holocellulose content (70.8 %) and highest 1% NaOH solubility (26.5%) as compared to the middle and top portions. Significant interactions were reported between the chemical composition and fibre morphology (Jamaludin and Abdul Jalil 1994 [330]; Jamaludin *et al*. 1994) [331]. Regardless of age and culm height, the high cellulose and low ash content together with fibre characteristics of *Gigantochloa scortechinii* from Malaysia were found beneficial to pulping process (Jamaludin *et al*. 1993 [161]; Abdul Latif Mohamod *et al*. 1994) [324]. Variations in chemical constituents due to age (1- to 6-year-old culms of *Bambusa bambos*) were reported by Shanmughavel (1995) [190].

The **silica** in bamboo causes problems in pulping. Tsuji and Ono (1966) [433] reported the ash and silica contents of 14 tropical bamboo species used for pulping. The Philippine species *Gigantochloa levis, G. aspera, Schizostachyum lumampao, Bambusa blumeana, B. vulgaris* and *B. vulgaris* var. s*triata* are reported to have a higher range of ash and silica content. A positive correlation between the silica content and the specific gravity and cell wall thickness in *Bambusa blumeana* was reported by Espiloy (1982) [280]. Sadwarte and Prasad (1978) [562] described the process of removing silica from bamboo prior to pulping. A **wax** of *Bambusa bambos* culms causing problems in chipping and pulping can be reduced by treatment with steam for two hours. The wax was chemically analysed and found to be of industrially low quality (Beri *et al*. 1967) [135].

The chemical analysis of 3-year-old culms of *Dendrocalamus strictus* revealed that the material contains 64.8 per cent **holocellulose**. The main structural component of the bamboo **hemicelluloses** was reported to be 4-O-methyl glucuronoarabino xylan (Karnik 1960 [296]; Karnik *et al*. 1963) [297]. The hemicellulose of *Dendrocalamus strictus* is reported to be composed of glucuronoxylan having a molecular weight of 6600 containing D-xylose and D-glucuronic acid units in the molar proportion of approximately 9:1 (Ingle and Bose 1969) [293]. The hemicellulose contains 78.0per cent xylose, 9.4 per cent arabinose and 12.8 per cent uronic acid; the acetyl and methoxyl value being nil (Negi 1969 [309]; 1970) [310]. The hemicellulose of *Bambusa bambos* contains 78.8 per cent xylose, 11.6 per cent arabinose and 1.8 per cent galactose (Guha and Pant 1967) [394]. Xylose (82-92% yield) was the main constituent of the hemicelluloses isolated from *Dendrocalamus strictus, D. hamiltonii* and *Melocanna baccifera* (Dhawan and Singh 1982) [278]. Glucose, arabinose, rhamnose and glucuronic acid were also found to be present in small amounts in all the hemicellulose isolates. The yield of sugars was highest in the case of *D. strictus* whereas pentosans and methoxyl content were the highest in the case of *D. hamiltoni, Melocanna baccifera* had the lowest yield of sugars, pentosans and methoxyl content.

As **pentosans** constitute more than 85 per cent of the hemicelluloses, their effect on pulping characteristics is important. The pentosans are reported to be retained in the cellulose pulps even after a final stage of cold-alkali purification with 17.5per cent NaOH. This suggests that there are ‘alkali resistant’ pentosans in close association with the cellulose proper (Negi 1970) [310]. A probable inter-relation between cellulose, lignin and hemicellulose in *Dendrocalamus strictus* is described by Mukherjea and Guha (1971) [307] in their studies on the methods for isolating cellulose from lignin and pentosan components. Once the pentosans are rendered non-resistant, treatment with alkali before chlorite treatment produces pulps with a high content of resistant pentosans whereas chlorite treatment alone makes the pentosans non-resistant to alkali extraction (Guha and Negi 1972) [394]. Maximum amount of alkali resistant pentosans are retained in chlorite pulp and minimum in the sulphate pulp of *Dendrocalamus strictus* (Singh *et al*. 1974) [317]. Biyani *et al*. (1967) [378] obtained a pulp with low pentosan content from *Bambusa bambos* by nitric acid pulping. Prehydrolysis /sulphate process may be the only effective means of removing the pentosans from bamboo chips (at a cost of considerable loss of alpha-cellulose) and thus enabling a dissolving-grade pulp to be obtained (Bawagan 1968) [268]. The pentosans present and ash content of the various bamboos used in India for making rayon pulp were reported by Saboo (1992) [482].

Bamboo **lignin** is a typical grass lignin composed of mixed dehydrogenation polymers of coniferyl, sinapyl and p-coumaryl alcohols. The unique feature of bamboo lignin is that it contains 5-10 per cent ester of p-coumaric acid (Higuchi 1958 [288], Higuchi and Kaivamura 1966) [289]. Lignin of *D. strictus* is found to be composed of two fractions, one carrying high methoxyl value (19%) and the other having low value (2%) (Pant *et al*. 1975) [311]. The former is easily extractable under mild conditions whereas the latter requires drastic conditions. Aldol type side chain (R-CH-(OH)-CH_2-CHO) and presence of bivanillyl structure with alpha-alpha linkage and 1-(4-hydroxy-3-methoxy)-3 hydroxy propane-1-one have been suggested for the bamboo lignin. Vanillic acid, vanillin and syringaldehyde are present as terminal moieties and are linked through beta-position of side chain of the main precursors via carboxylic acid group (Bist *et al*. 1974 [275]; 1975 [276]; Sabharwal *et al*. 1962) [313].

The difference in the lignin content of different species of Indian bamboos is reported to be negligible (24 ± 3%). The structure of bamboo lignin is more similar to hardwood lignin than that to conifer lignin. There is a correlation between the number of C 9 units of different bamboos and breaking length of the beaten pulps. Prehydrolysis of *Dendrocalamus strictus* will lead to decreased pulp yield at higher pH and at more cooking time. The lignin yield from prehydrolysate decreases as the pH goes towards acidic side. The methoxyl content in isolated lignin decreases with increase of lignin yield, while total hydroxyl increases. The acidic and aqueous lignins are less condensed than soda lignin. The chemical characteristics of milled lignin from *Ochlandra travancorica* and the C, H, O and S content of *Dendrocalamus giganteus* lignin and their functional groups (methoxyl, hydroxyl and carboxylic) and correlations between these and on the oxidation products of the lignins are also reported (Kapoor and Guha 1984 [295]; Vijan and Madan 1996) [263]. Clear differences in the structure exist between lignin isolates from sound and flowered bamboos.

The **extractive contents** of *Dendrocalamus strictus* and their effect on sizing were described by Rao *et al*. (1983) [469]. The removal of extractive components will improve sizing substantially. The presence of oleic acid and its derivatives in the extractives are attributed to be responsible for this effect. Glucose and starch contents were higher in samples from middle and upper portions of the culms of 1-, 3- and 5-year-old *Bambusa vulgaris vulgaris* (Azzini *et al*. 1987) [266]. Fengal and Shao (1984) [244] reported 2.6 per cent extractives, 25.5 per cent lignin, 15.3 per cent alpha-cellulose and 24.3 per cent polyoses in *Phyllostachys makinioi*. The main polyoses are arabinoxylan with xylose : arabinose ratio of about 17 : 1. **Ultra structure** revealed through electron micrographic studies shows a lamellar deposition of lignin and polyoses within the secondary walls. Lignin is soluble by parts in alkaline as well as in acidic reagents. Sodium hydroxide solution removes cell wall substance mainly from secondary walls, whereas trifluoro acetic acid removes substance from compound middle lamellae. Wang and Lirn (1984) [438], in their study on the high yield pulping of bamboo waste (shavings and nodes of *Dendrocalamus latiflorus, Phyllostachys edulis* and *Phyllostachys makinoi)* using neutral sulphite- anthraquinone process reported that the **ash** and extractive contents of bamboo wastes were higher than those of wood. Lignin content was lower than that of softwood, but similar to that of hardwood. The lignin content of *Phyllostachys edulis* was the highest.

The **nodal and internodal portions** of bamboo culm differ in their chemical constituents. Internodal portion of *Dendrocalamus strictus* has higher holocellulose and lower lignin, pentosans, extractives and ash compared to its nodal portion (Maheshwari and Satpathy 1988) [175]. The contents of chemical components in *Gigantochloa scortechinii* increase with **age and height level** of the culms, but the correlation is insignificant (Abdul Latif *et al*. 1994) [324]. Regardless of age and culm height, the high cellulose content of this species makes it suitable for pulping.

7. FIBRE MORPHOLOGY

Fibre length of bamboo is generally greater than that of hardwoods. The fibre morphology of 12 bamboo species from India showed a mean fibre length ranging from 1.01 to 4.03 mm (Bhargava 1945) [136]. Various studies have been reported on the fibre dimensions of different bamboo species from different countries and their suitability for commercial pulping [Seabra (1954) [189] on some African bamboos; Istas *et al*. (1956) [159] ten species from Belgian Congo; Du (1957) [386] on seven Taiwan species including *Sinocalamus latiflorus* having the longest fibre; Ku (1971) [165] on the Thailand species *Bambusa beecheyana* Munro var. *pubescens;* and on the Indian species *Bambusa vulgaris*, *Dendrocalamus strictus*, *Oxytenanthera monostigma* and *Melocanna baccifera* by Maheshwari *et al*. (1976a) [227], Azzini (1976) [366] and Guha *et al*. (1980) [457]]. Varshney (1965) [262] reported the effect of anatomical characteristics of bamboos on pulping. The quality of the cook, especially the mechanical properties of the pulp are determined by the degree of impregnation of cooking chemicals in the chips, the diffusion rate during cooking and the amount of screen rejects and by the residual parenchyma and ray cells. Pulps made from different species of bamboo show less variation than expected (Grant 1962) [37]. The fibre content was found to increase with culm height and decrease from outer to inner part of the culms in *Phyllostachys reticulata* of age 1-6 years (Kitamura 1962) [332]. But, the variation in parenchyma proportion in this species due to age was not significant. The parenchyma proportion in *Phyllostachys reticulata* was very close to that of *Dendrocalamus strictus* Singh *et al*. (1971) [354]. In general, it is therefore probable that parenchyma proportion in different species varies within narrow limits only; fibre dimensions, however, vary widely in different species (Monsalud 1965) [338].

Chu and Yao (1964) [326] provided details on the fibre length, cell wall thickness and percentage of fibres and other elements of 33 Chinese bamboo species and classified these bamboos on the basis of fibre characteristics for pulp and paper. Out of these, 21 species were found promising for yielding high quality pulp. Later, Xia (1989) [241] reported the fibre length of eight Chinese bamboo species. The fibre dimensions, flexibility coefficients, Runkel and slenderness ratios of four Thai bamboo species were described by Premrasmi and Aranyaputi (1965) [63]. Monsalud (1965) [338] described the fibre characteristics of 13 Philippine bamboo species. Unlike woods, fibre dimensions or their derived values are not useful in classifying bamboos. The fibre dimensions of some Philippine bamboos for long fibred paper pulps were described by Tamolang (1962) [355], Monsalud and Tamolang (1962) [8] and Zamuco (1972) [359]. The morphological as well as chemical composition and suitability for pulping of various bamboo species as well as pulping processes were reviewed by Ukil (1961) [203] and Witkoski (1964) [210].

Within a culm, the proportion of different cell types shows a regular pattern from interior towards periphery within the wall as well as from base to top (Liese and Mende 1969). But, between species *Dendrocalamus strictus* and *Bambusa tulda*, the variation in parenchyma proportion is found not significant. With increasing height, the amount of parenchyma cells decreases with corresponding increase in proportion of fibres.

In brief, a number of domestic bamboos tested for paper pulp have shown a wide variation in the mean fibre and tissue characteristics as given below:

Fibre length	152 0– 4030 μm
Fibre diameter	13.14–19.94 μm
Lumen diameter	2.18 – 9.94 μm
Cell wall thickness	3.71 – 6.16 μm
Parenchyma proportion	17.1 – 26.9%

Singh *et al*. (1976 [353]; 1988) [237] described the fibre morphology of 12 Indian bamboo species (Appendix 3. B). No relationship could be found between fibre characteristics and strength properties of paper, since wide variations existed within species. Because of the variation within species, pulp sheet properties of bamboos could not be predicted from fibre dimensions or chemical composition. Fibre characteristics cannot be used as a criteria for classifying the bamboos for paper and pulp production. Fibre length is generally considered to be an important factor for tearing strength while the l/d ratio is associated with breaking length and burst factor of the wood pulp (Dinwoodie 1965). The average l/d ratio for bamboo is around 180 (Podder 1979) [15].

Studies on fractionated pulp of *Dendrocalamus strictus* have shown a highly negative correlation between parenchyma proportion and pulp sheet properties. However, along with fibre length, parenchyma proportion accounted for 94 per cent of the variation in the strength properties of the sheets (Singh *et al*. 1976) [534]. Within clump, variation of fibre length was reported for 12 Indian bamboo species (Pattanath 1972) [346]. While the fibre length in the lower portion of the culm is more than that at higher levels, the pattern of variation differs from species to species. Fibre length also does not show any consistent relationship with internode length. Variations have also been reported from outside to inside in bamboo walls (Liese and Grosser 1972) [336]. Thus, bamboo should be regarded as a physically heterogeneous mixture of fibres. A positive correlation between cell wall thickness, silica content, and specific gravity is reported in Philippine bamboos (Espiloy 1982) [280].

Based on the values of Runkel ratio obtained, Wai and Murakami (1984) [356] categorized different species from Myanmmar into groups A, B and C. Group A contains species having a substantial number of thin walled fibres (eg, *Melocanna baccifera*), group B contains a small number of thin walled fibres (eg. *Bambusa polymorpha* and *Dendrocalamus membranaceus*) and group C consists almost entirely of thick walled fibres with very small lumen (eg. *Cephalostachyum pergracile, Bambusa tulda* and *Dendrocalamus longispathus*). This grouping was very useful in evaluating and explaining the sheet properties. The influence of fibre morphology on sheet properties was much greater in the fines-free pulp sheets than in the whole pulp sheets. The sheets of group A pulp were denser and had significantly better strength properties, except for tear index, than the sheets of other pulp groups of the same beating levels. The small amount of thin-walled fibres contributed to the burst index and the folding endurance of the group B fines-free pulp sheets.

Data on the variation in fibre length, diameter, cell wall thickness and Runkel ratio of five bamboo species from Bangaladesh (*Melocanna baccifera, Oxytenanthera nigrociliata, Dendrocalamus longispathus, Bambusa tulda* and *Neohouzeaua dulooa*) with age revealed no appreciable changes in fibre dimensions with increasing age (from 3 - 36 months), indicating that the species probably attain maturity within their first year of growth (Razzaque and Siddique 1970) [68]. The fibre dimensions (average fibre length, diameter and cell wall thickness) and values derived from these (Runkel ratio, flexibility coefficient and relative fibre length) of 13 Bangladesh bamboo species were reported by Siddique and Chowdhury (1982) [352], out of which three species were found very much suitable for paper making. Studies on the effect of parenchyma cell content on the characteristics and properties of kraft pulp from *Bambusa vulgaris* with an optimum degree of delignification revealed that the presence of parenchyma cells will greatly reduce the pulp strength (Gomide *et al*. 1985) [248].

Significant within culm variations in fibre properties such as cell wall thickness, fibre length and slenderness ratio have been reported for *Bambusa vulgaris* (Jamaludin and Abdul Jalil 1991) [330]. The basal portion is reported to have the longest fibres (3.51 mm) and highest slenderness ratio (245.0) compared to the middle and top portions. Studies on the fibre morphology of 1to 3-year-old *Gigantochloa scortechinii* from Malaysia showed that the fibres were long to about 3.0-5.0 mm with thick cell wall of 7 microns. The high Runkel ratio and low flexibility coefficient of this species indicated its undesirability for paper making; however, its long fibres with high slenderness ratio and high holocellulose content make the species suitable for paper pulp production (Jamaludin *et al*. 1993 [161]; Abdul Latif *et al*.1994 [324]; Abdul Latif and Mohamod Tamizi 1992). Within culm variation as well as variations due to age in the anatomical properties of *Bambusa vulgaris, Bambusa blumeana* and *Gigantochloa scortechinii* from Malaysia were reported by Abdul Latif and Mohamod Tamizi (1992). The fibre dimensions (except fibre wall thickness and Runkel and l /d ratios) increased with age. A fibre length of 2.65 mm with Runkel ratio of 1.03 reported for *Bambusa vulgaris* from China indicates its suitability for pulp and paper making (Sekyere 1994) [234]. The variations in fibre dimensions of *Bambusa vulgaris* from Malaysia based on a detailed study on 50 mature culms are also available (Jamaludin *et al*. 1994) [331].

The fibre properties of 22 Chinese bamboo species were described by Zhang (1995) [214]. Xia and Zeng (1996) [358] described the fibre length, fibre width, cell wall thickness and cavity diameter of *Bambusa distegus*. The fibre length and cell wall thickness increased with age, while cavity diameter decreased.

The fibre length and percentage content of +50, +65, +100 and –100 mesh fibres in both bleached and unbleached fibres from *Bambusa bambos* increased with age (Shanmughavel and Francis 1996) [350].. This result indicates that the species attains maturity during the first year of growth, so that for pulping purpose a 1-year cutting cycle can be followed. The finding of Mazzei and Rediko (1967) [179] that 1-year- old culms of *Bambusa vulgaris* gave the best pulp, is also in support of the suggested 1-year cutting cycle. These confirm the conclusion of Siddique and Chowdhury (1982) [352]. A comparison between 10 Indian bamboo species from a natural stand and two species from plantations on fibre dimensions did not reveal any significant correlations between fibre length, diameter and wall thickness. There was only a minimal increase in fibre length with increasing age of plantation grown *Bambusa bambos* (Shanmughavel and Francis 1998) [351]. However, there was a significant difference in fibre length across the culms.

8. TYPES OF PULP

Investigations for utilizing bamboo for different types of pulps started in the early 1890s (Sindall 1909 [192]; Vincent 1911 [205]; Pearson 1912 [186]; Raitt 1912 [231]; Bhargava and Singh 1942) [26,137]. *Bambusa bambos* and *Dendrocalamus strictus* were reported to be suitable for the production of rayon pulp (Karnik and Sen 1948) [480]. The preparation of dissolving pulp from bamboo was described by Jogleker and Donofrio (1951) [162]. The use of *Phyllostachys bambusoides* of not more than 15 years of age from Savannah as a raw material for the preparation of dissolving grade pulp by prehydrolysis and sulphate pulping was described by Nafziger *et al*. (1960) [417]. This species was also suggested for producing newsprint from chemical, semi-chemical and mechanical pulps. Dissolving pulp from *Melocanna bambusoides* was prepared by prehydrolysis sulphate process (Oye and Mizuno 1970) [421]. From *Ochlandra travancorica,* viscose rayon grade pulp was prepared by prehydrolysis sulphate process (Bhat and Viramani 1961) [475]. Prehydrolysis cooking of bamboos at 160 – 165 ^{0} C for 4 hours followed by sulphate cooking at 160 ^{0} C for 2 hours with a total sodium hydroxide 20 per cent and sulphidity 20 per cent, were suggested for the preparation of dissolving grade pulp (Tsuji *et al*. 1965) [432]. With these prehydrolysis conditions, pentosans were less than 5 per cent. The average degree of polymerisation compared favourably with that of similar pulps from wood. In comparison with wood, bamboo pulp has a higher rate of depolymerisation during aging, low cold-alkali solubility but comparatively high hot-alkali solubility, and a similar degree of crystallinity, but a higher rate of acid hydrolysis and lower levelling of degree of polymerisation (Oye and Mizuno 1970) [421]. The chemical properties and filterabilities of viscose showed no great difference from those of wood. *Bambusa bambos* was found superior to *Phyllostachys reticulata* in polymerisation and yield.

Bamboo dust (wastes) can also be used for rayon and paper grade pulps and the process is described by Gupta and Jain (1966) [477]. Improved sulphate pulping procedures for preparing dissolving grade pulp from *Dendrocalamus strictus* (in which nearly 25% of the total lignin is held in the lumen and between the primary and secondary walls of the fibres) are described by Pande (1966 [523, 524]; 1967 [525]). The manufacture of dissolving pulp from the Chinese bamboos *Sinocalamus latiflorus* and *Bambusa stenostachya* was described by Chang and Kuo (1976) [382]. The role of bamboos in the industrial manufacture of rayon grade pulp as well as a general picture of the process of industrial manufacturing of dissolving grade pulp from bamboo was described by Saboo (1992) [482].

Nitric acid pulping of bamboo for making paper-grade pulp from *Bambusa bambos* yielded highest screened pulp (40.9%) as obtained by cooking with 10 per cent nitric acid at 80^0 C for 6 hours and extracting with 1 per cent sodium hydroxide at 120 ^{0}C for 1 hour (Biyani *et al*. 1967) [378]. In view of the low pentosan content of the pulp, the process is promising.

High-yield and good quality pulp, especially with regard to tearing strength suitable for paper making, can be produced from *Bambusa vulgaris, B. vulgaris* var. *vittata* and *B. tuldoides,* the most common bamboos found in Southern Brazil (Mazzei *et al*. 1967) [179]. One-year-old culms gave the best result. Indian bamboos were reported to be suitable for high-yield refiner mechanical pulping (Eberhardt 1968) [362]. Escolano and Semana (1970) [147] reported the suitability of *Bambusa vulgaris* sulphate pulp for paper. On the basis of the quality of pulp, optimum conditions for producing kraft pulp from *Oxytenanthera ritcheyi* were described by Bhandari (1981) [445]. Similarly, the cooking conditions for producing bamboo + mixed hardwood pulps were also reported (Bhargava *et al*. 1985) [217].

9. PULPING

Tissot (1970) [198], on the basis of a study of four Indian mills, discussed the problem of making pulp and paper from bamboo. The cooking processes used (kraft, sulphite and neutral sulphite) and the bleaching and refining procedures followed were reviewed. He suggested solutions to overcome problems of blade wear due to the presence of silica.

An account of investigations carried out on the pulping of bamboos at FRI, Dehra Dun, India, from 1860 to 1944 was described by Bhargava (1945) [136]. Data on the semi-commercial pulping tests of *Dendrocalamus strictus*, *D. hamiltonii*, *D. longispathus*, *Melocanna bambusoides*, *Bambusa bambos*, *B. polymorpha*, *B. tulda*, *Ochlandra travancorica*, *Oxytenanthera nigrociliata* and *Teinostachyum dulooa* were provided in this report. Later, Singh and Mukherjea (1965) [79] summarised the results of 50 years of work at the FRI, Dehra Dun, India, on the pulping of various indigenous materials, including bamboos. Guha and Pant (1972) [6] reviewed the work carried out at FRI, Dehra Dun since 1964 on various indigenous materials for pulp, paper and board industry including bamboos, reeds, grasses and agricultural residues. Singh and Guha (1981) [194] reviewed the research carried out on pulping, bleaching and paper making from different bamboo species occurring in India.

9.1. Mechanical pulping

The mechanical pulping of bamboo was reported by Bhat and Viramani (1957) [273] and they showed that the newsprint prepared from the furnish of groundwood pulp and chemical pulp in the ratio 70:30 was as strong as the then imported newsprint.

9.1.1. Thermo-mechanical pulping

Soda thermo-mechanical (STM) and soda sulphite thermo-mechanical (SSTM) pulp from bamboo (*Dendrocalamus strictus*) was prepared from pre-impregnated chips, using a 10 per cent solution of NaOH and a mixture of NaOH and sodium sulphite in the ratio of 4:1 separately, respectively. Impregnated chips were heated at 120 ^{0}C steam temperature for 3 minutes (Singh *et al*. 1987) [318].

9.1.2. Chemi-mechanical pulping

Mukherjea and Guha (1965) [416] described a newly developed chemi-mechanical high-yield process used at FRI, Dehra Dun, India for pulping non-wood forest products including bamboos. The resultant pulps are reported to be suitable for preparing newsprint, writing, printing and grease-proof papers.

9.2. Chemical pulping

Bamboo pulp has been used in India from the beginning of the last century for making a variety of papers (Anonymous 1915). It was the **Raitt process** that was employed in those days for the pulping of bamboo in India (Raitt 1912 [231], 1925 & 1931) [424]. Digesting methods defers according to the different pulp characteristics desired (Tutiya and Imai 1940 [202]; Kato 1955) [408, 409]. *Dendrocalamus strictus*, *Bambusa bambos* and reed bamboo are the preferred species that were subjected to pulping by various chemical processes (Ahamed and Karnik 1944) [265]. Addition of sodium aluminate as an auxiliary was found to increase the alpha-cellulose content of the pulp, but the ash content was increased. An important factor in bamboo pulping is to achieve good penetration of the cooking chemicals into the bamboo tissue. This difficulty is caused by the presence of an impenetrable epidermis and strong bundle sheaths as well as the limited area of conducting channels and complete absence of rays (Despande 1953) [143a]. Severe mechanical crushing of the bamboo and chipping to short particles were suggested as the means of resolving this problem. Pressure impregnation cooking developed later improved the quality of pulps (Istas *et al*. 1956) [159].

Belvin (1957) [25] described the research efforts in bamboo pulping in South America. The process of making the "Joss" paper (ceremonial paper) from *Bambusa stenostachya*, *B. oldhamii, Dendrocalamus latiflorus* and *Phyllostachys pubescens* in China was described by Perdue *et al*. (1961) [363].

9.2.1. Alkaline pulping processes

9.2.1.1. Soda pulping

Gremler and McGovern (1960) [391] reviewed the history of cold-soda pulping, emphasizing the various continuous methods used. Pulping *Bambusa polymorpha* showed that short impregnation periods would result in completely defibrated pulp and high freeness. Good quality hand-made paper was produced from the cold- soda bamboo pulp (Rao *et al*. 1962) [364]. Later, Nicholas and Navarro (1964) [419] evaluated the cold-soda pulps from some Philippine bamboos. The characteristics of unbleached bamboo cold-soda pulp was described by Islam *et al*. (1989) [511] (Appendix 5.B).

Sulphite process being the best and soda process the poorest for pulping bamboo, Devgan (1964) [425] suggested the incorporation of 2 per cent elemental sulphur in the soda-cooking of *Dendrocalamus strictus*.. The kinetics of alkaline pulping of *Dendrocalamus strictus* was described by Singh and Guha (1975) [429]. Up to a yield level of 70 per cent there was a linear correlation between the lignin content and kappa number as well as between lignin- carbohydrate ratio and yield. Regression equations were also developed for these parameters.

9.2.1.2. Kraft (sulphate) pulping

A kraft cooking conditions of 20-22 per cent alkali, 25 per cent sulphidity, 162-177 ^{0}C temperature and 5-6 hours cooking time for the pulping of culms of all ages in a mixture including nodes, were used initially (Raitt 1912) [231]. A fractional method of digestion was developed later which involved 10 per cent total alkali on air-dry bamboos at a concentration of 2 per cent alkali for 2 hours at 115-121 ^{0}C for the first stage followed by a second stage consisting of a total alkali of 18 per cent on air-dry bamboo at a concentration of 6 per cent cooking liquor for 3 hours treatment at 150 ^{0}C. The spent liquor from the second stage of digestion was used for the first stage. The pre-cook could be considered as buffered soaking at high temperature, to achieve penetration without damage to the carbohydrates prior to the actual cooking reactions. Yield of 45-50 per cent unbleached pulps was obtained. The sulphate pulping of reed bamboo was reported to produce 92.7 per cent alpha-cellulose (Anonymous 1947). The requirements of alkali charges for the unbleached and bleached grades of bamboo pulp at temperatures of 160-170 ^{0}C for several hours were described by Anonymous (1949) and Sproull (1955) [472a]. *Bambusa vulgaris* from Mexico was reported to be suitable for kraft pulping (Carrasco and Salvador 1961) [30]. The giant Philippine bamboo *Gigantochloa aspera* was reported to produce sulphate pulps of excellent tearing strength (Monsalud 1964) [58]. By maintaining optimum conditions for sulphate cooking, it was possible to obtain good quality kraft pulp with a yield of 45 per cent from *Neohouzeaua dulooa* (Nepenin and Bang 1969) [467]. The kraft/sulphate pulps were darker and hard to bleach, but were strong enough for packaging products. Later, Kadarisman and Silitonga (1974) [405] described the sulphate pulping of some South-East Asian bamboos. Sulphate pulping of *Dendrocalamus giganteus* was tried and results were compared with those of *D. strictus*, the main species of bamboo used for pulp and paper in India. *D. giganteus* is a better raw material for both unbleached and bleached pulps (Guha *et al*. 1975) [41]. Unbleached pulp from *Bambusa tulda by* kraft process can be produced with a yield of up to 44.1 per cent the species is suitable for the manufacture of wrapping, writing and printing papers (Bhola 1976) [218].

9.2.1.3. Kraft-anthraquinone (AQ) pulping

Anthraquinone (AQ) can act as a pulping catalyst and increase the rate of delignification and the alkali demand. Low sulphidity (15%) kraft pulping of muli bamboo (*Melocanna baccifera*) with anthraquinone (0.05%) increased the pulp yield by 2 per cent of oven-dried bamboo compared with that from low sulphidity kraft pulping alone, and by 0.8 per cent over that of normal (25% sulphidity) kraft pulping (Maheshwari 1979 [464]; Nazak 2*et al*. 1979) [465]. The viscosity of AQ-catalysed low sulphidity kraft pulps was almost equal to that of the normal kraft control and better than that of the pulp from low sulphidity (15%) kraft pulping alone. Burst, tear and tensile strength properties were almost the same as or better than that of pulp obtained in normal kraft pulping. The use of AQ is therefore, not only beneficial at low sulphidity in improving the yield and quality of the pulp but it will also lead to reduction of air pollution because of the lower sulphidity input (Bhowmick *et al*. 1991 [376, 447]; 1992) [449] . A tentative economic analysis of kraft and soda-anthraquinone pulping of muli bamboo showed that better benefits could be achieved in soda + AQ pulping compared with soda pulping (Goyal and Misra 1982 [456]; Bhowmick *et al*. 1992) [449]. Bhandari (1981) [445] prepared kraft pulps from *Oxytenanthera ritcheyi* by three different cooking schedules. On the basis of pulp evaluation for various strength properties, kappa number and unbleached pulp yield, optimum pulping conditions, *O. ritcheyi* was a suitable raw material for the production of wrapping and writing /printing papers. Vapour phase kraft pulping of *Dendrocalamus strictus* was described by Goyal and Misra (1982) [492].

9.2.1.4. High-yield kraft pulping

To improve the pulp yield to about 60-64 per cent, a process for the separation of fibres and parenchyma and separate digestion of both, followed by blending was developed by Vyas *et al*. (n.d.) [435, 436]. In the conventional sulphate pulping process, *Dendrocalamus strictus* containing 35.7 per cent parenchyma and 64.5 per cent fibres gave a yield of 40.5 per cent only. About 91 per cent of original parenchyma contained in the bamboo was lost during the sulphate pulping. The improved process developed for high-yield pulping consisted of mechanically disintegrating bamboo chips for splints to cause cleavage between fibres and parenchyma tissues and separately processing each tissue to pulp. From the mechanically separated fibre fraction chemical pulp was obtained by conventional digestion and beating process. The amount of bleached fibre pulp and parenchyma pulp obtained was the same. On mixing the two pulps, the final yield went up to 60-70 per cent of original bamboo. The pulp was found to be suitable for the production of cheap grade printing paper.

9.2.1.5. Alkaline sulphite pulping

The use of magnesium sulphite for the digestion of bamboo was reported (Tutiya *et al*. 1941) [201] and later 'magnifite' process was reported for *Dendrocalamus latiflorus* (Chao and Pan 1963) [360]. Increased pulp yield, stronger pulp, shorter cooking time and reduced consumption of cooking chemicals, etc. were the advantages of this process. Rydholm (1966) [71] reported the sulphite pulp yield of Dowga bamboo *Bambusa bambos*.

Bamboo chips, after impregnation with 40 per cent Na_2SO_3 for 24 hours and steam cooking for two minutes at 187^0 C (saturated steam pressure 1.26 MPa) was found not capable of producing good quality pulp at ultra-high yield. A combination of Na_2SO_3 with a lower percentage of NaOH was suggested to be a compromise between pulp yield loss and a gain in strength properties (Ray *et al*. 1994) [67].

9.2.1.6. Alkaline sulphite - anthraquinone (AS – AQ) pulping

Pulping bamboo using the alkaline sulphite process, with added anthraquinone facilitated easier pulping at comparatively low cooking temperatures and gave a higher yield, higher pulp brightness and easier bleaching than did kraft pulping (Jauhari and Ghosh 1984) [404]. Addition of 0.1% AQ offered the advantage of producing pulp of low kappa number (originally 25 and 32) with high pulp yield (originally 61and 60 respectively for kappa numbers 25 and 32) and also enabled the cooking temperature to be reduced. Alkaline sulphite-AQ pulping for *Bambusa arundinaceae* was reported by Wang (1982) [439] and *Phyllostachys pubescens* by Yao and Zou (1986) [442].

9.2.1.7. Neutral sulphite semichemical (NSSC) pulping

Unbleached pulps of yield 56-68 per cent and with satisfactory strength properties were prepared from *Dendrocalamus strictus* by the NSSC process (Guha and Pant 1961) [395]. Bleaching of the NSSC pulp achieved 37-44 per cent yield with satisfactory brightness and strength properties for the production of white papers. The suitability of *Bambusa vulgaris* from Mexico for the NSSC pulping was reported by Carrasco and Salvador (1961) [30]. Acid soluble lignin to the extent of 1.5 per cent was reported from the bamboo NSSC pulp (Schowing and Johanson 1965).

Out of the three pulping processes (cold-soda, neutral sulphite-NSSC and sulphate) compared by Chen *et al*. (1973) [383], the NSSC pulps, although the lowest in yield, showed good strength (near that of imported Canadian kraft pulp) and to 72-88 per cent GE brightness by the C-E-H (chlorination /alkali extraction / hypo-chlorite bleaching sequence) schedule. The net yield of 48.3-53.2 per cent for the bleached pulp was well above that obtained from fully cooked pulps. Bamboo NSSC pulps were suitable for high-grade papers.

9.2.1.8. Neutral sulphite – anthraquinone (NS-AQ) pulping

Bose *et al*. (1998) [395] conducted neutral sulphite anthraquinone pulping of muli bamboo in the laboratory. The total yield gain in the NS-AQ process was 6 to 7.9 per cent more than that of the kraft control at kappa number 20. The use of 0.1 per cent AQ was sufficient to give the desired effect. The strength properties of unbleached NS-AQ pulps were lower than those of kraft pulps.

9.2.1.9. Kraft – semichemical pulping

Semichemical pulp with encouraging yield and characteristics from muli bamboo (*Melocanna baccifera*) was obtained by cooking with white liquor from the recovery cycle, *ie*., by adopting the kraft semi-chemical process. The strength properties of the semi-chemical pulp were relatively lower than those of conventional kraft pulp, but it was possible to produce an acceptable grade of pulp under carefully chosen cooking conditions. The yield was higher (72-74%) than that of conventional kraft pulp (45-48 per cent). The optimum limit of sulphidity in kraft (sulphate) pulping of muli bamboo was about 17 per cent, yielding best quality pulp (Alam *et al*. 1997) [365, 443].

9.2.1.10. Rayon grade pulping

Prehydrolysis kraft pulping of bamboo for preparing rayon grade pulp was studied by various authors (Gohel and Thoria 1936; Jogleker and Donofrio 1951 [162]; Horio and Takhama 1958 [477a]; Karnik 1958 [477b] & 1963 [479a]; Karnik and Sen 1958 [480a] and Ramsarma 1962) [481] and carried to the mill scale in the Gwalior, India (Rydholm 1965) [78]. Prehydrolysis kraft pulping of reed has also been investigated (Simionescu *et al*. 1956 [482a]; 1957 [482b] & 1958 [482c]; Ivanov 1957) and carried to the mill scale in Rumania.

Dissolving grade pulp from *Phyllostachys bambusoides* was prepared by prehydrolysis sulphate pulping techniques. Influence of the condition of raw material and different variables in the hydrolytic treatment upon the yield and characteristics of the pulps under constant pulping and bleaching condition was described by Nafziger *et al*. (1960) [417]. *Dendrocalamus strictus* was reported to be suitable for rayon grade pulp by the sulphate prehydrolysis process (Karnik 1961) [478, 479]. Viscose rayon pulp from *Ochlandra travancorica* was prepared by water prehydrolysis sulphate process (Bhat and Viramani 1961) [475]. Dissolving pulp can be prepared by prehydrolysis cooking at 160 or 165 ^{0}C for 4 hours, followed by sulphate cooking at 160 ^{0}C for 2 hours, with total NaOH 20 per cent, and sulphidity 20 per cent. With these prehydrolysis conditions, pentosans were less than 5 per cent. Rayon grade pulp was prepared from *Bambusa bambos*, *Dendrocalamus strictus*, *Melocanna baccifera* and *Ochlandra travancorica* by using prehydrolysis sulphate pulping (followed by multi-stage bleaching sequence consisting of chlorination/ caustic extraction/ hypochlorite/ chlorine dioxide/ SO_2 treatment. Suzuki (1964) [484] reported about a Japanese technique, the 'Kakusapu process', for the preparation of viscose from bamboo. Pulps produced from *B. bambos*, *B. vulgaris* and *B. aurea* (Syn. *B. atrovirens*) using commercial digestion conditions were found not suitable for rayon manufacture (Lele 1964) [480b]. It was found that *Bambusa bambos* was superior to *Phyllostachys reticulata* in polymerisation and yield (Tsuji *et al*. 1965) [432]. Rydholm (1966) [71] reported the data on chemical composition (percentage of extractives, lignin, cellulose and hemicelluloses), sulphite pulp yield, alpha cellulose content and prehydrolysis kraft pulp yield for Dowga bamboo (*Bambusa bambos*). He also described the role of bamboo in India for dissolving pulp industry.

Prehydrolysis may be the only effective means of removing the pentosans from the bamboo chips (though at a cost of considerable loss of alpha-cellulose) and thus enabling a dissolving grade pulp to be obtained (Bawagan 1968) [268]. Among many species evaluated *Bambusa bambos*, *Dendrocalamus* *strictus*, *Melocanna bambusoides* and *Ochlandra travancorica* are commonly utilized for the production of rayon grade pulp (Singh and Bhola 1968) [483]. The relationship between pulping conditions and reactivity of dissolving pulp prepared from bamboo (*Melocanna bambusoides*) by the prehydrolysis sulphate process was examined by Oye *et al*. (1970) [421] and Oye and Mizuno (1972) [423]. Bamboo pulp has lower resistance to mercerisation than hardwood pulp made by similar process and has low resistance to sulphidation. Its filterability is similar to that of wood pulps. Pande (1970) [62] described a promising technique in sulphate pulping that permits the removal of sufficient pentosans to bring the pulp within the limits specified for dissolving grade pulp. The characteristics of rayon grade pulp produced from Indian bamboos were reported by Nair (1970) [9] (Appendix 5.C)

Chang and Kuo (1976) [382] described the manufacturing of dissolving grade pulp from the Chinese bamboos, *Sinocalamus latiflorus* and *Bambusa stenostachya*. Kuang *et al*. (1985) [461] made a comparison of the mercerisation of kraft pulps from bamboo and spruce.

9.3. Non-conventional and other pulping methods

Hydrotropic pulping, as an effort to develop pollution-free pulping processes using sodium xylene sulphonate as solvent, was reported for making bamboo rayon grade pulp. In this method, the bamboo is cut, crushed, dried and then digested by means of a 30-50 per cent solution of aqueous sodium xylene sulphonate at about 160 ^{0}C for 6 hours and at 180 ^{0}C for 7-8 hours. After digestion the pulp is washed in a solution of about 20 per cent sodium xylene sulphonate and bleached. The lignin can be separated from the digestion liquor by adding water and the liquor can be used again. A yield of 46 per cent unbleached pulp was obtained by this process from *Bambusa tulda* and 42 per cent from *Phyllostachys bambusoides*. The pulp had a high cellulose content and was suitable for rayon manufacture (Anonymous 1947).

During hydrotropic pulping of bamboo, a fraction of pentosans is converted to furfural and dissolved in the hydrotropic liquor along with lignin. However, the sum of dissolved furfural and of pentosans remaining in the pulp is less than the pentosan content of bamboo. Approximately 50 per cent of alpha xylose is converted into furfural if the latter does not decompose in the hydrotropic solution. The proportion of converted xylose increases upon addition of acetic acid to the solution and decreases upon addition of lignin (Hasegava and Ito 1959) [287]. Schwenzon (1963 [74]; 1965) [75] reported the possibility of hydrotropic pulping of bamboo, especially using salicylic acid/ glycol at temperature 160-170 ^{0}C for 3-6 hours cooking period.

Organosolv pulping of *Dendrocalamus strictus* using ethanol-water as the delignifying agent results in chemical pulps with yield 43-44 per cent. Use of sodium xylene sulphonate (1.0%) as a pulping additive can improve the strength properties: tensile index by about 5 per cent, tear index 30 per cent and burst index by about 15 per cent, but the tensile index and burst index was lower than that of bamboo kraft pulp of equivalent yield by about 20 per cent and 37 per cent respectively whereas tear index was slightly higher (4.0%). However, use of dodecyl benzene sulphonate sodium salt as pulping additive does not exhibit any significant influence on either type of pulp. Ethanol-water - sodium xylene sulphonate – bamboo pulp gives the best results in respect of strength properties. Sodium xylene sulphonate helps in stabilization of carbohydrates during the process of delignification, as a result of which an improvement in strength properties is observed (Singh *et al.* 1989) [193].

The **chlorination process** is reported to be suitable for the production of bleachable pulp from *Cephalostachyum pergracile* (Mai-Aung 1961) [520]. Mahanta *et al.* (1979) [412] described the **non-sulphur pulping** of bamboo. Maheshwari (1982) [51] described some basic aspects of **high-yield pulping**. A laboratory study conducted by Zafar and Abdullah (1987) [122] indicated that **bio-mechanical pulping** (biological delignification) of bamboo by *Coriolus versicolor* might be possible.

Under some economic considerations, **nitric acid pulping** of bamboo is worth commercial consideration (Bolker and Singh 1965 [379]; Mahanta and Chaliha 1970) [411]. A highest screened pulp yield of 40.9 per cent was obtained in the cooking of *Bambusa bambos* with 10 per cent HNO_3 for 6 hours and extracting with 1 per cent NaOH at 120 ^{0}C for 1 hour. In view of the low pentosan content of the pulp, nitric acid pulping is promising for paper grade pulp (Biyani 1966 [377]; Biyani *et al.* 1967) [378].. Air-dry chips of *Dendrocalamus strictus* were cooked with nitric acid and sodium nitrite and the residual wood was extracted with dilute solution of caustic soda. Addition of sodium nitrite up to a certain extent enhanced the delignification while pulping by nitric acid process. The Klason lignin content, pentosan content and permanganate number of the pulp were found to decrease with increase in concentration of nitric acid and cooking time and temperature (Dhawan 1980) [385]).

Yamagishi *et al.* (1970) [440] delignified the Japanese Sasa bamboos (*Sasa senanensis*) by **peracetic acid pulping** at 70 ^{0}C. The pulp yield was 57.3 per cent, with low lignin content. The brightness of the pulp was high, but the pentosan content was greater than 20 per cent. The pulp was markedly superior in breaking length and burst factor, and slightly superior in tear factor, to a semi-kraft pulp of similar yield and lignin content, while its folding endurance was satisfactory. Microscopic observation revealed fibres with an intact structure accompanied by many small parenchyma cells.

9.4. Effect of variables - Factors affecting pulp yield

Phyllostachys makinoi and six other species were pulped in the Raitt process and the effect of variables such as time, sulphidity, etc. were investigated and yields of 41-47 per cent were obtained

(Du 1957) [386]. Yields of 82 and 62 per cent for cold soda semi-chemical and neutral sulphite pulps respectively were attained from *Phyllostachys bambusoides*, but stone grinding with and without chemical pre-treatment failed to produce satisfactory pulps from the mature culms (Nafziger *et al*. 1961) [417]. The effect of temperature, pressure, alkali strength, and cooking time while pulping *B. bambos*, *B. vulgaris* and *B. aurea* (Syn. *B. atrovirens*) on their alpha cellulose content and optimum conditions for each species was reported by Lele (1964) [480b].

Splitting of the digestion into two stages with an intermediate refining stage will increase the pulp yield of bamboos (Singh *et al*. 1970) [427]. The increase in yield of kraft bamboo pulp from 47.1 to 53.3 per cent is without any significant effect on the strength properties. In the binary pulping process suggested for *Dendrocalamus strictus*, the chips are disintegrated by a kollergang or a refiner and separated by screening into prosenchymatous and parenchymatous tissues. These are pulped separately by the sulphate process or by mechanical process. The pulps of yield 75 per cent (based on OD weight) are then mixed to obtain maximum yield of pulp of acceptable strength. Pulping procedures that give yields of approximately 40-45 per cent bleached chemical pulp from prosenchymatous tissues and approximately 29-35 per cent mechanical pulp from parenchymatous tissues, will help in using pulp mixtures with more than 50 per cent chemical pulp (Mukherjea 1967) [182].. Refiner is more suitable than a kollergang, both for disintegrating chips and for grinding the steamed chips.

Factors affecting the relative yield of sulphate pulp obtainable from bamboo (*Dendrocalamus strictus*) by two different cooking systems were evaluated. An alkaline treatment for the brown stock was also suggested for its high yield pulping (Banthia *et al*. 1972b&c). Mild alkali treatments on hard, moderately hard and normally cooked chemical and semi-chemical pulps of bamboo can produce soft pulps with minimum loss of yield and properties (Banthia *et al*. 1972) [371, 372]. Alkali treatment for *Arundinaria jaunsarensis* (Ringal) at 30 ^{0}C is beneficial as far as the pulp characteristics are concerened. The ash, pentosan and lignin content of the soaked material decreases with increase in cellulose content and in the concentration of alkali in the soaking liquor (Khanduri and Biswas 1960) [410]. Treatment with alkali before chlorite treatment will produce pulp with high content of alkali resistant pentosans whereas chlorite treatment alone will make the pentosans non-resistant to alkali extractions, and once pentosans are rendered non-resistant, it will be difficult to revert them back to resistant pentosans (Guha and Negi 1972) [394].

Kraft sulphate pulp yield from the Taiwan bamboos, *Bambusa beecheyana* var. *pubescens*, *B. dolichoclada*, *B. stenostachya*, *Dendrocalamus latiflorus* and *Phyllostachys makinoi* varied with cooking conditions, from 41 to 47 per cent (Chao and Pan 1972) [452]. Chen *et al* (1974) [361] prepared pulps for printing papers from five species of bamboo by three pulping processes: (a) two-stage digestion with hot water (150^0 C) followed by NaOH; (b) two-stage digestion with dilute NaOH (at 100 ^{0}C) followed by more concentrated NaOH; and (c) single-stage digestion with NaOH. In each trial the pulp was bleached in three stages before testing. Process (a) (2- stage digestion with hot water followed by NaOH) gave the highest yield and best physical properties of pulp and the lowest bleaching ratio, resulting in economical pulping. The pulp with the best physical properties was from *Bambusa beecheyana* var. *pubescens* and *B. dolichoclada* followed by *B. stenostachya* and *Dendrocalamus latiflorus*. *Phyllostachys makinoi* was judged the least suitable. This result about the suitability of these species was in agreement with the earlier findings of Chao and Pan (1972) [452].

The effect of pH on the pre-hydrolysis of *Dendrocalamus strictus* was described by Devi *et al.* (1982) [384]. Chips were cooked in 1per cent H_2SO_4, 10 per cent NaOH or water for 90 or 150 minutes. Pulp yield decreased at higher initial and final pH values and with longer pre-hydrolysis. Kar *et al.* (1987) [406] described the effect of moisture content in the bamboo chips on pulping characteristics.

Strength properties and bleachability of high yield pulp can be improved through chemical modifications of their lignin Singh *et al.* (1987) [318] Soda thermo mechanical (STM) and soda–sulphite thermo mechanical (SSTM) pulps of bamboo can be modified using chlorine, sodium sulphite and hypochlorite.

Alkali consumption, kappa number, unbleached pulp yield and chemical composition of 12 Indian bamboo species and their pulps are described by Singh (1989) [77] (Appendix 5.A)

9.5. Effect of active alkali content

Semana (1965) [426], in his studies on the variables in sulphate pulping of the Philippine bamboo, *Gigantochloa aspera* has shown the interactions of active alkali concentration, kappa number and sulphidity as well as cooking temperatures, pulp yield and pulp strength. A total of 12-24 per cent alkali (based on OD fibre) is sufficient to produce pulp ranging from high kappa numbers (up to 70) suitable for wrapping papers to easily bleachable grades with kappa numbers as low as 12.6. Yields and strength properties of pulps often are practically unaffected within a sulphidity range of 17.0-33.9 per cent. If alkali content drops below 20 per cent, the kappa number will rise when sulphidity exceeded 25.5 per cent. Pulp from bamboo cooked at a maximum temperature of 180 ^{0}C may show similar yields but will have low strength than those digested at 170 ^{0}C. At lower alkali concentrations, 180 ^{0}C cooking will yield pulps with lower kappa number. For making wrapping paper and linear board stock, less than 20 per cent alkali and a maximum temperature of 170 ^{0}C are preferable.

Kraft semichemical pulps with the best physical properties were produced with the use of 15 per cent active alkali, which also enabled the yield to be increased by approximately 5 per cent compared with the conventional sulphate pulp. The kraft semi-chemical pulp was having excellent chemical properties, superior to larch and birch pulps (Ujiie and Matsmoto 1967) [473]. The low yield of bamboo pulp compared with that of hardwoods can be improved at the expense of strength by pulping with only 10 or even 5 per cent active alkali. Sulphate pulp at a screened yield of 41.4 per cent and permanganate number of 15 from *Bambusa vulgaris* was produced using an active alkali of 15.6. Evaluation of the pulp characteristics showed that addition of beater adhesives will yield pulp with improved quality desired for bag and wrapping papers (Escolano and Semana 1970) [147].

To find out to what extent the cooking should be continued in kraft pulping of muli bamboo (*Melocanna baccifera*), the effect of active alkali charge was studied by Shah *et al*. (1991) [472]. The rate of delignification increased with an increase in active alkali charge. The transition points between the initial and bulk, and between the bulk and residual phases shifted to a lower lignin content with an increase in alkali charge. The use of an active alkali charge of 18 per cent as NaOH was sufficient to continue the cook in the delignification phase. Cooking of *Bambusa vulgaris* grown in Ghana with 18 per cent active alkali for 90 minutes yielded 54.2 per cent pulp with kappa number of 48.2 (Sekyere 1994) [234]. From the physical and strength properties of the pulp, it was found that *B. vulgaris* could produce good paper.

9.6. Pulping of mixture of bamboo and hardwoods

The cooking of different species (*M. smithii* and *B. vulgaris*) separately and as mixture and the papers made from both the pulps were described by Istas and Raekelboom (1960) [220]. For the production of unbleached pulps from a mixture of bamboo and mixed hardwoods, the minimum proportion of bamboo required is 50 per cent for good strength properties (Guha *et al*. 1966) [397]. Pilot scale trial production of bleached pulps from a mixture of 50:50 proportion of bamboo and mixed hardwoods at the Bengal Paper Mill, Raniganj, India was carried out under different conditions of sulphate pulping and bleaching. The ideal condition for the sulphate cooking is to use a sulphidity of 25 per cent with total chemicals of 15.5 per cent Na_2O at 170 ^{0}C for 2 hours. A pulp yield of 52 per cent can be achieved with permanganate number 18.8. Good breaking length (5310 m), burst factor (39.4), tear factor (120) and folding endurance (double folds of 240) can be expected.

Studies on sulphate pulping of bamboo and mixed hardwoods showed that satisfactory high- and low-brightness pulps and semi-bleached pulps could be obtained from a 50:50 mixture of bamboo and mixed hardwoods (Singh *et al* 1968) [532]. Bhargava *et al*. (1969) [487] studied the effect of impregnation temperature and alkali concentration on the cooking of mixture of bamboo and mixed hardwoods. For a mixture of 60 per cent *Dendrocalamus strictus* and the remaining portion with hardwood, *Boswellia serrata*, the optimum unbleached pulp yield from chips cooked with 18.5-20 per cent active alkali was obtained at an impregnation temperature of 125 ^{0}C. With higher alkali concentration, a lower impregnation temperature can be used, but the total yield of unbleached pulp will be reduced.

Generally, bamboos and hardwoods have different cooking characteristics. Thus, ideally, it is better to cook separately and then blend the pulps together. Bamboo and a hardwood, *Boswellia serrata,* although grown under the same climatic and soil conditions, had different cooking characteristics; while a better grade pulp with less chemical consumption was produced from bamboo by the 2-stage temperature treatment method, it took a 4- stage impregnation method for *B. serrata*. Bamboo and *B. serrata* should therefore be cooked separately. However, as the total bleach demand of the two pulps produced by the same method of cooking to the same kappa number level is very similar, pulps can be mixed together and bleached (Mishra and Rao 1969) [57].

Guha and Sharma (1970) [38] compared the chemical pulping of the hardwood, *Casuarina equisetifolia* with the bamboo *Dendrocalamus strictus*. They produced wrapping paper from unbleached pulps of *C. equisetifolia*, bamboo and a 75:25 mixture of the two. Yield and strength properties were higher for the hardwood pulp, but it was not suitable for mechanical pulps. Pasaribu and Silitonga (1974) [497] reported on trials of sulphate process of a 3-component mixture of hardwoods and four bamboo species (*Bambusa bambos*, *B. vulgaris*, *Dendrocalamus asper* and G*igantochloa ater*). Cooking conditions were recommended for mixed pulping of bamboos with hardwoods. The strength properties of pulps containing different component ratios are also discussed.

Barrichello and Foelkel (1975) [374] briefly described the Kleinert's rapid alkaline pulping process and gave the results of an experiment on the use of this method in the production of chemical pulp from *Bambusa vulgaris* var. *vittata* in Sao Paulo, Brazil. Pulp yields and strengths comparable with those obtained by the normal sulphate process were achieved, and there were savings in time and energy. They further found that in the case of blends containing 5 and 10 per cent bamboo (on total chip weight basis) with the hardwood *Eucalyptus saligna*, pulps were superior in yield and tear strength than the pulp from *E. saligna,* alone. There was no difference between the pulps in beating time, hand sheet density, tensile and burst strengths (Barrichello and Foelkel 1975) [373].

Satisfactory kraft pulps have been obtained with (a) 70 per cent bamboo (*Dendrocalamus strictus*), 15 per cent Mysore gum (*Eucalyptus tereticornis*) and 15 per cent dadup (*Erythrina suberosa*) and (b) 50 per cent bamboo, 20 per cent *Acacia arabica*, 15 per cent Mysore gum and 15 per cent dadup (Krishnamachari *et al*. 1975) [48]. Alternatively, from a furnish containing 30 per cent chemical pulp from *Ochlandra travancorica* and 70 per cent stone groundwood/ refiner mechanical/ cold-soda/ sulphate pulp from stored and fresh *Eucalyptus* hybrid (Mysore gum), yielded newsprint of satisfactory strength properties (Guha *et al*. 1975) [41]. The preparation of mixed pulps from bamboos and hardwoods was described by Rai and Jaspal (1976) [498] also. Guha *et al*. (1980) [42] studied the yield and properties of pulps from bamboo (*Dendrocalamus strictus*) combined with different proportions of mixed hardwoods. They found that increase in the percentage of hardwood slightly increased the yield and but decreased the strength properties. Mixed pulps had satisfactory properties for the manufacture of writing, printing and wrapping paper and 3- layer board. Singh *et al*. (1981) [78] took *Dendrocalamus strictus*'s pulpability suitability index as 100 and compared its pulping characteristics with hardwoods, whose suitability indices was 100 + /- 15, for wrapping and writing /printing papers. Cold-soda pulps mixed with bamboo sulphate pulp in the ratio of 4:1 appeared suitable for newsprint. A mixture containing 30 or 40 per cent bamboo residue along with mixed hardwoods was also reported to give satisfactory sulphate pulp yield with good strength properties (Chiou and Tsai 1982) [489]. Dwivedi *et al*. (1983) [490] described the high yield semi-chemical pulping of a mixture of bamboo and hardwoods.

Small dosage addition of anthraquinone (AQ) in the kraft pulping of bamboos with mixed tropical hardwoods was reported to be beneficial (Nazak *et al*. 1979) [466]. Comparison of kraft pulping at 17 per cent sulphidity on bamboo + mixed hardwoods (70:30) with bamboo (100 per cent) and mixed hardwoods (100 per cent) using anthraquinone revealed that anthraquinone addition in kraft pulping liquor is beneficial for the economy of pulping bamboo and tropical mixed hardwoods (Goyal and Misra 1982 [492]; Rawath *et al*. 1985) [470]. A test case showed that the cost of pulp production could be reduced by Rs. 80/- tonne for bamboo and tropical mixed hardwoods in a medium sized pulp mill. Addition of different AQ dosages (0.05 to 0.25%) led to the reduction of the kappa number of bamboo+mixed hardwood pulp. Anthraquinone addition further helped to reduce the bleach consumption and improved the strength properties. AQ in small dosage (0.05%) is more effective in improving the yield of bamboo + mixed hardwood (70:30) digested at lower kappa number.

Increasing the sulphidity from 0 to 20 per cent increased the pulp yield, reduced the rejects percentage and generally improved the strength properties. The effects were greatest in the 60:40 mixture of bamboo and mixed hardwoods and least in bamboo alone. Optimum sulphidity was 16 per cent for bamboo and 18 per cent for bamboo/mixed hardwoods (Mishra *et al*. 1984) [415]. It was reported that bamboos needed only lesser alkali than hardwoods for producing bleachable pulps. It was also found that pulps in higher yield can be produced by separate digestion of bamboos and mixed hardwoods (Bhargava *et al*. 1985) [217]. Mixed hardwoods, to 20 per cent in the mixed furnish, had no detrimental effect on pulping quality and the physical and strength properties.

As it will be expensive to have separate streams for the cooking of bamboo and hardwoods, the feasibility of pulping them together was investigated in a 50:50 mixture. Encouraging results were obtained in the laboratory as well as pilot-plant trails. The investigation revealed that as the percentage of hardwoods in the mixture increased, the breaking length improved, burst factor improved slightly; tear factor and double folds decreased with the increase in the amount of hardwoods (Singh 1989) [193].

9.7. Effect of age, position of culm and nodes

Kitamura (1962) [332] described the variation in fibre content of 1- to 6-year-old *Phyllostachys reticulata* after pulping by soda process. Age played no significant part, but fibre content was found to increase with culm height and to decrease from outer to the inner parts of the culms. Culms (from 15-year-old clumps at Campinas, Brazil) ranging from 1 to 4 years in age were pulped by soda process. The effect of culm age on pulp yield was significant at the 5 per cent level for 2-year-old culms only. No effects on tearing, tensile or folding strength could be attributed to culm age. Paper from 2-year-old culms, however, had a significantly higher bursting strength. Pulps were in general highly porous. *Bambusa vulgaris* can produce paper of good quality, resembling that from unbleached kraft soft wood pulp in tearing strength. From the industrial viewpoint, no advantage is gained by selecting culms of a particular age (Medina and Ciaramello 1965) [181]. Processing variables in pulping, age and decay at the time of processing cause variation in the quality of sulphate pulp (Gopal 1968) [505].

Maheshwari and Satpathy (1984) [174] reported the pulp and paper making characteristics of bamboos of different ages. The pulp from young culms of sasa bamboo (*Sasa kurilensis*) was comparable with that of sulphite pulps of full-grown culms (Ujiie *et al*. 1986) [239]. In a study using 1-, 3-, or 5-year-old *Bambusa vulgaris* culms, shredded and treated with dilute H_2SO_4, fibre yield for paper making was higher in younger culms (Azzini *et al*. 1987) [266]. No appreciable changes in pulp yields and strength properties could be found with increasing the age of bamboos (*Melocanna baccifera*, *Oxytenathera nigrociliata*, *Dendrocalamus longispathus*, *Bambusa tulda* and *Neohouzeaua dulooa*) from Bangladesh, taken at three months intervals from 3 to 36 months (Razzaque *et al*. 1981) [233]. Subjecting *Bambusa bambos* of 1- to 6- years of age separately for pulping and evaluation of their characteristics indicated that this species attains maturity during the first year of growth, so that for pulping purposes, it is suitable for a 1-year cutting cycle (Shanmughavel and Francis 1996) [350]. As bamboos probably attain maturity within their first year of growth, a 12- month cutting cycle can be recommended for pulping material.

Muli bamboo belonging to four age groups (9, 21, 33 and 45 months) from Bangladesh was kraft pulped. A bleachable grade pulp was obtained at lower cooking times with 9-month-old bamboo than with older ones. The pulp yield at a given point of delignification was highest with 21-month-old bamboo. The strength properties of the pulp were independent of age Bose *et al*. 1988) [451]. The pulping properties of bamboos of different ages were investigated by Xia (1989) [241] also. It was found that 1- to 2-year-old bamboos were suitable for pulping. The pulping characteristics of bamboos of different ages and different portions of the culms of a few common varieties are described by Maheshwari and Satpathy (1983 [172] & 1990) [228]. Jamaludin *et al*. (1992) [161] reported the effect of age, active alkali and beating revolutions on the pulping characteristics of 1- to 3-year-old *Gigantochloa scortechinii*. The pulp properties of 1- to 3-year-old bamboos show satisfactory strength properties. Variations of fibre morphology and chemical constituents of *Gigantochloa scortechinii* due to position in the culm (within culm), between culms, and age (1-, 2-, 3-year-old) revealed that the fibre dimensions increased with age and decreased with height. Chemical composition data correlated insignificantly with age and height. Contents of chemical components increased with age and height. Regardless of age and culm height, the high cellulose content of this species together with its fibre characteristics indicates its good potential as a raw material for pulp and paper (Abdul Latif Mohamod *et al*. 1994) [324].

Although nodal portions produce poor kraft pulp, it is not feasible to separate nodes and internodes before digestion and the reduction in yield and quality of whole bamboo pulp due to the nodal portion is not significant (Maheshwari *et al*. 1976) [171]. Nodal and internodal portions of the bamboo culms differ in their chemical constitution. Internodal portion of bamboo has higher holocellulose and lower pentosans, extractives, ash and lignin compared to nodal portion. Pulp yield is lower with more rejects in the case of nodal portion (Maheshwari and Satpathy 1988) [175]. Fibre length and strength properties of pulp from nodal region is also comparatively lower. As such bamboo culms show the intermediate trend in all properties. Evaluation of the pulp properties of *Bambusa vulgaris* from Ghana also showed that it is not necessary to separate the node from internode during pulping (Sekyere 1994) [234].

9.8. Optimum utilization

About 50,000 tonnes of bamboo dust are being reported to be wasted in India every year, and with the increase in utilization of bamboo from one million tonnes to two million tonnes, this wastage will naturally be on the increase. Many reports suggest the possible avenue of utilization of bamboo wastes for pulping. This includes the production of pressed pulp boards by Asplund thermomechanical defibration process (Singh 1960) [76]; for paper and rayon grade pulps (Gupta and Jain 1966) [477]; for the production of wrapping paper from the sulphate pulps and writing and printing papers from the bleached sulphate pulps (Guha *et al*. 1966) [457a]. From bamboo shoot – sheath (BSS) of *Sinocalamus latiflorus*, after steam treatment, soda pulp was produced in the laboratory, and by neutral sodium sulphite in a paper mill; it was were found to have an average fibre length of 1.6 mm (equal to or longer than hardwoods), and suitable for making good quality printing paper and corrugating medium, or for blending with other pulps. The yield was low (20% on oven-dried basis)

(Ku and Pan 1975) [224]. Chang and Duh (1978) [139] also described the utilization of bamboo residue for pulp and paper. Pulping of bamboo tops/twigs and branches was described by Ku (1978) [166] and Maheshwari (1982) [170]. The beneficial effect of anthraquinone (AQ) on the alkaline pulping of bamboo wastes was also established (Wang 1981) [437]. The shavings and nodes of *Dendrocalamus latiflorus*, *Phyllostachys edulis* and *P. makinoi* were pulped using the neutral sulphite–anthraquinone process. Yields and pulp strength (breaking length, burst and tear factors) were reported for varying total alkali, alkali ratio and anthraquinone in the pulping process (Wang and Lirn 1985) [537].

10. BLEACHING

Use of bleaching powder for the bleaching of bamboo chemical pulps has the problem of a reversion of colour to a brownish shade while storage. A two-stage bleaching using the application of 70-80 per cent of the total bleach demand on the first stage and the remainder, 20-30 per cent, in the second stage overcomes the above issue of colour reversion (Bhargava 1945) [136]. An intermediate hot alkali wash with 0.1 per cent NaOH solution, containing about 2 per cent NaOH on the weight of air-dry pulp was given to partially bleached pulp at the end of first stage. After the second stage of bleaching, the pulp is thoroughly washed with water and then poured with chlorine or bleaching powder solution in the order of 0.1-0.2 per cent or 0.3-0.6 per cent respectively, on the weight of the pulp. Pulps bleached by this way is found to retain the whiteness and brilliancy of shade for reasonable long periods while storage.

Many bleaching agents of both reducing as well as oxidising nature such as sodium bisulphite, zinc hydrosulphite, zinc dust and sulphur dioxide, sodium peroxide and sodium chlorite are accepted for the bleaching of bamboo mechanical pulps (Bhat and Viramani 1961) [475]. Of the reagents used, only sodium peroxide and chlorine to give satisfactory results with reasonable consumption of chemicals.

Kato (1955) [408, 409] described the digestion of bamboo pulps. When bleached, NSSC pulps from *Dendrocalamus strictus* (yield 37-44%) were found to have satisfactory brightness and strength properties for the production of white paper (Guha and Pant 1961) [395]. Bleachable pulp could be made by the chlorination process from shredded *Cephalostachyum pergracile* (Mai-Aung 1961) [520]. The colour reversion of bamboo pulp bleached with CEH sequence was also reported (Bapna *et al*. 1961 [500], Maheshwari *et al*. 1980 [519]; Maheshwari 1981) [517]. The sulphate pulp from *Bambusa blumeana* responded well to the standard three stage bleaching process. Good quality bond, air-mail bond, onion skin, kraft wrapping and bag papers could be produced from this species of bamboo (Escolano *et al*. 1964) [387]. Bleached sulphate pulp yields of 39-58 per cent are reported for bamboos (Gajdos *et al*. 1971) [389]. An optimum viscosity dissolving grade pulp from *Dendrocalamus strictus* was achieved by replacing the chlorination stage by CIO treatment; after further bleaching a most satisfactory bleached pulp was obtained (Pande 1966 [523]; 1967) [525]. The bleaching qualities of the sulphate pulp (yield 46%) produced from the Philippine bamboo, *Schizostachyum luampao*, equalled or exceeded those of Indian bamboos and the best North American bamboos.

Satisfactory bag and wrapping papers were made with 100 per cent bamboo pulp and good writing paper from 70 per cent bleached bamboo and 30 per cent unbleached Philippine hardwood pulp (Anonymous 1966). The production of bleached sulphate pulp from mixture of bamboo and mixed hardwoods (50:50 mixture) was described by Guha *et al*. (1966) [398]. The unbleached pulp of bamboo and mixed hardwoods obtained by cold-caustic soda process possessed low initial brightness and consequently was hard to bleach. Bhat *et al*. (1972) [501] tried various bleaching methods and assessed the yield and efficiency of the methods to improve brightness of the pulps. Bleached pulps in satisfactory yields could be produced from ringal (*Arundinaria* spp.) (Guha *et al*. 1966) [397]. The bleach consumption and strength properties of sulphate pulp obtained from *Phyllostachys bambusoides* are comparable to those obtained from *Dendrocalamus strictus* except in the case of tear factor and folding endurance which are found lower in the case of *P. bambusoides*. But strength obtained is found sufficient for the production of writing and printing papers (Guha and Pant 1966) [396]. The Philippine bamboos, *Gigantochloa levis, G. aspera, Schizostachyum lumampao, Bambusa vulgaris, B. vulgaris* var. *striata* and *B. blumeana* are reported to be easily digested and bleachable pulps with permanganate numbers from 13.0 to 18.2 and screened pulp yield from 41.3 to 48.0 per cent can be obtained (Semana *et al*. 1967) [471].

Decayed bamboos consume more bleaching chemicals because of the high content of residual lignin in the pulp; cost of production is therefore higher than that from healthy bamboos (Bakshi *et al*. 1968) [540]. The bleachability of bamboos from Gabon and reeds from India is described by Doat (1970) [502]. The CEH sequence of bleaching is detailed here. A comparison with typical pulps made from Central European conifers and hardwoods shows that bamboo pulps are more difficult to bleach and are generally inferior in mechanical properties. A procedure consisting of controlled hypochlorite bleaching followed by a mild H_2O_2 / SO_2 treatment was developed for improved economical bleaching of bamboo sulphate pulp without loss of pulp yield or quality (Banthia *et al*. 1972) [372]. Maheshwari (1975) [495] detailed the chlorination of sulphate pulps of bamboo. The peroxide bleaching of CEHH bleached pulps and sulphate pulps was described by Ledouse *et al*. (1981) [516]. The effect of peroxide addition in extraction stage on optical properties of bamboo pulp was described by Maheshwari (1990). The effect of hydrogen peroxide addition in the alkaline stage of CEH as well as CED bleaching of bamboo pulp on the final bleached pulp properties was described by Rao *et al*. (1988) [529]. Inclusion of hydrogen peroxide in the bleaching extraction stage is advantageous.

The results of bleaching tests on the sulphate pulps from the Taiwan bamboos, *Bambusa beecheyana* var. *pubescens*, *B. dolichoclada, B. stenostachya, Dendrocalamus latiflorus* and *Phyllostachys makinoi* were reported by Chao and Pan (1972) [452]. The pulping and bleaching trials on five Taiwan bamboo species by the cold-soda neutral sulphite (NSSC) and sulphate process were reported by Chen *et al*. (1973) [383]. The NSSC pulps, although lowest in yield, showed good strength and were bleached to 72-88 per cent GE brightness by the chlorination /alkali extraction / hypochlorite (CEH) bleaching sequence. The net yield of 48.3 – 53.2 per cent for the bleached pulp was well above that obtained from fully cooked pulps. The sulphate pulps were darker and hard to bleach, but were strong enough for packaging products. The best properties were shown by pulps from *Bambusa beecheyana* var. *pubescens,* followed by *Bambusa dolichoclada, Bambusa stenostachya, Sinocalamus latiflorus* and *Phyllostachys makinoi*; the last two being unsuitable for pulping. Bleached pulp from muli bamboo (*Melocanna baccifera* / *M. bambusoides* / *Bambusa baccifera*) was prepared by Guha *et al*. (1980) [42] in India and Karim *et al*. (1994) [407] in Bangladesh.

The kinetics of chlorination stages of bleaching bamboo kraft pulps was described by Kumar *et al*. (1974) [515] and Maheshwari (1975) [495]. The bleaching properties of *Bambusa tulda* from Shillong were described by Bhola (1976) [218]. Bleaching of kraft pulp changes the properties of pulp throughout the CEH bleaching sequence (Jain *et al*. 1976) [512]. Bhandari (1981) [445] produced kraft pulp from *Oxytenanthera ritcheyi* at the optimum conditions of cooking and the pulp was bleached. The optimum bleaching conditions, bleached pulp yield, brightness and various strength properties of bleached sheets were also reported. This species was found as a suitable raw material for the production of wrapping, writing and printing paper. Hypochloite pre-treatment prior to chlorination has a beneficial effect on tear strength and folding endurance of bleached bamboo pulps (Fellegi and Rao 1980 [4]; Rao *et al*. 1980) [528]. The effect of chlorination and pH on final bleached pulp characteristics was explained detailed by Faul (1982) [504]. The effect of bleached pulp viscosity on strength properties was described by Maheshwari (1982) [518].

Pulps from the high-yield alkaline sulphite process with and without anthraquinone (AQ) can be easily bleached with calcium hypochlorite to a brightness of 78 and 76 per cent with bleached pulp yield of 59.4 and 57.4 per cent respectively. The physical and strength properties and opacity were matching with those of sulphite pulp (Jauhari and Ghosh 1984) [404]. The kraft – AQ pulping of bamboo and mixed hardwoods showed that bleach consumption of all the AQ-based pulps was lower and physical strength properties of the bleached pulps superior to pulps without AQ additive (Rawat *et al*. 1985) [470]. Pulps in higher yield can be produced by separate digesters and separate bleaching of bamboos and mixed hardwoods, instead of mixed digestion of these two raw materials of heterogeneous nature (Bhargava *et al*. 1985) [217]. High-yield pulps from bamboo wastes can also be bleached satisfactorily (Wang and Lirn 1985) [537]. The bleachability of pulp from both nodes and internodes is same under identical conditions. The bleached pulp viscosity is lower in case of pulp from nodal portion (Maheshwari and Satpathy 1988) [175].

The bleaching of bamboo pulps can be done to desired level of brightness with CHH sequence. Total chlorine requirement and post colour number are higher while the strength properties are lower in CHH bleached pulp compared to CEHH bleached pulp. For CHH bleached pulp of low kappa number adverse effects are not much (Suman and Subhash 1987) [535]. As the alkali extraction stage is eliminated, the alkali consumption is lower and colour of combined effluent of CHH sequence is very light compared to CEHH sequence. It is suggested that on maintaining the pulp kappa number low (below 25), CHH sequence can be followed. The bleachability of high yield pulps can be improved by chemical modification of lignin. Soda thermomechanical (STM) and soda sulphite thermomechanical (SSTM) pulps of bamboos are modified using chlorine, sodium sulphite and hypochlorite (Singh *et al*. 1987) [318]. The C/ S/ H combination (chlorine-sodium bisulphite-hypochlorite) for bleaching of STM and SSTM pulps gave optimum strength properties at a brightness level of 45 per cent ISO (Tewari 1992) [124].

Singh *et al*. (1988) [237], in their review on aspects of pulping and paper making from bamboos, gave a brief account on the research efforts carried out on pulp bleaching. Cold-soda high-yield bamboo pulp has low initial brightness (20-27% ISO) and high yellowness (51-63%). Even with 25 per cent calcium hypochlorite, brightness achieved under normal conditions is only 45 per cent ISO (Rao *et al*. n.d [527]; Roy *et al*. n.d) [530]. In general, conventional methods of bleaching lignin rich high-yield pulps are ineffective in brightening bamboo cold-soda pulp. Infra-red spectra of thin sheets of bamboo cold-soda pulp will indicate the presence of chromophoric groups such as acetyl, carboxylic structures, unsaturated carbonyl, ring quinone and conjugated structures which are either present in the raw material or produced during pulping and/ or bleaching are responsible for poor bleachability and high yellowness of bamboo cold-soda pulps (Islam *et al*. 1989) [511]. Also, it may be that some fine quality wax portions are present in the fibre may be creating a barrier to bleaching agent. Hypochlorite may be exerting an oxidising action on the wax causing the production of ester groups which are difficult to remove/ bleach. It is also possible that some colour bodies present undergo photochemical polymerisation and are strongly absorbed on the fibre surface (Tewari 1992) [124]. Bleachability of the pulp with oxidative and reductive bleaching agents like calcium hypochlorite, hydrogen peroxide, dithionite and borohydride are ineffective in improving the brightness of cold-soda bamboo pulp. Pre-treatment with SO_2/ H_2SO_4 and extraction of cold-soda pulp with alkali prior to hypochlorite bleaching has beneficial effect on brightness improvement (Rao *et al*. 1980) [528]. Presence of small amount of hydrogen peroxide in the pre-alkali extraction stage further improves the brightness even up to a level of 48 per cent ISO. To achieve a brightness gain of 6-7 points, about 5-6 per cent yield has to be sacrificed. Peroxides are used for the delignification of bamboo sulphate pulps (Maheshwari 1985) [304]. Calcium hypochlorite bleachability of this pulp is enhanced when sodium carbonate is used as additive. The enhanced bleachability is due to the elimination of carbonyl groups following oxidation with nascent oxygen which is believed to be the active bleaching agent in sodium carbonate buffered calcium hypochlorite bleaching systems.

The effectiveness of 12 commercial enzymes for pre-bleaching bamboo (*Bambusa bambos* and *Dendrocalamus strictus*) kraft pulps was investigated by Bajpai and Bajpai (1996) [444]. Different xylanases varied in their maximum obtainable effect. The enzymes, 'Bleachzyme F' and 'Irgazyme 40 S' were able to decrease the active chlorine requirement in the first stage of bleaching by 20 percentage or decrease ClO_2 in the last stage of brightening by 4 kg per metric tonne of pulp in the CDEHD sequence. Alternatively, at the same chemical charge, it was possible to increase the final brightness approaching 89 per cent ISO. The use of enzymes had no adverse effect on the pulp viscosity and strength properties.

The fines in bamboo unbleached pulp amount to around 30 per cent. The fines contain more of lignin, extractives and ash than the fibrous fraction. In the 'whole' pulp, the fines consume bleaching chemicals more than the fibrous part. Though the fines have comparatively poor optical property, according to Sahu and Patel (1996) [349], these do not deteriorate correspondingly the optical properties of the whole pulp and there may not be any need therefore to eliminate the fines during paper manufacturing.

11. BEATING

As bamboo fibres are heterogeneous in respect of lumen width, fibre length, and diameter and proportions of parenchyma, which all in turn will result in differences in the physical properties of the pulp, beating will reduce the difference in these physical properties. Grant (1964) [506] described the beating characteristics of bamboo pulps. Singh *et al*. (1988) [237] gave a brief review of the research efforts carried on beating properties of bamboos.

Control of temperature and consistency during the beating process is required to develop proper fibre to fibre bonding during the course of sheet formation. For bamboo pulp, the optimum temperature for beating is found to be 35 ^{0}C and the optimum consistency is 1.5^{0}. From a study made on the beating characteristics of bamboo pulp in a Valley beater, power consumption was more at higher temperature and less at higher consistencies (Guha *et al*. 1976) [508]. Beating of commercial bleached sulphate pulp from *Dendrocalamus strictus* in a Valley beater revealed that from the point of strength, the optimum temperature for beating is around 35 ^{0}C. However, there is a linear relationship between breaking length/ bulk and freeness, which is independent of temperature and consistency (Guha *et al* 1976) [508].

As pentosan content in the bamboo pulp is increased, the beating time progressively reduces (Negi 1970) [310]. Pulping and beating of mixed hardwoods and bamboo separately and then blending are preferred than cooking and beating of hardwoods and bamboo together (Biswas 1971; Singh *et al*. 1971) [533]. Krishnagopalan *et al*. (1975) [514] described the effect of refining on the morphology and properties of bamboo paper. The effect of beating revolutions on the pulp characteristics of 1- to 3-year-old *Gigantochloa scortechinii* was described by Jamaludin *et al*. (1992) [161].

The effect of beating variables like consistency and temperature on strength development in bamboo pulp was reported by Singh *et al*. (1976) [533]. Investigations on the variations in fibre morphology as well as orientation of the fibres in the hand sheets revealed no significant difference in the strength properties, but when the temperature was varied, significant differences in fibre dimensions were observed. On beating, various cell wall layers of bamboo fibre open up leaving a gap between. This gap not only increases the percentage of void area in the sheet, but also does not allow the fibres to bind to a compact mass. This appears to be the main handicap of the bamboo fibres. Breaking length and burst factor are found higher when the pulp is beaten with a phosphor bronze tackle and the difference is more pronounced at lower consistency, whereas a stone roll beater gives a higher tear factor and the difference is more pronounced at higher consistency (Singh *et al*. 1976) [534]. In respect of strength properties there was a marked difference between the beaten and unbeaten pulps (Singh *et al*. 1976) [353].

Effects of beating on the fibre dimensions and the strength and optical properties of the sulphate pulp from *Dendrocalamus strictus* were described by Rao *et al*. (1978) [526]. Morphological changes in the fibres were illustrated by them through photomicrographs. The changes in relation to the observed critical beating value above which tensile strength and bursting strength declined were discussed.

Bamboo pulp fibres respond to beating more rapidly than do wood fibres; this is probably due to the difference in secondary wall structure between the fibres. The secondary wall consists of alternately arranged broad and narrow layers. During the beating process, a number of transverse and concentric cracks are generated in the broad layers, which cause an internal fibrillation. The outer broad layers with their numerous cracks separate from the inner layers and swell greatly toward the outside. The outer secondary wall layer of bamboo fibres has a micro fibril angle of about 20^0 with respect to the fibre axis which is much smaller than that of the S_1 layer of wood fibres. As a result, this layer appears to offer little resistance to prevent the external swelling of the broad layers (Wai *et al*. 1985) [357]. The mean values of strength properties of unbeaten and beaten pulps of 12 Indian bamboo species were reported by Singh (1989) [77] (Appendix 7).

The optical properties of the bamboo pulp in terms of brightness remain almost constant as the beating proceeds while the brightness and opacity of wood pulps decrease. The increase in opacity and light scattering coefficient of bamboo pulp with increasing beating time has been attributed to the presence of fines. The bamboo pulp has a low scattering coefficient due to its rather high fibre coarseness (Hunter 2002) [157].

Addition of beater adhesives such as starch, guar gum and locust–bean gum improves the burst, fold and tensile strength considerably and produces high quality bag and wrapping papers from sulphate pulps of *Bambusa vulgaris*. The resulting papers have strength properties superior to those of the commercial papers and exceed the US Federal specifications (Escolano and Semana 1970) [147]. Guha *et al*. (1970) [393] reported the effect of 16 natural gums available commercially, two varieties of commercial carboxymethyl cellulose (Cellpro-LSH and Cellpro-LVE) and six samples of seed gums on bleached bamboo pulp as wet additives.

12. PULP AND SHEET CHARACTERISTICS

Bhargava (1945) [136] in his review of the investigations on bamboo for pulp and paper manufacture at the Forest Research Institute, Dehra Dun from 1860 to 1944, described the strength properties of kraft pulps of some selected Indian bamboo species. The compositions and strength of pulps obtained by soda, kraft and NSSC processes under varying conditions of cooking were compared and described by Fukuyama *et al*. (1955) [388]. The kraft process gave the strongest pulps. The NSSC pulp (yield 54-57%) showed excellent tearing strength, with an alpha-cellulose content of 59.8 per cent. Both kraft and NSSC processes were recommended for the pulping of sasa bamboos. The properties of pulps and papers prepared from 10 bamboo species of Belgian Congo, using three different methods of cooking, were described by Istas *et al*. (1956) [159]. Good sulphate pulps are obtainable, but except in tearing strength, the resulting papers are inferior to those of a medium quality kraft. The application of pressure while cooking will improve the quality of pulps. Unbleached pulps (yield 56-68%) of satisfactory strength properties can be prepared from *Dendrocalamus strictus* by the neutral sulphite semi-chemical (NSSC) process. When bleached, these pulps (yield 37-44%) will have satisfactory brightness and strength properties for the production of white papers (Guha and Pant 1961) [395]. Kato (1961) [47] prepared drawing paper from Japanese bamboo pulp and found it excellent.

Kraft pulps made from the Philippine species, *Schizostachyum lumampao*, *Gigantochloa aspera*, *Bambusa vulgaris*, *Bambusa blumeana* were found deficient in burst strength, but had sufficient tear strength for Grade A and Grade B wrapping papers (Monsalud *et al*. 1965) [59]. Investigations on the soda pulp characteristics of 1- to 4-year-old culms of *Bambusa vulgaris* (Medina and Ciaramellao 1965) [181] revealed no effects on tearing, tensile or folding strength due to culm age. Paper from 2-year-old culms, however, had a significantly higher bursting strength. *Bambusa vulgaris* produces paper of good quality, resembling that from unbleached kraft softwood pulp in tearing strength. From the industrial stand point, no advantage is gained by selecting culms of a particular age. No appreciable changes in the strength properties of pulp are found with increasing the age of five species of bamboos of Bangladesh origin (*Melocanna baccifera, Oxytenanthera nigrociliata, Dendrocalamus longispathus, Bambusa tulda* and *Neohouzeaua dullooa*) (Razzaque *et al* 1981) [233]. The pulp strength properties of 1- to 3-year-old *Gigantochloa scortechinii* were described by Jamaludin *et al*. (1992) [161] and found satisfactory.

The yield, bleach consumption and strength properties of the pulps obtained from *Phyllostachys bambusoides* are comparable to those obtained from *Dendrocalamus strictus* except in the case of tear factor and folding endurance which are found lower in case of *P. bambusoides*. But the strength obtained is found sufficient for production of writing and printing papers (Guha and Pant 1966) [396].

Bleached kraft pulp of bamboo and mixed hardwoods (in the ratio1:1) is found to possess satisfactory strength properties. A bleached pulp yield of around 45 per cent is obtained with a tensile index of 63.8-73.8 Nm/g, burst index 4.81-5.22 kPa.m^2/g, and tear index 17.8-19.8 mNm^2/g.

Studies on the variations of sheet properties of the various sulphate pulp fractions from *Gigantochloa aspera* have shown that bursting and tensile strength increased, the tear strength decreased, and the folding endurance remained constant on going from long to short fibre fractions (Gonzalez and Escolano 1965) [390]. The Philippine bamboos, *Gigantochloa levis, G. aspera, Schizostachyum lumampao, Bambusa vulgaris, B. vulgaris* var. *striata* and *B. blumeana* gave kraft pulps with higher tearing resistance but lower folding endurance, bursting and tensile strength than softwood and hardwood pulps (Semana *et al*. 1967) [471]. The sulphate pulp obtained from *Bambusa vulgaris* (screened yield of 41.4 and permanganate number of 15.0) by using an active alkali charge of 15.6 was characterised by very high tearing resistance but low bursting strength. The folding and tensile strength was within the range of other commercial kraft pulps, which are tested and used as standards. The experimental bag and wrapping papers produced from this pulp were higher in tearing resistance but lower in burst, fold and tensile strength. Addition of beater adhesives such as starch, guar gum and locust-bean gum in the pulp overcomes the above deficiencies and produces good quality bag and writing papers.

As the pentosan content of the bamboo pulp is increased, the strength properties are also found to increase up to a critical limit of 14, 9 and 14 per cent respectively for breaking length, burst factor and tear factor (Negi 1970) [310].

Investigations on the influence of variation in fibre dimensions and parenchyma proportion on the sulphate pulp sheet properties of *Dendrocalamus strictus* revealed that inclusion of parenchyma lowered the tensile strength and tearing resistance up to 30 per cent (Singh *et al*. 1971) [354]. Jain and Reddi (1964), claimed that removal of parenchyma increased the bulk and reduced the strength properties. Fibre length, determined from unbeaten pulp, accounts for 77-90 per cent variations in strength properties. A high negative correlation with parenchyma proportion and the pulp sheet properties was reported. Fibre length and parenchyma proportion together accounted for 90 per cent of the variations in strength properties.

Comparative data on the sulphate pulp properties and the properties of hand sheets from the sulphate pulps of *Bambusa beecheyana* Munro var. *pubescens* and some other Taiwan bamboos were reported by Ku (1971) [165]. Sulphate pulps of good strength properties, especially with high tearing strength are obtained from the Taiwan bamboos, *Bambusa beecheyana* var. *pubescens, B. dilichoclada, B. stenostachya, Dendrocalamus latiflora* and *Phyllostachys makinoi*. Pulp yields varied with cooking conditions, from 41-47 per cent (Chao and Pan 1972) [452]. Krishnagopalan (1973) [333] described the paper forming properties of bamboo in relation to its fibre characteristics. The tensile, burst and tear indices at lowest pulp yield (45%) was 45.4 Nm/g, 3.13 kPam^2/g and 18 mNm^2/g respectively (Singh and Guha 1975) [429]. The yield and strength of pulp obtained by the Kleinert's rapid alkaline pulping process of *Bambusa vulgaris* var. *vittata* from Sao Paulo were comparable with those obtained by the normal sulphate process (Barrichello and Foelkel 1975) [374]. Because of the variation of properties within species, no relationship could be established between fibre characteristics and strength properties of paper; the variation in pulp sheet properties cannot be predicted from fibre dimensions or chemical composition (Singh *et al*. 1971 [354], 1976 [353]). Grading 12 Indian bamboos (including 5 species of *Bambusa* and 3 species of *Dendrocalamus*) for their pulping suitability based on pulp yield, alkali consumption and sheet properties showed that *Dendrocalamus hamiltonii* was the best. High quality unbleachable pulps could be prepared from *Ochlandra travancorica* and *O. rheedi* (yield 48-49%, kappa number 22-25) using 15 per cent active alkali at 25 per cent sulphidity and 943 H-factor at 170 ^{0}C. The tensile index, burst index and tear index ranged 63.9-70.6 Nm/g, 4.40-5.66 kPam^2/g and 20-3-22.5 mNm^2/g respectively (Singh *et al*. 1977) [236]. *Dendrocalamus hamiltonii* when compared with *D. strictus* and *Bambusa tulda* from Pakistan gave the highest soda pulp yield and best tearing strength properties comparable to those of karft pulp from *Pinus roxburghii* and Southern pine kraft pulp (Suleiman 1994) [196]. However, the bonding properties of bamboo pulp were inferior to those of softwood kraft pulp. The pulp sheet properties of some Indian bamboos were described by Singh and Bhola (1978) [316].

The characteristics of chemical, semi-chemical, chemi-mechanical and mechanical pulps obtained from the Brazilian bamboos (*Guadua angustifolia, G. glomerata, G. morim, G. superba* and *Nastus* (*Cenchrus*) *amazonicus*) were described by Correa *et al*. (1977) [143].

The strength properties of mixtures of bamboos and mixed hardwoods in different component ratios were described by Pasaribu and Silitonga (1974) [497]. The yield and properties of pulps from bamboo (*Dendrocalamus strictus*) combined with different proportions of mixed hardwood pulps (a mixture of 30-40% each of *Terminalia tomentosa* and *T. bellirica* and 2.5-5% each of 8 other species) were reported by Guha *et al*. (1980) [42]. Increase in the percentage of hardwoods slightly increased the yield, but decreased strength properties. Even then, mixed pulps still had satisfactory properties for the manufacture of writing, printing and wrapping paper as well as for 3-layer board.

Evaluation of strength characteristics of bleached and unbleached kraft pulps obtained from *Oxytenanthera ritcheyi* at optimum cooking conditions revealed that the species was a suitable raw material for the production of wrapping, writing and printing paper (Bhandari 1981) [445]. Sulphate, neutral sulphite, lime and thermo-mechanical pulps were prepared from *Bambusa vulgaris, B. viridi*, *Gigantochloa apus* and *G. aspera*. The chemical properties of the pulps were analysed in relation to their effect on paper properties. Neutral sulphite pulp gave the best results in terms of high yield and satisfactory paper mechanical properties (Tshiamala *et al*. 1984) [431]. The soda thermo-mechanical (STM) and soda-sulphite thermo-mechanical (SSTM) pulp from *Dendrocalamus strictus* was bleached with chlorine (2.5%) at 30 ^{0}C and pulp consistency 2.5 per cent for 60 minutes followed by sodium sulphite (5%) treatment at 80 ^{0}C and 5 per cent consistency for 60 minutes (C/ S combination). In a second set of experiment, the above treated STM and SSTM pulps were further treated with calcium hypochlorite (5% available chlorine) at 45 ^{0}C and 8 per cent consistency (C/ S/ H combination). It was found that the C/ S/ H combination with the application of 5 per cent of each chemical gave optimum improvement in strength properties in all the pulps at brightness level 45 per cent ISO. For STM pulp, the tensile index increased from 22.07 to 30.18 Nm/g and burst index from 0.72 to 1.56 kPam^2/g. For SSTM pulps the tensile index rose from 32.28 to 42.96 Nm/g and burst index increased from 1.62 to 2.55 kPam^2/g.

The strength properties of unbleached normal sulphite (NS) – anthraquinone pulps from muli bamboo (*Melocanna baccifera*) were lower than those of kraft pulps (Bose *et al*. 1988) [451]. The physical and strength properties of the pulp were found to be independent of age of the bamboos. Anthraquinone (AQ) catalysed low sulphidity kraft pulp obtained from muli bamboo (*Melocanna baccifera*) had almost the same viscosity as that of the kraft control and better than the pulp of 15 per cent sulphidity (Bhowmick *et al*. 1991) [447, 448]. The burst, tear and tensile strength properties of the pulp increased on addition of anthraquinone. The strength properties of the anthraquinone catalysed pulps were almost the same or better than the pulp obtained in normal kraft pulping.

The unbleached pulp (yield 49.8% with kappa number 28.3) properties of eight Chinese bamboos were described by Xia (1989) [241]. The pulp strength was found satisfactory. Based on the unbleached pulp yield and strength properties, he ranked *Schizostachyum funghomii* as the best and *Bambusa textillis* and *B. pervariabilis* as second and third and *Phyllostachys pubescens* (moso bamboo) as last.

The pulp characteristics and physical properties of the paper handsheets made from bamboo and water hyacinth pulp blends were described by Goswami and Saikia (1994) [36]. Blending of bamboo pulp with water hyacinth increased the strength. Paper handsheets made with a blend of water hyacinth pulp (75^{0}SR) at 75:25 proportion gave a tear index of 4.9 Nm^2/g, tensile index of 51.1 Nm^2/g and burst index of 7.3 kPam^2 g. These were higher than the values obtained from sheets made with pulp blends of 80:20 or 90:10. Blends of 75:25 were also found to give satisfactory greaseproof properties.

The difference in secondary layer structure of bamboo fibres leads to different swelling behaviours compared to that of wood fibres. Bamboo paper showed a low drainage resistance (0.55) compared to

Scandinavian birch (0.66) and eucalypts (0.77) and drainage time at a tensile index of 70 Nm/g. The presence of fines and their characteristic swelling behaviour may be the reason for this. The morphological characteristics of the bamboo fibres give paper with a high tear strength and burst index, which is rather similar to that of hardwood. The tensile stiffness is low compared to that of Scandinavian softwood. The strain strength lies between that of hardwood and softwood (Hunter 2002) [157]. The ratio of fibre strength to bond strength is higher in the case of bamboo pulp compared to that of commercial softwoods. The tensile strength of bamboo can be improved by removing primary fines prior to refining. The bamboo fibres give sheets with high bulk and high porosity. The coarseness and the characteristic shape of the fibres cause an uneven surface, which necessitates coating with a pigment layer in order to achieve good printing results in pure bamboo papers.

13. BLACK LIQUOR

The bamboo kraft black liquor usually contains silica in the range of 5-8 g/l as SiO_2. The high silica content leads to the formation of soluble silicates during pulping which causes troubles at the chemical recovery stage. The addition of calcium oxide to the black liquor is effective in reducing the silica content from 5.0-7.2 g/l to 1.3-1.8 g/l, and the precipitated calcium silicate is easily removed by filtration without reducing the amount of organic matter and sodium (Tsuji and Ono 1966) [433]. Desilicification of high silica containing kraft black liquor is achieved by using various reagents such as aluminium sulphate and magnesium sulphate, carbon dioxide (Isono and Ono 1967 [399]; 1968) [401, 402] and kraft green liquor by aluminium sulphate (Isono and Ono 1968) [400]. Kulkarni *et al*. (1984) [462] made an attempt for desilication by the method of lowering the pH of black liquor by carbonation. It was found that temperature and pH were the two important parameters that needed to be optimised for the selective precipitation of silica. The pH range for silica precipitation was largely influenced by the temperature during carbonation. Also it was found that at all temperatures and pH levels there was a co-precipitation of lignin. Treatment of sludge with calcium oxide or aluminium hydroxide at 80 ^{0}C helps in re-dissolution of co-precipitated lignin without dissolving silica portion. The carbonised black liquor can be filtered easily on 600 mesh nylon cloth under reduced pressure of around 0.3 kg/cm^2. Sathyanarayana *et al*. (1992) [73] made adaptations to black liquor evaporators so that a mixture of bamboo and hardwood pulp (at a ratio of 70:30) could be processed as effectively as bamboo alone. The viscosity of black liquors from bamboo alone and bamboo with mixed hardwoods in different proportions can be reduced with increase in initial residual alkali of the black liquor (Khare *et al*. 1984) [494]. This will help in reducing the clogging of the evaporated tubes and better performance of the recovery.

Vanillin can be produced from bamboo black liquor by alkaline nitrobenzene oxidation, but yields are too low to make the process technically feasible (Bharatia and Veeramani 1974) [375]. The engineering properties (thermal conductivity and specific gravity) of bamboo kraft black liquors were reported by Koorse and Veeramani (1976) [459, 460].

Khanna and Swaleh (1981) [513] made the first report on the analysis of bamboo (*Dendrocalamus strictus*) black liquor. Madan and Vijan (1995) [252] described the physico-chemical properties of *Dendrocalamus giganteus* kraft spent liquor. With a view to the possible utilization of kraft lignin as a by-product, lignin from spent liquor left from the pulping of sound and flowered *Dendrocalamus giganteus* by the kraft process was isolated (Vijan and Madan 1996) [263]. Data were tabulated on the C, H, O and S content of the lignins and the content of Klason lignin and functional groups (methoxyl, hydroxyl and carboxylic) and correlations between them, and on the relative retention time and percentage of alkaline nitrobenzene oxidation products of the lignins. The results indicate clear differences in structure between lignin isolates from sound and flowered bamboos.

14. TYPES OF PAPER

Experiments conducted at the Forest Research Institute, Dehra Dun have established the suitability of bamboo as a material for the manufacture of kraft paper and have led to the pioneering of the industry in India (Bhargava and Singh 1942) [26]. The bamboo pulp from *Dendrocalamus strictus* combined with different proportions of mixed hardwood pulps has satisfactory properties for the manufacture of writing and printing paper, wrapping paper and 3- layer board (Guha *et al*. 1980) [42].

Newsprint was produced from the bamboo *Phyllostachys bambusoides* (Nafziger *et al*. 1961) [417]. *Dendrocalamus strictus* was reported to be suitable for the production of white papers (Guha and Pant 1961) [395]. *Phyllostachys bambusoides* is suitable for the production of writing and printing papers (Guha and Pant 1966) [396]. Ringal (*Arundinaria* spp.) is reported to be suitable for the production of chemical pulps by the sulphite process for writing and printing papers (Guha *et al*. 1966) [397]. Good quality bond, air-mail bond, onion skin, offset book, kraft wrapping and bag papers can be produced from the sulphate pulp of *Bambusa blumeana* (Escolano *et al*. 1964). *Bambusa vulgaris* was reported to be suitable for bag and wrapping papers with excellent tearing but poor bursting strength properties (Escolano and Semana 1970) [147]. The folding and tensile strength of both the pulp and paper are within the range of imported pulps/papers. Guha *et al*. (1970) [40] reported that Braille printing paper can be successfully produced from Indian bamboos. Jati bamboo (*Bambusa tulda*) was reported to be unsuitable for manufacture of wrapping, writing and printing papers (Bhola 1976) [218]. *Oxytenanthera ritcheyi* was reported to be a suitable raw material for the production of wrapping, writing and printing paper (Bhandari 1981) [445].

15. INDUSTRIAL EXPERIENCE

Bamboo can be chipped in the same way as wood giving basically the similar chip form and appearance. The large sized bamboo has to be crushed before chipping. The chipping should be such that it should not produce fines. Bhargava and Singh (1942) [137] tested chips of *Dendrocalamus strictus* for uniformity, bleachability and pulp yield under identical conditions of digestion. The most satisfactory was that from the crushed one, but crushing has the disadvantage of high power consumption and also size of crushed chips was more irregular and uneven than that of chips obtained by oblique chipping. An ideal method would be to cut the bamboo into more or less uniform chips, and crush the chips, so that the bundle sheets of the bamboo vascular bundles would be loosened and separated out from the ground tissues and their rigidity reduced, thus giving an easier and quicker penetration of the cooking liquors. Initially mills used the two-stage pulping process developed by Raitt (1912 [231]; 1925; 1931) [424] at FRI, Dehra Dun, India. But with the advancement in research, at present mostly pulping is carried out in a single-stage cooking by kraft process. The general pulping conditions employed in paper mills in India are: active pulping chemicals 14-18 per cent as Na_2O; sulphidity varying between 13 and 25 per cent at 160-170 ^{0} C. The kappa number ranges between 16 and 25 and the pulp yield between 40 and 45 per cent.

Generally, in short fibred pulps, it is necessary to incorporate 25-30 per cent long fibred pulps, such as from bamboo (Bhat and Guha 1952 [269], 1953 [270]; Bhat *et al*. 1952 [271], 1956, 1960 [27]; Bhat and Jaspal 1957) [272]. Chen (1958) [140] described the layout, equipments and methods of the mill of the Longlived Pulp and Paper Corporation Ltd. at Formosa. Lund (1942) [362a] developed a mechanical disintegrator for the production of fibres. A defibrating machine, the ‘Chemifiner’, was introduced and its contribution to the process of low-power cold-soda pulping was described by Gremler and McGovern (1960) [391]. Bamboo shredded by a machine developed by the Armour Research Foundation in co-operation with the Union of Burma Allied Research Institute showed distinct advantages of easy to wash pulp, requiring less water and satisfactory chemical recovery and over chipped bamboos (Mai-Aung and Fleury 1960) [177]. Bamboo nodes were practically eliminated in the shredding action and therefore there was almost no silica in the resulting pulp. The absence of hard nodes results in less screening and uncooked particles.

In order to reduce the surface wax content of *Bambusa bambos* while pulping, a steam treatment for 2 hours is necessary (Beri *et al*. 1967) [135]. The penetration of alkaline liquor is much quicker and deeper in the cross-sectional than the longitudinal direction of the culm or chips. Alkali penetrates rapidly and uniformly once the outer waxy skin has been dissolved. Consequently, the deciding factor for effective cooking is not the length of the chip, but thickness of the culm which if shredded or crushed, is uniformly cooked whatever its length (Banthia *et al*. 1970) [369a].

Bamboo fibres have become an established raw material for paper making in tropical countries using different types of paper machines. The study of Mishra and Kothari (1969) [56] will be of interest to paper technologists as well as those who are engaged in paper designing to suit the requirements of running bamboo pulp stock on a fourdrinier machine.

To increase the yield of pulp for the production of kraft paper from bamboo and *Eucalyptus grandis*, experiments were conducted by splitting the digestion into two stages with an intermediate refining stage. The yield of bamboo pulp was found to increase from 47.1 to 53.3 per cent without any significant effect on the strength properties of pulp (Singh *et al*. 1970) [427]. The experiences on the pulping of bamboos and mixed hardwoods, from the Sirpur Paper Mills, India, showed that higher alkali concentration in the range of 16-20 per cent Na_2O was required to produce a bleachable pulp with permanganate number 20, in comparison to the very low alkali (11-13% Na_2O of 16-18% sulphidity) to produce pulp of the above quality from bamboos only (Mishra 1971) [54]. Sulphate pulps from both eucalypts and rubber wood can be mixed with bamboo chemical pulp for making the ordinary quality writing and printing papers (Nair 1971) [60]. The Bengal Paper Mill in India was the first pulp mill in the world to use the mixture of different species of hardwoods and bamboo in a continuous digester for pulping (a mixture of 60% of bamboo and 40% mixed hardwoods) with high heat diffusion washing (Bhargava 1968 [486]; Aggarwal 1971) [22]. The rejects on Johanson knotter are 2.5 per cent of raw material. The pulps are bleached with 12 per cent chlorine in four stages. Various qualities of paper are made from the pulp. Evaluation of the strength properties of the pulps of composition 30 per cent mixed hardwoods and 70 per cent bamboo, beaten in Valley and Lampen mills at consistencies varying from 1.37 to 1.97 per cent, for different time intervals, obtained from the Bengal Paper Mills revealed that pulps beaten in the Valley beater at higher consistencies gave better strength properties (Singh *et al*. 1971) [531].

Hydraulic and steam phase type Kamyr digesters were employed earlier for the cooking of bamboo. Later on, modified pressurised feeder, the 'ASTHMA' digester has been employed for the pulping of bamboo. The raw material is heated up to 115 ^{0}C by steaming in the steaming vessel. A plug feed discharges into the digester by means of high pressure steam of about 10-12 bar. The steam flow is used for heating the raw material to a cooking temperature of about 165 ^{0}C. The raw material is retained at the cooking temperature in the liquor phase. Then it reaches the discharge zone located in the bottom of the digester. The pulp is discharged by means of a slowly rotating scraper and cooked by injecting wash water in the digester bottom. Then the pulp is discharged at 10 per cent consistency through the blow valve. This digester type is used in the Phoenix Mill in Thailand and operates on bamboo and kenaf alternatively. The next development was to combine ASTHMA feeding system with conventional 'Hi-heat' washing system which can be applied to the chip characteristics of bamboo. The steam and power consumption in the ASTHMA digester is considerably lower compared with that of the batch digester system or other digester types for bamboo. The considerable amount of hot water with a temperature of 75 ^{0}C produced could be used for pulp washing and in the bleaching plant. Two mills of the Hindustan Paper Corporation (HPC) in India, the Novgong and Cachar Mills are equipped with ASTHMA digester with Hi-heat washing system. The experience from Thailand and India clearly confirmed that the simplified ASTHMA feed system is a satisfactory system which gives proper impregnation and a small amount of rejects and the Hi-heat washing technique is as efficient on bamboo as it is on hardwood and softwood pulps (Singh *et al*. 1988 [237]; Tewari 1992) [124].

The sulphate pulping of bamboo (*Dendrocalamus strictus*) was studied from the beginning to the end of cook, applying the concept of representing the times and temperatures of the cooking cycle by Vroom's H-factor. The experimental results showed that H-factor can be employed as a means of predicting compensating adjustments of cooking times and temperatures to give the same yield of pulp, kappa number and lignin content with varying cooking cycles. This indicated that the concept of H-factor can suitably be applied as a guide for controlling sulphate pulping process of bamboo in mills by predicting times for a variety of temperatures or vice-versa to make necessary adjustments in the cooking cycle so as to get equivalent pulp yield. For an experimental standard cooking cycle of 90 minutes from 80-170 ^{0}C and 90 minutes at 170 ^{0}C employed, the H-factor was found to be 91982 (Singh and Guha 1976) [430].

The design of special drum-type chippers for processing bamboo without splintering was described in Anonymous (1978b). The performance of a PN bamboo disc chipper (investment, maintenance costs and chip quality) was reported to be superior to that of others used in the Indian pulp and paper industry (Pandit *et al*. 1978) [13]. Suitability of some Indian bamboos for pulp and paper was reported by Nair (1970) [9] (Appendix 8).

In many mills, the bleaching of kraft pulps is carried out by using chlorine and calcium hypochlorite as bleaching agent with intervening caustic soda extraction. Total bleach demand varies from 12 to 15 per cent to attain a brightness of 70-75 per cent. The Phoenix Mill in Thailand follows the C-D-E-H-D bleaching obtaining 87 per cent ISO brightness. The Novgong and Cachar mills in India use 5-stage bleaching with C-E-H-E-D sequence.

With the increase of the cost of bamboo, efforts are made to utilize bamboo at the maximum for pulping. Banthia and Misra (1968) [369] described an economical method of recovery of bamboo dust and knotter (nodes) rejects in a bamboo kraft pulp mill (wastes amount to 2-5% of the weight of bamboo chipped and 0.5-2.0% of the weight of pulp produced respectively), with minimum use of alkali and maximum yield recovery. Patnaik *et al*. (1984) [256] reported about the cooking of bamboo pin chips, which are removed as bamboo dust during the screening of chips. Studies showed that the small quantity of pulp obtained from separate cooking of pin chips can be mixed with normal kraft pulp for the manufacture of kraft paper without any significant effect on the physical and strength properties of paper. Mixing of up to 5 per cent of pin chips with the usual chips, the quality of pulp does not deteriorate much. An improved process control strategy was reported for the kraft pulping of *Dendrocalamus strictus* so as to produce pulp of uniform quality (Pravin 1987) [468]. Adaptations were made to black liquor evaporators so that a mixture of bamboo and hardwood pulp (at a ratio of 70:30) could be processed as efficiently as bamboo only (Sathyanarayana *et al*. 1992) [73].

The available information on the suitability of different species is consolidated and given in the next chapter. Almost all varieties of paper are made from bamboo; eg. Machine glazed (MG) kraft, kraft linear, wrapping and printing paper, typing paper, map litho, duplicating paper, duplex board, newsprint, etc(Tewari 1992) [124] (Appendix 9.B). In India, bamboo pulp meets the requirements of long fibred pulp for producing various kinds of paper. However, bamboo mechanical pulps/ emichemical high-yield pulps have limited use due to poor strength and bleachability. Concerted researches are under way using microbial modification of lignins in high-yield pulps.

16. SPECIES SUITABILITY

The following Tables consolidate the available information on investigations on pulping qualities of various species from different countries.

1. *Arundinaria alpina*

Subject of investigation	Country	Reference
Storage; fibre morphology; chemical composition; cooking schedules; pulp and paper properties	Belgian Congo (Africa)	Istas and Raekelboom 1962
Pulping potential	Ethiopia	Cunningham and Clark 1970

2. *Arundinaria jaunsarensis*

Cold caustic soda treatment	India	Khanduri and Biswas 1960
Alkali treatment	India	Khanduri and Biswas 1961
Sulphate pulp; pulping of mixture of bamboo and mixed hard woods; bleaching	India	Guha *et al*. 1966 (b,d)

3. *Arundinaria nitida*

Suitability for pulping	Belgian Congo (Africa)	Istas 1958

4. *Arundinaria simonii*

Suitability for pulping	Belgian Congo (Africa)	Istas 1958

5. *Bambusa atrovirens* (Syn. *B. aurea*)

Suitability for rayon pulp, pulping conditions	India	Lele 1964

6. *Bambusa balcooa*

Pulp bleaching, yield	India	Guha 1961b
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982

7. *Bambusa bambos* (Syn. *Bambusa arundinaceae*)

Pulping trials	India	Ahamed and Karnik 1944
Semi-commercial pulping tests	India	Bhargava 1945
Rayon grade pulping	India	Karnik and Sen 1948
Fibre morphology	India	Ghosh and Negi1958
Suitability for rayon pulp, pulping conditions	India	Lele 1964
Rayon grade pulping	Japan	Tsuji *et al*. 1965
Fibre morphology; chemical composition; method of pulping; yield of pulp; product for which the pulp is suitable (Review)	India	Singh and Mukherjea 1965
Nitric acid pulping	India	Biyani 1966
Species introduction, suitability for pulping	Ghana	Kadambi and Ashong 1966
Prehydrolysis kraft pulp yield, sulphate pulp yield	-	Rydholm 1966
Pre-steaming for wax removal	India	Beri *et al*. 1967
Chemical composition; nitric acid pulping	India	Biyani *et al*. 1967
Pulping of flowered bamboos	India	Bakshi *et al*. 1968
Pulping with mixed hardwoods	India	Bhargava *et al*. 1969
Variation in fibre length	India	Pattanath 1972
Suitability for pulping	Indonesia	Pasaribu and Silitonga 1974
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Fibre morphology; pulping characteristics	India	Maheshwari *et al*. 1976
Chemical composition	India	Maheshwari *et al*. 1976
Alkaline sulphite and – AQ pulping	Taiwan	Wang 1982
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988
Effect of age on fibre length and pulp characteristics	India	Shanmughavel 1995; Shanmughavel and Francis 1996 & 1998
Biological pre-bleaching / biological delignification	India	Bajpai and Bajpai 1996

8. *Bambusa beecheyana*

Fibre morphology; chemical composition; cooking conditions; sulphate pulp properties	Taiwan	Ku 1971

9. *Bambusa beecheyana* var. *pubescens*

Fibre morphology; pulp sheet properties	Taiwan	Ku 1971
Kraft pulping; pulp sheet properties	Taiwan	Chao and Pan 1972
Pulping process; pulp for printing paper; bleaching; yield; pulp properties	Taiwan	Chen *et al*. 1974
Pulping suitability	Taiwan	Ku and Wang 1990

10. *Bambusa blumeana*

Pulping qualities; bleaching	Philippines	FPRDI 1962
Single– stage sulphate pulping process; three-stage bleaching process; types of paper	Philippines	Escolano *et al*. 1964
Bleaching; sulphate pulp and paper	Philippines	Escolano *et al*. 1964
Kraft pulping qualities	Philippines	Semana *et al*. 1967
Chemical composition (silica content); Sulphate pulping; beater adhesives	Philippines	Escolano and Semana 1970
Chemical composition (silica content)	Philippines	Espiloy 1988
Fibre morphology	Malaysia	Abdul Latif Mohamed and Mohamed Tamizi 1992

11. *Bambusa distegus*

Effect of age on fibre morphology	China	Xia and Zeng 1996

12. *Bambusa dolichoclada* (Syn. *Leleba dolichoclada*)

Kraft pulping	Taiwan	Chao and Pan 1972
Methods of cooking; cold soda; NSSC and sulphate process; bleaching; pulp characteristics; yield; types of paper	Taiwan	Chen *et al*. 1973
Methods of cooking; pulp for printing paper; bleaching; yield; pulp properties	Taiwan	Chen *et al*. 1974
Pulping suitability	Taiwan	Ku and Wang 1990

13. *Bambusa hoffii*

Chemical composition; paper making qualities	Belgian Congo (Africa)	Istas and Hontoy 1952

14. *Bambusa nutans*

Fibre morphology; chemical composition; method of pulping; yield; types of paper (Review)	India	Singh and Mukherjea 1965
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982

15. *Bambusa oldhamii*

Mechanical pulp for Chinese "Joss" (ceremonial) paper	Taiwan	Perdue *et al*. 1961
Cooking process; kraft pulping; fibre morphology; yield; properties of pulp	Brazil	Ciaramellao 1970; Ciaramellao and Azzini 1971
Pulping suitability	Taiwan	Ku and Wang 1990

16. *Bambusa pervariabilis*

Effect of age on chemical composition; pulping properties	China	Xia 1989

17. *Bambusa polymorpha*

Semi-commercial pulping tests	India	Bhargava 1945
Cold soda pulping	USA	Gremler and McGovern 1960
Fibre morphology; chemical composition; method of pulping; yield; types of paper (Review)	India	Singh and Mukherjea 1965
Bleached kraft pulp	Myanmar	Mai- Aung *et al*. 1968
Storage of pulpwood	Myanmar	Mai- Aung *et al*. 1969
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Fibre morphology; paper making properties	Myanmar	Wai and Murakami 1983 & 1984
Fibre ultra-structure; beating characteristics	Myanmar	Wai *et al*. 1985
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988

18. *Bambusa stenostachya*

Industrial kraft pulping	Formosa	Chen 1958
Mechanical pulp for Chinese "Joss" (ceremonial) paper	Taiwan	Perdue *et al*. 1961
Kraft pulping	Taiwan	Chao and Pan 1972
Methods of cooking; pulp for printing paper; bleaching; yield; pulp properties	Taiwan	Chen *et al*. 1974
Rayon grade pulping	China	Chang and Kuo 1976
Pulping suitability	Taiwan	Ku and Wang 1990

19. *Bambusa textiles*

Effect of age on chemical composition; pulping properties; pulp strength	China	Xia 1989

20. *Bambusa tulda*

Semi-commercial pulping tests	India	Bhargava 1945
Rayon grade pulping	India	Anonymous 1947
Fibre morphology; chemical composition; method of pulping; yield of pulp; product for which the pulp is suitable (Review)	India	Singh and Mukherjea 1965
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; kraft pulping; types of pulp bleaching; types of paper	India	Bhola 1976
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Effect of age on chemical composition, fibre dimensions, pulp yield and strength	Bangladesh	Razzaque *et al*. 1981
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Fibre morphology; paper making properties	Myanmar	Wai and Murakami 1984
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988
Soda process; yield; pulp strength	Pakistan	Suleiman 1994

21. *Bambusa tuldoides*

Sulphate pulping; effect of age	Brazil	Mazzei *et al*. 1967
Effect of age on sulphate pulping; pulp strength	Brazil	Mazzei and Rediko 1967
Fibre morphology; cooking process; yield; pulp properties	Brazil	Ciaramellao 1970
Pulp strength	Brazil	Barrichello and Foelkel 1975

22. *Bambusa vulgaris*

Suitability for pulp	Belgian Congo (Africa)	Frison 1951
Chemical composition; paper making qualities	Belgian Congo (Africa)	Istas and Hontoy 1952
Fibre morphology; chemical composition	Belgian Congo (Africa)	Istas *et al*. 1956
Fibre morphology; chemical composition; pulping suitability	Belgian Congo (Africa)	Istas 1958
Pulping of mixture of species	Belgian Congo (Africa)	Istas and Raekelboom 1960
NSSC pulping suitability	Mexico	Carrasco and Salvador 1961
Storage; fibre morphology; chemical composition; cooking schedules; pulp and paper properties	Belgian Congo (Africa)	Istas and Raekelboom 1962
Pulping; bleaching	Philippines	FPRDI 1962
Suitability for rayon pulp, pulping conditions	India	Lele 1964
Kraft pulping; effect of culm age on the paper making qualities	Brazil	Medina and Ciaramellao 1965
Species distribution, suitability for pulping	Ghana	Kadambi and Ashong 1966
Pulp strength; pulp blending	Africa	Doat 1967 (*Continue next page*)

Fibre morphology; effect of age on sulphate pulping; pulp strength	Brazil	Mazzei and Rediko 1967
Fibre morphology; high- yield pulping	Brazil	Mazzei *et al*. 1967
Kraft pulping qualities	Philippines	Semana *et al*. 1967
Pulp characteristics	Philippines	Semana *et al*. 1967
Pulping with mixed hardwoods	India	Bhargava *et al*. 1969
Cooking process; kraft pulping; fibre morphology; yield; pulp properties	Brazil	Ciaramellao 1970
Pulping potential; pulp strength	Brazil	Cunningham and Clark 1970
Sulphate pulping; beater adhesives; types of paper	Philippines	Escolano and Semana 1970
Pulping with mixed hardwoods	India	Guha and Sharma 1970
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Cooking process; kraft pulping; fibre morphology; yield; pulp properties	Brazil	Ciaramellao and Azzini 1971
NSSC pulping	Brazil	Janci *et al* 1971
Suitability for pulping	Indonesia	Pasaribu and Silitonga 1974
Pulping with mixed hardwoods	Brazil	Barichello and Foelkel 1975 (a,b)
Fibre morphology; chemical composition	Brazil	Azzini 1976
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b,c)
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Pulp strength	Brazil	Gomide *et al*. 1985
Effect of age on pulping	Brazil	Azzini *et al*. 1987
Fibre morphology; chemical composition	Malaysia	Jamaludin and Abdul Jalil 1991
Fibre morphology	Malaysia	Abdul Latif Mohamod and Mohamod Tamizi 1992
Kraft process	Malaysia	Jamaludin and Abdul Jalil 1993
Kraft pulping; yield	Malaysia	Jamaludin *et al*. 1993
Fibre morphology; alkaline pulping; effect of active alkali content; effect of age on pulping	Ghana	Sekyere 1994
Fibre morphology; chemical composition	Malaysia	Jamaludin *et al*. 1994

23. *Bambusa vulgaris* var. *striata*

Fibre morphology; chemical composition; methods of cooking	Belgian Congo (Africa)	Istas *et al*. 1956; Istas 1958
Fibre morphology; chemical composition; methods of cooking	Belgian Congo (Africa)	Istas and Raekelboom 1962
Kraft pulping qualities; bleaching	Philippines	FPRDI 1962
Chemical composition; kraft pulping qualities; pulp characteristics	Philippines	Semana *et al*. 1967

24. *Bambusa vulgaris* var. *vittata*

Chlorination process; bleached kraft pulp	Myanmar	Mai-Aung 1961
High –yield pulping	Brazil	Mazzei *et al*. 1967
Effect of age on sulphate pulping; pulp strength	Brazil	Mazzei and Rediko 1967
Cooking process; kraft pulping; fibre morphology; yield; pulp properties	Brazil	Ciaramellao 1970; Ciaramellao and Azzini 1971 (*Continue next page*)

Rapid alkaline pulping process; yield and strength	Brazil	Barrichello and Foelkel 1975(a, b)
Fibre dimensions; pulp sheet properties	India	Singh *et al*. 1976
Fibre morphology; paper-making properties; pulping suitability	Myanmar	Wai and Murakami 1984
Alkaline sodium sulphite- AQ pulping	China	Yao and Zou 1986

25. *Cephalostachyum pergracile* (Syn *Schizostachyum pergracile*)

Bleachable grade pulp by chlorination process	Myanmar	Mai- Aung 1961
Mixed pulping; bleached kraft pulp; pulp strength	Myanmar	Mai- Aung *et al*. 1968
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Fibre morphology; paper-making properties	Myanmar	Wai and Murakami 1984

26. *Dendrocalamus asper*

Suitability for pulping; pulping with mixed hardwoods	Indonesia	Pasaribu and Silitonga 1974

27. *Dendrocalamus brandisii*

Pulp bleaching	Myanmar	Mai-Aung *et al*. 1968

28. *Dendrocalamus giganteus*

Pulp strength	Africa	Doat 1967
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Sulphate pulp; chemical composition	India	Guha *et al*. 1975
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Physio-chemical properties of spent liquor	India	Vijan and Madan 1995
Chemical composition	India	Vijan and Madan 1996

29. *Dendrocalamus hamiltonii*

Semi-chemical pulping	India	Bhargava 1945
Fibre morphology; chemical composition; pulping; yield (Review)	India	Singh and Mukherjea 1965
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1971, 1976 (a,b,c)
Variation in fibre length	India	Pattanath 1972
Chemical composition	India	Dhawan and Singh 1982
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988
Pulp strength; soda pulping	Pakistan	Suleiman 1994

30. *Dendrocalamus latiflorus*

Industrial kraft pulping	Formosa	Chen 1958
Mechanical pulp for Chinese "Joss" (ceremonial) paper	Taiwan	Perdue *et al*. 1961
Magnifite process	Taiwan	Chao 1963
Alkaline sulphite pulping	Taiwan	Chao and Pan 1963
Kraft pulping; bleaching	Taiwan	Chao and Pan 1972
Methods of cooking; pulp for printing paper; bleaching; yield; pulp properties	Taiwan	Chen *et al*. 1974
High–yield pulping; chemical composition; utilization of residue for pulping	Malaysia	Wang and Lirn 1984
Pulping suitability	Taiwan	Ku and Wang 1990

31. *Dendrocalamus longispathus*

Semi-commercial pulping tests	India	Bhargava 1945
Fibre morphology; chemical composition; methods of cooking; effect of age on pulp properties	Belgian Congo (Africa)	Istas *et al*. 1956
Fibre morphology; chemical composition; method of pulping; yield; types of paper (Review)	India	Singh and Mukherjea 1965
Storage of pulp wood	Myanmar	Mai-Aung *et al*. 1969
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b,c)
Effect of age on fibre morphology; chemical composition; pulping; pulp sheet properties	Bangladesh	Razzaque *et al*. 1981
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Fibre morphology; paper making properties	Myanmar	Wai and Murakami 1984
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988

32. *Dendrocalamus membranaceus*

Fibre morphology; paper making properties	Myanmar	Wai and Murakami 1984

33. *Dendrocalamus strictus*

Pulping trials	India	Ahmed and Karnik 1944
Semi-commercial pulping trial	India	Bhargava 1945
Rayon grade pulping (prehydrolysis sulphate process)	India	Karnik and Sen 1948; Karnik 1961(a ,b)
Fibre morphology; chemical composition; methods of cooking; effect of age on pulping properties	Belgian Congo (Africa)	Istas *et al*. 1956 (*Continue next page*)

Fibre morphology; chemical composition; methods of cooking	Belgian Congo (Africa)	Istas 1958
Fibre morphology	India	Ghosh and Negi 1958
Bleaching; pulp sheet characteristics	India	Guha and Pant 1961
NSSC pulping	India	Guha and Pant 1961
Fibre morphology; chemical composition; methods of cooking	Belgian Congo (Africa)	Istas and Raekelboom 1962
Dissolving grade pulp	India	Pande 1966
Sulphate pulp characteristics; pulp strength; types of paper	India	Guha and Pant 1966
Pulping process	India	Mukherjea 1967
Chemical composition	India	Ingle and Bose 1969
Pulping with mixed hardwoods	India	Bharagava *et al*. 1969
Sulphate pulping	India	Banthia *et al*. 1969(b)
Dissolving grade pulp; steam- vapour phase pre-hydrolysis	India	Pande 1970
Pulping and sulphate pulp sheet properties	India	Tissot 1970
Pulping with mixed hardwoods	India	Guha and Sharma 1970
Fibre morphology; chemical composition; methods of cooking	India	Mukherjea and Guha 1971
Pulping and sulphate pulp sheet properties	India	Singh *et al*. 1971
Variation in fibre length	India	Pattanath 1972
Sulphate pulping	India	Guha *et al*. 1975
Pulping with mixed hardwoods	India	Krishnamachari *et al*. 1975
Alkaline pulping	India	Singh and Guha 1975
Fibre morphology; chemical composition	India	Maheshwari *et al*. 1976
Fibre morphology; chemical composition; pulping	India	Maheshwari *et al*. 1976
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Beating	India	Rao *et al*. 1978
Kraft – AQ pulping	India	Maheshwari 1979
Fibre morphology; kraft paper	India	Guha *et al*. 1980 (a)
Pulping with mixed hardwoods; types of paper	India	Guha *et al*. 1980 (b)
Black liquor analysis	India	Khanna and Swaleh 1981
Pulp and paper-making characteristics	India	Maheshwari 1981 (a)
Pulping with mixed hardwoods	India	Singh *et al*. 1981
Chemical composition	India	Dhawan and Singh 1982
Vapour phase kraft pulping	India	Goyal and Misra 1982(b)
Pre-hydrolysis – effect of pH	India	Devi *et al*. 1982
Chemical composition; bleaching	India	Rao *et al*. 1983
Chemical composition	India	Kapoor and Guha 1984
Improved process control	India	Pravin 1987
Chemical composition	India	Maheshwari and Satpathy 1988
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988
Soda process; pulp strength	Pakistan	Suleiman 1994

34. ***Gigantochloa aspera***

Chemical composition and paper- making properties	Belgian Congo (Africa)	Istas and Hontoy 1952
Storage; fibre characteristics; chemical composition; cooking schedules; pulp and paper properties	Belgian Congo (Africa)	Istas and Raekelboom 1962
Pulping qualities; bleaching	Philippines	FPRDI 1962
Sulphate (kraft) pulping, pulp strength	Philippines	Monsalud 1964; Gonzalez and Escolano 1965
Effect of variables in sulphate pulping	Philippines	Semana 1965
Chemical composition (silica content); kraft pulping qualities; pulp strength	Philippines	Semana *et al*. 1967

35. ******Gigantochloa ater***, **36.** ***Gigantochloa apus*** **&** **37.** ***Gigantochloa verticillata***

Fibre morphology; chemical composition; 3 methods of cooking * Suitability for pulping	Belgian Congo (Africa) * Indonesia	Istas *et al*. 1956 * Pasaribu and Silitonga 1974
Fibre morphology; chemical composition; 3-methods of cooking; effect of age on pulping properties	Belgian Congo (Africa)	Istas 1958
Fibre morphology; chemical composition; 3 methods of cooking	Belgian Congo (Africa)	Istas and Raekelboom 1962

38. ***Gigantochloa levis***

Pulping qualities; bleaching	Philippines	FPRDI 1962
Chemical composition (silica content)	Japan	Tsuji and Ono 1966
Kraft pulping qualities	Philippines	Semana *et al*. 1967

39. ***Gigantochloa scortechinii***

Pulp beating	Malaysia	Jamaludin *et al*. 1992
Effect of age on fibre morphology; chemical composition; pulp sheet properties	Malaysia	Abdul Latif Mohamod *et al*. 1994

40. ***Guadua amplexifolia***

Pulping potential	Mexico	Cunningham and Clark 1970

41 ***Guadauaa angustifolia;*** **42.** ***Guadua glomerata;*** **43.** ***Guada morim ;*** **44.** ***Guada superba***

46. ***Nastus amazonicus***

Chemical, semi-chemical, chemi- mechanical and mechanical pulps; pulp characteristics; types of paper	Brazil	Correa *et al*. 1977

45. *Melocalamus compactiflorus*

Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982

46. *Nastus amazonicus*

Chemical, semi-chemical, chemi- mechanical and mechanical pulps; pulp characteristics; types of paper	Brazil	Correa *et al*. 1977

47. *Melocanna baccifera* (Syn. *Melocanna bambusoides*)

Semi-commercial pulping tests	India	Bhargava 1945
Fibre morphology; chemical composition; method of pulping; yield; product for which the pulp is suitable (Review)	India	Singh and Mukherjea 1965
Rayon grade pulping	Japan	Oye *et al*. 1970
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Kraft – AQ pulping	India	Maheshwari 1979
Fibre morphology; chemical composition; pulping; bleaching; pulp yield; pulp properties; kraft paper	India	Guha *et al*. 1980
Effect of age on chemical composition, fibre dimensions, pulp yield and strength	Bangladesh	Razzaque *et al*. 1981
Chemical composition	India	Dhawan and Singh 1982
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Fibre morphology; paper-making properties	Myanmar	Wai and Murakami 1984
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988
Neutral sulphite –AQ pulping; influence of age on kraft pulping; pulp strength	Bangladesh	Bose *et al*. 1998 (a,b)
Kraft pulping	Bangladesh	Shah *et al*. 1991
Kraft and soda – AQ pulping	Bangladesh	Bhowmick *et al*. 1991 (a, b) & 1992 (b)
Chemical composition; soda process; bleaching; types of paper	Bangladesh	Karim *et al*. 1994
High- yield alkaline/ kraft semi-chemical pulping	Bangladesh	Alam *et al*. 1997(a, b)

48. *Ochlandra scriptoria* (Syn. *Ochlandra rheedii*)

Industrial experience	India	Singh and Mukherjea 1965
Bleaching	India	Singh *et al*. 1977
Kraft pulping conditions	India	Singh *et al*. 1988

49. *Ochlandra travancorica*

Pulping trials	India	Ahamed and Karnik 1944
Semi-commercial pulping tests	India	Bhargava 1945
Rayon grade pulping	India	Anonymous 1947
Chemical composition and paper making properties	Belgian Congo (Africa)	Istas and Hontoy 1952
Fibre dimensions; chemical composition; 3-methods of cooking; effect of age on pulp properties	Belgian Congo (Africa)	Istas *et al*. 1956
Rayon grade pulping	India	Bhat and Viramani 1961
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988

50. *Oxytenanthera abyssinica*

Pulping suitability	Africa	Monteiro 1949
Suitability for pulping	Belgian Congo (Africa)	Frison 1951
Chemical composition; suitability for pulping	Mozambique & Guinea	Seabra 1954
Pulping suitability	Abyssinia (Africa)	Mooney 1959
Storage; fibre characteristics; chemical composition; cooking schedules; pulp and paper properties	Belgian Congo (Africa)	Istas and Raekelboom 1962
Species distribution, pulping suitability	Ghana	Kadambi and Ashong 1966
Pulp strength	Africa	Doat 1967
Variation in fibre length	India	Pattanath 1972

51. *Oxytenanthera monostigma*

Fibre morphology; pulping characteristics	India	Maheshwari *et al*. 1976

52. *Oxytenanthera nigrociliata* (Syn. *Gigantochloa rostrata*)

Semi-commercial pulping tests	India	Bhargava 1945
Fibre morphology; chemical composition; method of pulping; yield; types of paper (Review)	India	Singh and Mukherjea 1965
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b, c)
Effect of age on chemical composition; fibre dimensions; pulp yield and strength	Bangladesh	Razzaque *et al*. 1981
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988

53. *Oxytenanthera ritchei*

Kraft pulping; 3 cooking schedule; bleaching types of paper	India	Bhandari 1981

54. *Phyllostachys bambusoides*

Rayon grade pulping	India	Anonymous 1947
Dissolving grade pulp by pre-hydrolysis and sulphate pulping	Savannah, Ga	Nafzier 1960
Chemical, semi-chemical (cold soda semi-chemical and neutral sulphite) and mechanical pulp for newsprint	Savannah, Ga	Nafziger *et al*. 1961
Newsprint	India	Guha and Pant 1961
Sulphate pulp characteristics; pulp strength; bleaching; types of paper	India	Guha and Pant 1966
Sulphate pulp	India	Guha and Pant 1972

55. *Phyllostachys edulis*

Industrial kraft pulping	Formosa	Chen 1958
Pulping suitability; yield; economics	Georgia (Soviet)	Kandelaki 1976
Utilization of residue for pulping; fibre dimensions; chemical composition; neutral sulphate – AQ process	Taiwan	Wang and Lirn 1984

56. *Phyllostachys makinoi*

Raitt process; effect of different variables; yield; fibre length	Taiwan	Du 1957
Kraft pulping	Taiwan	Chao and Pan 1972
3- methods of cooking; pulp for printing paper; bleaching; yield; pulp properties	Taiwan	Chen *et al*. 1974
Utilization of residue for pulping; fibre dimensions; chemical composition; neutral sulphate – AQ process	Taiwan	Wang and Lirn 1984
Pulping suitability	Taiwan	Ku and Wang 1990

57. *Phyllostachys pubescens*

Mechanical pulp for Chinese "Joss" (ceremonial) paper	Taiwan	Perdue *et al*. 1961
Alkaline sulphite – AQ pulping	China	Yao and Zou 1986
Effect of age on pulping; chemical composition; pulping properties	China	Xia 1989
Pulping suitability	Taiwan	Ku and Wang 1990

58. *Phyllostachys reticulata*

Industrial kraft pulping	Formosa	Chen 1958
Fibre morphology; Effect of age on soda pulping	Japan	Kitamura 1962
Dissolving pulp	Japan	Tsuji *et al*. 1965

59. *Phyllostachys* spp. (2 species)

Chemical composition; pulping suitability; economics;	Georgia (Soviet)	Kandelaki 1976

60. *Pleioblastus amarus*

Pulping suitability	China	Zhang *et al*. 1998

61. *Sasa albomarginata;* 62. *Sasa* spp.

Acid pre-hydrolysis; alkaline (soda) pulping, kraft and neutral sulphite semi-chemical pulping processes; pulp strength	Japan	Fukuyama *et al*. 1955
Pulping trial	Japan	Fukuyama and Kawase 1955
Pulping of young culms	Japan	Kawase *et al*. 1986

63. *Sasa japonica*

Chemical composition and paper making properties	Belgian Congo (Africa)	Istas and Hontoy 1952
Fibre dimensions; chemical composition; 3-methods of cooking; effect of age on pulp properties	Belgian Congo (Africa)	Istas *et al*. 1956
Fibre dimensions; chemical composition; 3-methods of cooking	Belgian Congo (Africa)	Istas 1958; Istas and Raekelboom 1962

64. *Sasa kurilensis*

Chemical composition and paper- making qualities	Belgian Congo (Africa)	Istas and Hontoy 1952
Fibre dimensions; chemical composition; 3-methods of cooking; effect of age on pulp properties	Belgian Congo (Africa)	Istas *et al*. 1956
Fibre dimensions; chemical composition; 3-method of cooking	Belgian Congo (Africa)	Istas 1958; Istas and Raekelboom 1962
Alkaline pulping	Japan	Ujiie *et al*. 1986 (b)
Yield	Japan	Matsui 1963

65. *Sasa paniculata*

Suitability for pulping	Belgian Congo (Africa)	Istas 1958

66. *Sasa senanensis*

Per acetic acid pulping	Japan	Yamagishi *et al*. 1970
Semi-kraft pulp	Japan	Ujiie and Matsumato 1967

67. *Sasa variabilis*

Suitability for pulping	Belgian Congo (Africa)	Istas 1958

68. *Schizostachyum funghomii*

Effect of age on chemical composition, pulping properties	China	Xia 1989

69. *Schizostachyum lumampao*

Pulping qualities; bleaching	Philippines	FPRDI 1962
2- stage and single- stage sulphate pulping, bleaching; yield and paper- making properties; types of paper	Philippines	Anonymous 1966
Kraft pulping qualities	Philippines	Semana *et al*. 1967

70. *Sinocalamus latiflorus*

Fibre morphology; alkaline pulping (Raitt process); yield	Taiwan	Du 1957
Optimum utilization for pulping (bamboo shoot – sheath pulping); neutral sulphite pulping	India	Gupta and Jain 1966
Bleaching	Taiwan	Chen *et al*. 1973
Rayon grade pulping	China	Chang and Kuo 1976

71. *Teinostachyum dullooa* (Syn. *Neohouzeaua dullooa* / *Schizostachyum dullooa*)

Semi-commercial pulping tests	India	Bhargava 1946
Fibre morphology; chemical composition; method of pulping; yield; types of paper (Review)	India	Singh and Mukherjea 1965
Kraft pulp; optimum cooking conditions	Vietnam	Nepenin and Bang 1969
Fibre morphology	Bangladesh	Razzaque and Siddique 1970
Effect of age on chemical composition, fibre dimensions, pulp yield and strength	Bangladesh	Razzaque *et al*. 1981
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982
Storage; pulping; fibre morphology; bleaching; beating; pulp sheet properties	India	Singh *et al*. 1988

72. *Thyrostachys oliveri*

Variation in fibre length	India	Pattanath 1972
Fibre morphology; chemical composition; pulping; alkali consumption; pulp yield; beating; pulp strength; pulp sheet properties	India	Singh *et al*. 1976 (a, b,c)
Fibre morphology	Bangladesh	Siddique and Chowdhury 1982

(*Species confirmation / clarification reference* : Ohrnberger 1999) [114]

The following Table consolidates the available information on investigation on pulping of different species whose actual species details are not obtained (*original articles not seen*) :

1	6 spp.	Raitt process (alkaline pulping); pulping conditions; effect of variables; pulp yield; fibre morphology	Taiwan	Du 1957
2	33 spp.	Fibre structure	China	Chu and Yao 1964
3	13 spp.	Fibre morphology	Philippines	Monsalud 1965
4	11 spp.	Bleached kraft pulp; mixed pulping	Myanmar	Mai- Aung et *al*. 1968
5	5 spp.	3 –cooking conditions	Taiwan	Chen *et al*. 1974
6	13 spp.	Fibre morphology; suitability for pulping	Bangladesh	Siddique and Chowdhury 1982
7	8 spp.	Chemical composition	China	Xia 1989
8	22 spp.	Fibre and paper- making properties	China	Zhang 1995

17. APPENDICES

APPENDIX – 1

A. Some standard terms used in pulping process

Total chemical	:	All sodium salts, expressed as Na_2O
Total alkali	:	$NaOH + Na_2S + Na_2CO_3 + Na_2SO_4$, expressed as Na_2O
Active alkali	:	$NaOH + Na_2S$, expressed as Na_2O
Effective alkali	:	$NaOH + ½ Na_2S$, expressed as Na_2O, ie, the NaOH + the portion of Na_2S that gives NaOH when hydrolysed.
Sulphidity	:	Percentage found by dividing Na_2S by $Na_2S + NaOH$, as Na_2O, and multiplied by 100
Causticity	:	Percentage found by dividing NaOH by $NaOH + Na_2CO_3$, all expressed as Na_2O, and multiplied by 100
Alkali recovery	:	Percentage found by dividing the total alkali delivered to the digesters minus the sodium salts in new chemical by total alkali to the digesters and multiplying by 100. All figures expressed as Na_2O.
Green liquor	:	Liquor made by dissolving the smelt from the recovery furnace (recovered chemicals) in water and weak liquor preparatory to causticizing.
White liquor	:	Liquor made by causticizing the green liquor; the cooking liquor used in the digesters
Black liquor	:	Liquor recovered from digesters
Causticizing	:	Making of white liquor from green liquor by addition of slaked lime

B. Explanation of some general terms used in describing pulp strength properties

Burst strength	-	is a complex function of tensile strength at various angles to the machine direction of the paper together with stretch of the paper in these various directions.
Folding strength	-	is a very complicated function, involving tensile strength, stretch modulus and toughness or brittleness of the fibres.
Stiffness	-	is a direction reflection of the stiffness of the individual fibres assuming an adequate amount of inter-fibre bonding and a standard density level in the paper.

APPENDIX – 2

A. Proximate chemical analysis, fibre dimensions and pulp strength of some cellulose raw materials used in papermaking (all Indian fibres)

Particulars		Bamboo	Pine	Eucalypt	Bagasse	Rice straw	Kenaf
Approximate analysis :							
Lignin	%	26	27	25	18	12	18
Pentosans	%	15	9	20	20	23	20
Alpha cellulose	%	40	41	44	31	32	38
Ash	%	3.0	0.3	0.5	4.5	15	2.5
Fibre dimension :							
Fibre length (ave.)	mm	2.7	3.6	1.2	1.7	1.1	2.0
Fibre diameter (ave.)	µm	15	40	24	17	9	15
Unbleached pulp strength :							
Initial freeness	ml C.S.F.	690	700	650	590	400	550
Final freeness	m1C.S.F.	250	300	250	250	200	250
Breaking length	m.	5700	6900	6500	5100	4300	7000
Burst factor		42	57	50	34	28	55
Tear factor		110	160	75	60	50	95
Double-folds		200	600	320	38	11	400
Sheet density	g/cc	0.6	0.68	0.69	0.66	0.63	0.72
Pulping process		Kraft	Kraft	Kraft	Soda	Soda	Kraft

Initial freeness : m1 C.S.F. milli-litre Canadian freeness.
Final freeness : m1 C.S.F.
Source : Podder (1979)

B. Composition of raw materials used in paper industry. (All values are expressed as percentage on dry basis)

Raw materials	Cellulose (Cross& Bevan)	Pentosan	Lignin	Alcohol Benzene Extractables	Ash	Silica (SiO_2)
Bamboo	57.0	14.0	25	2.0	2.0	1-1.5
Rice straw	51.0	22.0	12	4.0	11.0	4-8
Bhutang grass (stems)	39.3	28.4	22.5	2.1	33.9	1.6
Khagre grass (stems)	36.5	29.0	23.3	4.4	2.7	0.9
Jute (stick)	56.0	20.0	21.0	1.0	2.0	-
Jute	70.0	15.0	11.0	1.0	3.0	-
Sisal hemp	77.0	13.0	6.0	1.0	3.0	-
Bagasse	50.0	25.0	18.0	3.0	4.0	1-1.5
Sal	56.0	13.4	24.9	6.0	1.0	-
Salai	50.7	13.0	27.3	4.3	1.8	0.29
Casuarina	56.7	19.2	23.2	3.4	0.8	-
Pine	61.0	11.0	26.0	1.0	1.0	0.1-0.3
Eucalyptus hybrid	54.0	14.1	30.9	-	0.4	0.03

Source : Podder (1979)

APPENDIX 3

A. Proximate chemical analysis of the two important Indian bamboo species (*Dendrocalamus strictus* and *Bambusa bambos* (Syn. *B. arundinaceae*))

Chemical constituents (%)	*D. strictus*	*B. bambos*
Cellulose (Cross & Bevan)	60.00	57.56
Lignin	23.89	3.09
Pentosans	15.84	19.62
Cold water solubles	7.85	5.95
Alcohol- benzene solubles	1.80	1.22
Other solubles	1.47	0.82
Ash	1.8	3.26
Silica	0.47	1.79
1% caustic soda solubles	23.18	19.35
10% caustic potash solubles	30.52	40.10

Source : Nair (1970)

B. Variation of fibre and tissue characteristics of some Indian bamboos

Sl. No.	Species	Mean fibre length (mm)	Mean fibre diameter (µ m)	Mean luman Diameter (µ m)	Parenchyma (%)
1	*Bambusa bambos*	2.24	16	4	21.7
2	*Bambusa nutans*	2.40	15	3	20.6
3	*Bambusa polymorpha*	2.53	16	4	22.4
4	*Bambusa tulda*	2.10	15	5	18.4
5	*Bambusa vulgaris*	2.02	15	5	20.0
6	*Cephalostachyum pergracile*	2.20	16	4	18.3
7	*Dendrocalamus hamiltonii*	2.40	13	3	26.6
8	*Dendrocalamus longispathus*	2.70	15	3	17.5
9	*Dendrocalamus strictus*	2.45	14	2	21.2
10	*Melocanna baccifera*	2.78	15	3	19.5
11	*Oxytenanthera nigrociliata*	2.43	15	3	18.7
12	*Thyrostachys olivery*	2.31	15	3	19.5

Source : Singh (1989)

APPENDIX – 4

A. Survey of pulping processes

Process / Pulp type			Chemical treatment	Mechanical treatment	Wood+	Yield (%)
Mechanical pulping						**80 - 99**
Stone grinding *		Groundwood (SGW)	None	Grindstone	S	93- 99
				Grindstone	S	80- 90
		Steamed ground-wood	Steam			
	**	Pressure ground-wood (PGW)	None	Grindstone (pressure)	S	
Refiner pulping		Refiner mechanical pulp (RMP)	None	Disk refiner	S	93-98
	**	Pressurized refiner mechanical pulp (PRMP)	None	Disk refiner (pressure)	S	
		Thermo-mechanical pulp (TMP)	Steam	Disk refiner (pressure)	S	91-98
		Asplund pulp	Steam	Disk refiner	S	80-90
Chemimechanical and Chemi-thermomechanical pulping						**65 - 97**
Stone grinding *		Chemigroundwood (CGW)	Neutral sulphite Or	Grindstone	S/ H	80-92
			Acidic sulphite Or		S/ H	80-90
			Na_2S + NaOH		S/ H	85-90
Refiner pulping		Chemi-refiner mechanical pulp (CRMP)	NaOH or $NaHSO_3$ Or Alkaline sulphite Or Acidic sulphite	Disk refiner	S/ H	80-90
		Chemi-thermo-mechanical pulp (CTMP)	Steam + Na2SO_3 + NaOH	Disk refiner (pressure)	S/ H	65-97
Semichemical pulping						**65 - 92**
		Neutral sulphite (NSSC-pulp)	Na_2SO_3 + Na_2CO_3 or $NaHCO_3$	Disk refiner	H	65-90
		Cold soda	NaOH	Disk refiner	H	85-92
		Alkaline sulphite	Na_2CO_3, Na_2S, NaOH NaOH + Na_2S	Disk refiner	H/ S	80-90
		Sulphate	NaOH	Disk refiner	H/ S	75-85
		Soda	$Na2_S$ + Na_2CO_3	Disk refiner	H	65-85
		Green liquor	Na_2CO_3 + NaOH	Disk refiner	H	65-85
		Nonsulphur		Disk refiner	H	65-85
High-yield chemical pulping						**55 - 70**
		Kraft	Na2S + NaOH	Disk refiner	S/ H	55-65
		Sulphite	Acidic sulphite (Ca, Na, Mg)or Bisulphite (Na, Mg)	Disk refiner	S	55-70

(*continue next page*)

Full chemical pulping					**30 - 60**
Alkaline pulping	Kraft (+ AQ)	$NaOH + Na_2S$ (+ AQ)	Mild to none	S/ H	40-55
	Kraft (Polysulphide)	$(NaOH + Na_2S)_x$	None	S/ H	45-60
	Soda	NaOH	None	H	40-55
	Soda – AQ	NaOH + AQ	Mild to none	H	45-55
	Soda – oxygen, two-stage	NaOH, oxygen	Disk refiner	H	45-60
Sulphite pulping	Acidic sulphite	Acidic sulphite (Ca, Na, Mg, NH_3)	Mild to none	S (no pine)	45-55
	Bisulphite	Bisulphite (Na, Mg, NH_3)	Mild to none	S/ H	45-60
	Neutral sulphite	Neutral sulphite	Mild to none	S/ H	45-60
	Magnefite	Mg- bisulphite	Mild to none	S/ H	45-60
	Multi-stage sulphite	Na_2SO_3 + $NaHSO_3$/ SO_2 or $NaHSO_3$ + SO_2/ Na_2CO_3	None	S/ H	45-55
**	Alkaline sulphite	Na_2SO_3 + NaOH	None	S/ H	
Dissolving pulping	Acidic sulphite	Acidic sulphite (Ca, Na)	None	H/ S	35-42
	Prehydrolysis kraft	Na_2S + NaOH after prehydrolysis	None	H/ S	30-35

* Wood used in the form of bolts. All the other processes use chips.
\+ Wood mainly used (S: softwood, H: hardwood)
** Not commercially established
Source : Fengel and Wegener (1984)

B. Non-conventional pulping procedures

Procedure	Process data
Nitric acid pulping	HNO_3 (1-60%); 15-150^{0}C; 0.25-3h; extraction with aqueous NH_4OH and /or NaOH
Hydrotropic pulping	Na-m-xylene sulfonate, Na-p-toluene sulfonate, Na-benzonate, Na-salicylate etc. in H_2O or organic solvents; 150-170^{0}C; 0.5-6h
Organosolv puling	Ethanol/ H_2O (1:1); 180-215^{0}C; 20-60 min Methanol/ H_2O (1:1); 150-210^{0}C; 30-180 min, 2 steps alkaline medium Butanol/ H_2O or Phenol/ H_2O (1:1); 180-205^{0}C; 2-12h
Alkali- methanol pulping	4% NaOH in 40% methanol; 140-160^{0}C; 30-120 min
Phenol pulping	Phenol (+ H_2O, HCl); 160-170^{0}C; 3-4 h
Holopulping	Defibration of alkali-impregnated chips; ClO_2 –delignification; extraction with alkali; disk refining
Acetic acid pulping	CH_3COOH/ conc. HCl/ acetone (7:1:2); 70^{0}C; 3- 6 h
DMSO pulping	DMSO/ H_2SO_4 (99:1), V/ V); 130- 160^{0}C NO_2/ SO_2/ H_2S or Cl_2 in DMSO or DMF; → 140^{0}C; 0.5- 3 h DMSO/ EDA, DMSO/ hydrazine; DMSO/ CH_3COOH, H_2SO_4 or HCl; 145-176^{0}C; 20 min- 3 h
NO_2 delignification	NO2 (2-3%) in coal oil or CCl_4; room temp.; 10-30 min; extraction with 1% NaOH
Vapour- phase SO_2- process	Saturated SO_2 vapour; → 110^{0}C
Explosion- CO_2- process	Aqueous CO_2 –solution; 160- 200^{0}C; 50 bar; pressure reduction defibration
Autohydrolysis delignification	Autohydrolysis (175- 220^{0}C); 4- 120 min; also in the presence of aromatic compounds (e.g. 2-naphtol); extraction with dioxane/ H_2O; defibration
Ketone delignification	Acetone, methyl- ethyl ketone; cyclohexanone or ketone- ammonia mixtures; 175- 210^{0}C; 60-150 min
Formaldehyde pulping	HCHO (25-50%); 130-200^{0}C; 5-200 min

Source : Fengel and Wegner (1984)

APPENDIX – 5

A. **Alkali consumption, Kappa No., unbleached pulp yield and chemical composition of some Indian bamboos and their pulps**

Sl. No.	Species	Caustic soda used in (%)	Kappa number	Pulp yield (%) Unscreened	Pulp yield (%) Screened	Chemical composition (%) Lignin in bamboo	Lignin in pulp	Pentosan in bamboo	Pentosan in pulp
1	*Bambusa bambos*	21	27.4	52.1	51.7	24.2	3.1	20.8	16.2
2	*Bambusa nutans*	20	24.3	54.7	54.5	21.7	2.8	20.0	16.8
3	*Bambusa polymorpha*	20	27.2	44.4	43.4	24.7	3.0	18.5	17.0
4	*Bambusa tulda*	21	28.2	54.8	54.4	23.1	4.7	18.1	11.3
5	*Bambusa vulgaris*	22	24.3	44.4	43.8	22.9	3.6	21.0	17.6
6	*Cephalostachyum pergracile*	20	28.2	54.5	52.8	24.9	4.3	18.4	15.9
7	*Dendrocalamus hamiltonii*	19	27.4	56.6	54.2	22.4	3.7	16.9	16.1
8	*Dendrocalamus longispathus*	20	25.2	48.9	48.4	25.0	3.9	18.6	15.8
9	*Dendrocalamus strictus*	22	28.0	51.0	50.9	26.0	3.0	23.2	15.3
10	*Melocanna baccifera*	25	25.0	43.9	43.8	27.0	4.1	19.6	15.5
11	*Oxytenanthera nigrociliata*	23	27.9	52.0	51.8	22.6	3.8	16.2	16.7
12	*Thyrostachys olivery*	22	27.2	48.9	47.0	20.9	3.0	18.5	17.0

Source : Singh (1989)

B. Characteristics of unbleached bamboo cold-soda pulp

Characteristics	Value
Kappa number	158
Brightness (% ISO)	19.40
Yellowness (%)	53.80
Ash (%)	2.50
Silica (%)	1.20
Solubility (%)	
(a) in cold water	2.74
(b) in 0.1N NaOH	11.36
Klason lignin (corrected for ash) (%)	23.31
Acid- soluble lignin (%)	0.90
Holocellulose (%)	71.14
Pentosans (%)	15.60

Source : Islam *et al*. (1989)

C. **Characteristics of rayon grade pulp produced from bamboo at M/s. Gwalior Rayons Silk Manufacturing Company, Kerala, India and that imported from Alaska**

Characteristics	**Indian bamboo rayon pulp**	**Imported rayon pulp from Alaska (Coniferous softwoods)**
Alpha cellulose (%)	95.30	93.03
Hemicelluloses (%)	4.62	4.05
Soda solubles (solubility in 7.14% NaOH (%)	6.87	11.18
Ether solubles (%)	0.21	1.3
Swelling index	6.6	6.42
Ash (%)	0.039	0.187
SiO_2 (%)	0.011	0.0048
Fe (ppm)	14	15
CaO (%)	0.003	0.025
Mg (%)	Traces	Traces
Fluidity (cp)	35.6	17.3
Copper number	0.7	1.4
Size (mm)	793 x 595	760 x 600
Basic weight (gm/m^2)	400	------

Source : Nair (1970)

APPENDIX – 6

A. Bleaching chemicals

	Oxidizing chemicals		Reducing chemicals	
Industrially important	Chlorine	Cl_2	Sodium dithionite	$Na_2S_2O_4$
	Sodium hypochlorite	$NaOCl$	Zinc dithionite	ZnS_2O_4
	Calcium hypochlorite	$Ca(OCl)_2$	Sodium bisulphite	$NaHSO_3$
	Chlorine dioxide	ClO_2		
	Hydrogen peroxide	H_2O_2		
	Sodium peroxide	Na_2O_2		
	Oxygen	O_2		
Less important or not commercially applied	Ozone	O_3	Sulphur dioxide	SO_2
	Sodium chlorite	$NaClO_2$	Sodium borohydride	$NaBH_4$
	Peracetic acid	CH_3CO_3H	Calcium dithionite	CaS_2O_4
	Chlorine monoxide	Cl_2O	Aluminium dithionite	$Al_2(S_2O_4)_3$
	Thioglycolic acid	$CH_2SHCOOH$		
	Hydrogen	H_2		
	Potassium-permanganate	$KMnO_4$		

B. General conditions / Parameters governing bleaching processes

Consistency (pounds of fibre in 100 pound of suspension, determined by the specific stage and type of equipment used for the stage); chemical addition (the percentage of chemical added, based on the amount of pulp in the stage); chemical/ bleach consumption (the percentage of active chemical consumed, based on the amount of chemical added); chemical concentration (the amount of chemical per given volume of liquid in the stage, which is controlled by the chemical requirement of the pulp and the consistency at which the particular stage operates); pH (determined by conditions of reactions); temperature (detected by the type of reaction and the conditions of the state); and time (determined by the type of reaction and the conditions for the particular stage).

C. The symbols used to describe the sequences used in multi-stage bleaching of pulps

Stage	Symbol	Chemicals
Chlorination	C	Cl_2
Alkaline extraction	E	NaOH
Hypochlorite	H	NaOCl + NaOH
Chlorine dioxide	D	ClO_2
Peroxide	P or P/ E	H_2O_2 + NaOH or
		Na_2O_2 + NaOH
Oxygen	O	O_2 + NaOH
Cupriethylenediamine	Cu En_2	$[Cu(H_2NCH_2CH_2NH_2)_4](OH)_2$
Chlorination with small amounts of ClO_2	C_D	Cl_2 + (ClO_2)
Sequential bleaching without intermediate washing	D/C	ClO_2/Cl_2
	C/H	Cl_2/NaoCl+NaOH
	D/H	ClO_2/NaOCl+NaOH
Bleaching with a mixture of Cl_2 and ClO_2	C + D	Cl_2 + ClO_2
Chlorination at low concentration	(C)	Cl_2
Gas-phase bleaching	C_g	Cl_2
	D_g	ClO_2
Ozone	Z	O_3
Acid	A	e.g. CH_3CO_3H

D. Common industrial bleaching sequences

SULPHITE AND BISULPHITE PULPS			KRAFT PULPS				
3- stages	**4- stages**	**5- stages**	**3- stages** (semi-bleached)	**4- stages** (partly semi-bleached)	**5- stages**	**6- stages**	**7- stages**
C-E-H	C-E-H-H	C-E-H-D-H	C-E-H	C-E-H-D	C-E-H-P-D	C-H-E-D-E-D	C-H-H-D-E-D-P
	C-E-H-D	C-C-E-H-H	D/C-O-D	C-E-H-P	C-E-H-D-P	C-E-H-D-E-D	
	C-E-D-H			C-E-H-H	C-E-H-E-H	C-E-H-E-H-D	
	C-C-E-H			C-H-E-H	C-E-D-E-D	C-E-H-D-P-D	
	C-H-E-H			C-D-E-D	C-E-D-P-D	C-E-H-E-D-P	
	H-C-E-H			O-C-E-H	C-E-H-E-D	C+D-E-H-D-E-D	
	C-E-D-D/H			O-C-E-D	C-H-D-E-D	C-E-H-D-E-D	
	C+D-E-H-D			O-D-E-D	D-E-D-E-D	O-C-E-D-E-D	
	E-C-H-D			O-D-O-D	C-C/H-E-H-H	O-C+D-E-D-E-D	
						O-D-E-D-E-D	
						O-C-D-E-H-D	

Source : Rydholms (1965)

E. Non-established bleaching sequences

Reduced chlorine application	(C)-P-H
	(C)-P-D-H
	(C)-P-H-D-H
Peroxide replacing chlorine	P-D-P
	P-D-H
	P-H-H
	P-H-D
	D-P-D
	P-H-D-H
	P-D-P-D
Oxygen bleaching	O-P
	O-D
	O-H
	O-P-D
	O-D-P
	O-C-P
	O-H-P
	O-C-P-D
	O-D-P-D
	O-C_g-E-D_g
	O- D_g-E- D_g
Ozone bleaching	Z-E-P
	Z-E-Z
	Z-E-Z-P
Peracetic acid	P-A-P
	A-E-A-E-A

Source : Fengel and Wegener (1984)

APPENDIX - 7

Mean values of strength properties of unbeaten and beaten pulp of some Indian bamboo species

Sl. No.	Species	Breaking length (m)		Burst factor		Tear factor	
		Unbeaten	Beaten	Unbeaten	Beaten	Unbeaten	Beaten
1	*Bambusa bambos*	2240	6750	8.0	41.3	54.5	122.9
2	*Bambusa nutans*	1430	7560	4.9	42.8	39.2	166.9
3	*Bambusa polymorpha*	1990	6320	8.0	51.3	76.4	218.7
4	*Bambusa tulda*	1060	7460	5.2	50.0	49.0	181.2
5	*Bambusa vulgaris*	2070	7260	9.1	50.9	88.2	134.9
6	*Cephalostachyum pergracile*	1730	7550	5.1	47.3	36.1	149.8
7	*Dendrocalamus hamiltonii*	2620	8320	10.2	53.3	133.9	194.7
8	*Dendrocalamus longispathus*	1450	7360	4.2	52.0	70.1	164.7
9	*Dendrocalamus strictus*	1440	6470	4.9	44.7	48.5	190.4
10	*Melocanna baccifera*	820	5480	2.9	40.0	32.0	210.7
11	*Oxytenanthera nigrociliata*	1580	6730	7.0	49.0	31.7	168.0
12	*Thyrostachys olivery*	1160	5800	2.5	48.4	52.6	164.1

Source : Singh (1989)

APPENDIX – 8

Suitability of some Indian bamboo species for pulp and paper

Sl. No.	Species	Average fibre length (mm)	Method of pulping	Bleached pulp yield (%)	Product for which the pulp is suitable
1	*Bambusa bambos*	2.75	Kraft (sulphate)	39.0	Writing and printing paper
			Water prehydrolysis sulphate	28.3	Rayon
2	*Bambusa polymorpha*	3.19	Kraft	41.3	Writing and printing paper
3	*Bambusa tulda*	2.98	Kraft	41.0	Writing and printing paper
			Mechanical	-	Newsprint, cheap paper and board
4	*Dendrocalamus hamiltonii*	3.36	Kraft	42.5	Writing and printing paper
5	*Dendrocalamus longispathus*	3.50	Kraft	41.3	Writing and printing paper
6	*Dendrocalamus strictus*	3.06	Kraft	47.2	Writing, printing, wrapping and greaseproof paper
			Water prehydrolysis sulphate	27.3	Cellulose derivatives and viscose rayon
			Mechanical	-	Newsprint, cheap paper and board, pressed board
			NSSC	44.0	Writing, printing and wrapping paper
7	*Melocanna baccifera* (Syn. *M. bambusoides*)	2.72	Kraft	41.8	Writing and printing paper
			Water prehydrolysis sulphate	32.2	Rayon
8	*Ochlandra travancorica*	4.03	Kraft	45.8	Writing and printing paper
			Water prehydrolysis sulphate	32.0	Rayon
9	*Oxytenanthera nigrociliata*	3.55	Kraft	42.2	Writing and printing paper

Source : Nair (1970)

APPENDIX – 9

A. Grades of paper

Sl No.	Type of paper	Made from	Description, Properties & Remarks
1	**Writing papers**		
	-Ordinary	Chemical pulps of wood, bamboo or grasses.	For writing purposes, records, letterheads, business forms etc.
	- High grade (*bond and ledger paper*)	From rags.	For document paper - High strength, stiffness, permanence, and durability for repeated handling, resistance to the penetration and spreading of ink, brightness, and cleanliness are the desired properties. . Good appearance, opacity, surface finish, good ink receptivity, capability to withstand action of eraser are also desired. The principal uses of bond paper are for letterhead stationary, advertising pieces, announcements, leases, deeds, writs, judgements and other legal documents, certificates and insurance policies.
	- Cheap quality	A mixture of chemical pulps and ground wood pulp	
	- Laid papers		Paper with ribbed like appearance; produced by the use of a dandy roll on which the wires are laid side by side.
	- Wove papers		Do not have the wire marks; the dandy is covered with a wire cloth during preparation.
	- Water mark paper		A design is soldered on the dandy roll. The raised portion of the design lightly touch the wet web of paper on the fordrinier wire at a suitable place between the suction boxes, making the paper slightly thinner at the places of contact and thus producing the water mark.

2	**Printing papers**		Printing papers are soft- sized since oil-based inks are used for printing. Requires good opacity so that the printed matter on one side of the paper is not discernible from the other side. Requires good finish and more absorbent towards printing ink. This is achieved by using the filler, china clay
	- *Newsprint*	Ground wood with small amount of chemical wood pulp	For newspapers; low cost magazines, paper bound books, catalogs, directories and for general commercial printing. Desires an even, uniform formation and high opacity. Do not have high whiteness and tend to turn yellow when expose to light and after long aging. These papers are bulky and are receptive to printing ink. Cheapness and necessary strength are of prime concerns. Halftone illustrations should be recognizable. The paper is machine finished and has little or no mineral loading. Durability is not a concern.
	- *Ordinary paper*	Chemical pulps from wood, grasses, bamboo etc.	
	- *Low quality paper*	Groundwood pulp mixed with chemical puls	
	- *Coated* book *papers* (*machine-coated papers*)		Suitable for graphic arts; for use as book papers, for best reproduction of fine halftone illustrations. With uniformly smooth surface, with good ink receptivity, have high brightness and gloss, and be capable of folding without cracking.
	- *Uncoated book papers*	Soda pulp	Uncoated book paper is available in four finishes: *Antique or egg shell* – made from slightly beaten stock, the sheet is only lightly calendared to provide a degree of surface smoothness while preserving the antique or egg shell appearance. *Machine finish* – has a medium –smooth surface for this finish from a calendar stock at the dry end of the machine. Use for books, catalogs, circulars, and other matter using line etchings and for halftone illustrations upto 100-line screen. Machine finish book is a relatively inexpensive general utility paper. *English finish* – a step higher in the book paper scale; by a higher degree of beaten stock. *Supercalendared* – is the smoothest surface that can be obtained without coating. It is used for books, brochures and magazines where halftone printing in the range of 100-120 line screen is required.
	- *Bible paper*	Cotton or linen rags	Light weight, thin, strong, opaque sheets for such books as bibles, dictionaries, and encyclopaedias, which require minimum bulk. Bible papers are pigmented (loaded) with such pigments as titanium dioxide and barium sulphate and contain long fibres and artificial bonding agents.

3	**Wrapping or bag papers**	Unbleached light brown kraft pulp	Requires strength, toughness and playability. The colour, formation and surface are of secondary importance only. Machine glazed for paper bag
	- *Kraft paper* (*multi wall bags*)	Kraft pulp from coniferous species	Requires outstanding tensile and tearing strength. Kraft wrapping is sized to retard wetting when exposed to water. Wet strength was imparted with special resins. For multi wall bags (for storing or transport of cement, shipment of bulk materials etc.) require higher strength properties. In some multi wall bags an inner lining of specially treated paper was used to provide. Grocer's bags are usually made of kraft paper.
	- *Notion bags*	Mixture of several pulps	For packaging light materials
	- *Other bags*		Requires water resistant papers with high wet strength.
	- *Fancy bags*	Sulphite pulp	For food packaging
4	**Sanitary papers (Absorbent papers)**	Various proportions of sulphite and bleached kraft pulp.	Little refining of the stock to preserve a soft, bulky, absorbent sheet; further softened by machine creping. Sanitary papers include : Towelling, facial tissue, napkins, etc. Because of the soft bulky texture of sanitary papers, they are relatively weak. To improve wet strength, they are treated with resins. The plastic nature of paper fibres when slightly moist permits the reproduction of surface patterns by embossing to a remarkable degree in paper napkins.
	- *Water leaf*		Absorbent papers, which are not sized. eg. blotting papers, cigarette papers, artificial leather paper, and vulcanised fibre etc.
5	**Wall paper** **(Hanging paper)**		
	- *Grade* 1	Bleached chemical wood pulps and small amount of groundwood pulp.	The essential properties are softness, playability, resistance to water, maximum bulk and minimum weight.
	- *Grade* 2	Major portion is groundwood pulp with small quantity of sulphite pulp.	

6	**Speciality papers :**		
	- *Currency paper*	Pulp from new rags	Tub sized with animal glue. Require high tensile strength, high folding endurance, and resistance to bear. It has also special features to protect against counterfeiting. Use for printing paper currency, Government securities etc.
	- *Cheque paper*		Not fully sized paper and have surface which readily comes away when strapped with a knife or wetted with an ink-remover. Some of this contains chemicals which change in colour when ink-remover is applied, leaving a characteristic stain. Used for cheque forms and similar documents on which the writing is liable to be tampered.
	- *Cigarette paper*	Pure flax, or linen fibre, hemp fibre and ramie pulps	The paper must be thin but opaque and must have no characteristic smell or taste on burning. Opacity is secured by addition of filler such as calcium carbonate which gives a good white appearance and helps to promote uniform burning of the paper.
	- *Blotting paper*	Rags, linters, chemical or mechanical wood pulps or mixture of these depending upon the quality required.	This is an unsized paper used to absorb excess ink from freshly written letters, manuscripts etc. The paper is aurous, bulky and of little strength.
	- *Manifold paper*		This a typical bond paper in light basis weights. Finish and porosity are important properties in this type of paper. Used for copies by interleaving with carbon paper.
	- *Grease proof paper*	Chemical wood pulps which are highly hydrated in the process of beating	Impervious to oil or grease. Use for wrapping greasy food products. High hydration imparts greaseproofness to the paper, which has comparatively few interconnecting pores between the fibres.
	- *Glassine paper*	Chemical wood pulp which are highly beaten (hydrated).	This is a dense glazed greaseproof paper. The greaseproof paper is put through a special super-calendar with a number of steam-heated rolls, so as to make it more smooth and transparent. When waxed, this paper becomes almost impervious to air and vapours used as wrapper for food products, tobacco, chemicals and also in the manufacture of bags, envelops, book covers etc
	- *Cartridge paper* (*Drawing paper*)	Kraft pulp or a mixture of karft and jute pulp. Bamboo kraft pulp is used for this purpose in Indian paper mills.	Used for making cases for cartridges require to be very strong
	- *Insulating paper*		Special properties may be given to these papers by mixing various additives into the pulps. These are divided into three classes : *Insulating materials* – such as floor lining felts, roofing felts, creep wadding, sheathing, and wallboards. *Electrical insulating materials* – include cable paper, condenser tissue vulcanised fibre, vegetable parchment, and paper impregnated with shellac, paraffin or bakelite *Sound insulating materials* – such as acoustical board. and paper impregnated with shellac, paraffin or bakelite Sound insulating materials – such as acoustical board.

7	**Bristol**	Various combinations of chemical wood pulp	Bristol refers to a group of stiff, heavy papers with thicknesses ranging from 0.15mm upward. The stock is beaten to a medium degree and usually well sized to prevent penetration of moisture. Used for punch cards in tabulating and sorting machines.
8	**Paperboards**	Wood, straw, waste paper pulps or a combination of these materials	Paperboard refers products of 0.30mm or more in thickness made from pulp.
	- *Boxboards*		Used for such products as food board, food trays, plates, and paper boxes / cartons for packaging. A wide range of properties, including particular strength, bending and scoring characteristics and a suitable surface for printing, can be built into this grade of paper. Resistance to air, water, fire, and oil can be obtained by appropriate treatments in the manufacturing process.
	- *Container boards*		For the manufacture of corrugated and solid fibre shipping containers
	- *Paperboard specialities*		Include such items as binder's board, electrical pressboard, and building boards
	- *Duplex board*	Sulphite and sulphate pulps	This is a paperboard made in two layers, the two sides being of two different colours or the layers may be from two different grades of stocks. This is made on a paper machine. The paper is used for cover papers, boxboard etc. Good tear resistance and playability are required. The papers are hard sized and are of high machine finish. Sometimes a high super-calendar finish was used to give
	- *Triplex board*	The top and bottom layers are made of rag, wood, or bamboo pulp or a mixture of any of these pulps, while the middle layer is of the groundwood or waste paper pulp.	This a paperboard made in three different layers pressed together. Made on a cylinder mould machine in the same way as duplex board. This is machine glazed and is used as cover paper

B. Types of commercial papers/ paper boards produced in India from bamboos

Bamboo pulp is reported to be currently used for the production of the following types of paper/ paperboards in India.

1. Printing paper

(a). *White printing paper / Coloured printing paper* : Hard sized paper of all kinds are suitable for writing. But an even paper of good surface is essential, generally machine finished.

(b). *Imitation art paper* : This is a highly finished printing paper manufactured by the addition of heavy percentage of China clay to the pulp and water finished or super-calenderer to give it a surface, opacity and absorbency, may be white or coloured.

(c). *Offset printing paper* : This type of paper is suitable for the offset printing process. It is normally made from bamboo or grass stock and may contain some amount of rag and wood pulp. It may be white or coloured.

(d). *M.G. poster paper* : A variety of paper which has been machine-glazed (M.G), suitable for printing posters, labels, etc.; may be white/ coloured.

2. Writing papers

(a). *Azure laid / Ledger paper* : An account book paper usually pale blue in colour and with laid lines.

(b). *Airmail / Manifold paper* : Lightweight well sized writing paper of a substance not greater than 35g/m^2 used for copying with carbon paper. Airmail papers are similar to manifold papers but are lighter in weight.

(c). *Bond paper* : A strong, durable, high class, writing paper with good surface characteristics and erasing quality of substance above 50 g/m^2.

3. Packing and wrapping paper

(a). *Match paper* : Coloured wrapping paper normally machine glazed (M.G) and used for the manufacture and packing of matchboxes. Normally made from bamboo pulp with a fairly large proportion of waste paper (usually blue or green).

(b). *Common wrapping paper* : Cheaper grades or wrapping papers made from bamboo, grass, rags and waste as well as recovered fibre. May be machine glazed or machine finished.

4. Paper boards

(a). *Duplex/Triplex board* : Two plyboard manufactured wholly from bamboo and bagasse or with one ply made an admixture of bamboo and bagasse while the other ply is made from waste paper/ mechanical pulp; may be white or coloured or may have two different colours in either ply. Board with three or more piles, has inferior furnish in the middle layer; may be white or coloured or may have different colours in either ply.

(b). *Ticket board* : Thick paste boards made from ticket middles or white mechanical bamboo pulp middles and white or coloured facing papers of mechanical pulp or sometimes coated with white or tinted coated liners are employed and used for show cards and window tickets, price tags, season tickets, etc.

(c). *Pulp board / Boxboard* : White and tinted, made from bamboo pulp on an ordinary Fourdrinier machine, well sized and finished in matt, super-calendared or water finishes in two sheets. Used for all kinds of general printing work such as tickets, cards, menu cards, price tags, etc.

(d). *Post card /Board* : Pulp boards are manufactured in one or two plys (simplex board). The term is used to distinguish it from paste board which consists of two or more layers pasted together. It is usually made from bamboo or grass pulp and may be coloured or white. It includes postcard boards and Bristol boards.

(e). *Tag boards* : Tag boards are mad from strong stuff furnishes of bamboo pulp. The boards must be even, hard sized and well rolled to give a good writing surface and lie perfectly flat for accurate ruling, printing and cutting. Made in buff, white and tints for card index systems in single thickness, as pasted boards bend and split at the corners with frequent handling.

5. Newsprint

Bamboo chemical pulp mixed with mechanical hardwood pulps are used for newsprint.

Source : Podder (1979)

PART - III

ANNOTATED BIBLIOGRAPHY

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General Pulping and Paper Making

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24. Atchison, J.E. 1996. **Twentyfive years of global progress in nonwood plant fiber repulping**. TAPPI Journal 79(10): 87-95.

25. Belvin, W.L. 1957. **Opportunities for increased use of hardwoods through improved pulping technique and processes**. Forest Products Journal 7(11): 424-426.

Discusses the need for, and economic advantages of, hardwood pulping, particularly in the Southern U.S.A., briefly surveying the chief processes-semichemical, chemi-groundwood and cold soda and the suitability of the pulps for various types of paper, on the basis of U.S. literature. Recent research into bamboo growing and pulping in the south is briefly mentioned. It is thought to be a promising material.

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Tests have been carried out with materials from three species of conifers, seven species of broadleaved trees and three species of bamboos to determine their use in the manufacture of newsprint, cheap papers and boards. Of the conifers, Abies pindrow and Picea morinda are suitable for newsprint production, and supplies of these species are said to be sufficient in Kashmir and Tehri-Garhwal States to support a moderate-sized newsprint mill. Pinus longifolia saplings are suitable for newsprint production, but supplies are uncertain. Of the broadleaved species, Broussonetia papyrifera, Kydia calycina and Excaecaria agallocha show promise for newsprint production but are not at present available in sufficient quantity to support a newsprint mill. Materials from the other four broadleaved species, mature Pinus longifolia, and the bamboo species yielded brown-coloured pulps unsuitable for newsprint production, which could, however, be utilized in small proportions in the manufacture of cheap wrapping papers, duplex boards and triplex boards.

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A report based on information from India, Bangladesh, Burma and Thailand. The aspects considered are; structure of bamboo forests, statistical information, labour force, transport systems, felling and conversion, off-road transport, long distance transportation, cost summary and mechanization and rationalization of harvesting. Difficulties of harvesting peculiar to bamboo are pointed out and fields for further research are suggested. A list of principal bamboo species used for pulp and paper, data on transport systems and cost of mechanized felling and extraction, etc. are included as appendices.

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The potential use of water hyacinth as a pulp material for producing greaseproof paper was investigated using plants collected from freshwater ponds in Jorhat. The proximate chemical analyses of the raw materials, the morphology, of the water hyacinth stalk and fibre, pulp characteristics, and data on the physical properties of the paper handsheets formed from water hyacinth and bamboo pulps and their blends are presented. Blending of water hyacinth and bamboo pulps increased the physical strength. Paper handsheets made with a blend of water hyacinth pulp (75^oSR) and bamboo pulp (80^oSR), at 75:25 proportion, gave a tear index of 4.90 mN m^2 g^{-1}, tensile index of 51.10 N mg^{-1} and burst index of 7.25 kPa m^2 g^{-1}. These were higher than values obtained from sheets made with pulp blends (water hyacinth:bamboo) of 80:20 or 90:10. The pulp sheets at a blend proportion of 75:25 also gave satisfactory greaseproof properties.

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43. Harris, J.F. 1974. **The role of total process concepts in evaluating pulping research**. Proceedings of the TAPPI Non-sulphur Pulping Symposium, Madison: 161-167.

44. Istas, J.R. 1958. **Studies on the use of tropical species of papyrus for paper-making**. Bulletin, Association Technique de Industries Papetiere, Paris (1): 18p.

Presents results of chemical and morphological examinations and of various pulping experiments on raw materials from the Belgian Congo. Although papyrus could be pulped satisfactorily, yields were too low for commercial use. Pulps from individual hardwood species were, with few exceptions, inferior to Pinus sylvestris; pulps of mixed species had qualities similar but slightly inferior to that of P. sylvestris. Bamboos are not at presently available in sufficient quantities, but more could be planted. The dwarf bamboos (Sasa paniculata, S. variabilis, Arundinaria nitida and A. simonii) are unsuitable for pulping (short, fine stiff fibres); the largest species examined (fibre length 2.7 mm.) gave promising results, especially Bambusa vulgaris.

45. Joedodibroto, R; Sugiharto, A. 1996. **Can bamboo substitute Pinus merkusii in paper making? An overall comparative study**. Bamboo, People and the Environment Vol.3 Engineering and Utilization. Proceedings of the Vth Internation Bamboo Workshop, Ubud, Bali, Indonesia, 19-22 June 1995. INBAR Technical Report 8. International Network for Bamboo and Rattan, New Delhi: 246-257.

Bamboo has a woody structure and relatively long fibres, and the culms can be harvested when 2-3 years old. Pinus merkusii, on the other hand, is a softwood with long fibres and its rotation is 15 years. It is of interest to know whether some bamboo species could be used as a substitute for P. merkusii in paper making and there by save timber resources and promote industrial bamboo plantations. This paper reports the results of a comparative study. If Gigantochloa apus and P. merkussii with regards to producing pulp for making strong paper. The results showed that G. apus pulp can be used as a substitute for P. merkusii pulp in paper making by choosing appropriate pulping conditions and pulp mixture composition.

46. Kadambi, K; Ashong, F.W.A. 1966. **Promise of technology in the conversion and efficient utilization of wood resources, with particular reference to utilization of wood waste in Ghana**. Paper presented in the IVth World Forestry Congress.

47. Kato, H. 1961. **Concerning physico-chemical properties of Japanese paper**. TAPPI Journal 15(8): 549-551.

48. Krishnamachari, K.S; Rangan, S.G; Ravindranathan, N; Reddy, D.V. 1975. **Seshasayee Paper and Board's experience in the use of hardwoods for papermaking**. Chem. Ind. Devts, Bombay 9(10): 41-45.

Locally available hardwoods are being used to supplement limited supplies of bamboo. Satisfactory kraft pulps have been obtained with (1) 70% bamboo (Dendrocalamus strictus), 15% Mysore gum (Eucalyptus tereticornis) and 15% dadup (Erythrina suberosa),and (2) 50% bamboo, 20% Acacia arabica, 15% Mysore gum and 15% dadup.

49. Kulkarni, A.Y; Parkhe, P.M. 1990. **Appropriate technologies for pulping and paper making of unconventional raw materials in India**. Proceedings of the Pulping Conference, USA: 313-320.

50. Labarre, E.J. 1952. **A Dictionary and Encylopedia of Paper and Papermaking with Equvalence of Technical Terms in France, German, Dutch, Italian, Spanish and Swedish**. 2nd Edn. Amsterdam.

51. Maheshwari, S. 1982. **Some basic aspects of high yield pulping**. IPPTA 20(2).

52. Mall, I.D; Upadhyay, S.N; Singh, A.R; Upadhya, Y.D. 1989. **Environmental pollution due to pulp and paper industry**. Paper presented in the IPPTA Silver Jubilee International Seminar and Workshop on Appropriate Technologies for Pulp and Paper Manufacture in Developing Countries, New Delhi: p18.

53. Merck, A.G.E. 1957. **Chemish - Technishe Untersuchungsmethoden fur die Zellstoff- und Papierfabrikation**, Verlag Chemi, Weinheim.

54. Mishra, N.D. 1971. **Pulping of hardwoods: Our experience at Sirpur Paper Mills**. Proceedings of the Conference on Utilisation of Hardwoods for Pulp and Paper, 19-20 April 1971, FRI & Colleges, Dehdra Dun: 71-79.

55. Mishra, N.D. 1973. **A tentative method of grading hardwoods for chemical grade pulp**. Indian Pulp and Paper 27(10): 7-10.

Suggests a system for grading Indian hardwood pulpwood, based on nine characteristics that take into account economy of pulping, suitability for paper-making, adaptability to existing manufacturing processes and quality of end product. The system, which distinguishes four grades of suitability for pulping, is used to classify 20 species viz. Bamboo (Dendrocalamus strictus), kenaf (Hibiscus cannabinus) and 18 hardwoods.

56. Mishra, N.D; Kothari, M.B. 1969. **A case study of bamboo fibre stock flow over a Fourdrinier paper machine**. Indian Pulp and Paper 23(9): 541-545.

57. Mishra, N.D; Rao, A.V. 1969. **Pulping characteristics of Anduk wood (Boswellia serrata Roxb.) grown in Andhra Pradesh**. Indian Pulp and Paper 23(12): 669-676.

A laboratory study on sulphate pulping of B. serrata, a hardwood readily available to supplement the inadequate supply of bamboo in Andhra Pradesh, showed that B. serrata and bamboo, have different cooking characteristics; a better grade of pulp, with less chemical consumption, is produced from bamboo by the 2- stage temperature treatment method and from B. serrata by the impregnation (4-stage) method; bamboo and B. serrata should therefore be cooked seprately. The data also show, however, that the total bleach demand of the two pulps, produced by the same method of cooking to the same K-number level, is very similar; it thus appears that the pulps can be bleached and mixed together.

58. Monsalud, M.R. 1964. **Pulp and paper evaluvation of Philippine species**. Annual Report 1963-64. Philippine Forest Products Research Institute.

59. Monsalud, M.R; Bawagan, P.V; Escolano, J.O. 1965. **Properties of wrapping papers from Philippine fibrous materials as related to pulp blending**. Lumberman 11(33): 10, 12, 16, 54-55.

Data on fibre length, cell-wall thickness, lumen width, Runkel ratio and specific gravity for 6 long and 9 short-fibred materials including (a) Pinus insularis (b) three bamboos and (c) Samanea saman, Pantacme contorta, and other hardwoods are provided. Properties of papers from various pulps and blends are tabulated.

60. Nair, V.K.S. 1971. **Certain aspects on utilisation of evergreen hardwoods for pulp and paper making in India**. Proceedings of the Conference on Utilisation of Hardwoods for Pulp and Paper, 19-20 April 1971, FRI & Colleges, Dehra Dun, India: 21-26.

61. Nelson, G.H. 1966. **A search for new fibre crops: Analytical evaluations**. TAPPI Journal 49(1): 40-48.

An evaluation of 208 monocotyledonous and dicotyledonous species, mainly herbaceous annuals, but including some bamboos (Sinarundinaria murielae, 3 Phyllostachys spp., 2 Arundinaria spp., and Oxytenanthera abyssinica), considered promising sources of pulp for planting in the S.E. and on the Pacific coast of the U.S.A.

62. Pande, G.C. 1970. **A modified technique for steam-vapour phase prehydrolysis of bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 25(1/6): 403-407.

Describes a promising new technique in sulphate pulping that permits the removal of sufficient pentosans to bring the pulp within the limits specified for dissolving-grade pulp.

63. Premrasmi, T; Aranyaputi, S. 1965. **Rudimentary study of suitability of some Thai timbers for paper and pulp**. Vanasaran 23(2): 105-106.

64. Qiu, F.G. 1993. **An approach to utilization of the bamboo waste left over from its processing**. Journal of Bamboo Research 12(2): 28-32.

At the moment the 3 main uses for bamboo residues in Zhejiang Province are: (i) pulping; (ii) bamboo particleboards; and (iii) fodder. Alternative uses of the residues are suggested, such as production of charcoal and xylose.

65. Raitt, W. 1911. **Suitability of various woods, bamboos and grasses for paper making**. Indian Forester 37(7): 389-390.

A memorandum which contains instructions for the selection and collection of materials for paper making.

66. Ramaswami, V; Ramanathan, T. 1989. **Recent developments in biotechnology related to pulp and paper industry**. Paper presented in the IPPTA Silver Jubilee International Seminar and Workshop on Appropriate Technologies for Pulp and Paper Manufacture in Developing Countries, 1989, New Delhi: p15.

67. Ray, A.K; Garceau, J.J; Kokta, B.V; Carrasco, F; Bridgwater, A.V. 1994. **Upgrading Nonwood Fibres by Chemical Impregnation and High-pressure Pulping**. Advances in thermochemical biomass conversion Vol 2: 1598-1624. Blackie Academic & Professional, Glasgow, UK.

Preimpregnated bamboo chips, sugarcane bagasse and rice straw of Indian origin were cooked at 463 K (saturated steam pressure 1.26 MPa) in a Stake Technology batch reactor with different chemical charges and different types of chemicals. Bamboo required much more drastic impregnation for a protracted time with severe chemical treatment, and, for improved pulp quality, the most effective pulping agents were either caustic soda alone at high charge or an optimum mixture of sodium sulfite and alkali. Loss of pulp yield was observed for all species when impregnated with NaOH. The optical properties of unbleached pulp were acceptable for newsprint-quality pulp. A combination of Na_2SO_3 with a lower per centage of NaOH may be a compromise between pulp yield loss and a gain in strength properties for bamboo. The drainage times of bamboo pulp were greatly superior to those of bagasse and rice straw pulps.

68. Razzaque, M.A; Siddique, A.B. 1970. **Fibre analysis of 20 tropical hardwoods and 20 grass species of East Pakistan**. Bulletin No. 10 Pulp and Paper Series 3/6, Forest Research Institute, Chittagong, Bangladesh.

69. Rodriguez, S.K; Torres, M. 1995. **Use of Chusquea culeou for producing chemical pulp**. Ciencia e Investigacion Forestal 9(2): 165-175.

Samples of Chusquea culeou, which is abundant in Chile, were processed to produce unbleached kraft pulp. Variables tested included 14 and 18 alkali, maximum temperature of 160 and 170°C, and 15 or 30 min and maximum temperature. Total yields ranged between 46 and 55; Kappa number was 7-20. Strength properties were similar for 2 pulps with H factor 431 and 195. Under the experimental conditions, pulps of C. culeou had physical and mechanical properties that were lower than those from softwoods and several hardwoods.

70. Rydholm, S.A. 1965. **Pulping Process**. Interscience Publishers, New York: 1269p.

The book begins with a survey of the forests of the world and includes and discusses data on wood species, the gross and minute structure of trees and wood fibres, and the chemical composition and reactions of their components. The operations involved in the preparation of cellulose pulp from the forest to the finished product are then described and discussed. The section headings comprise the manufacture of unbleached and of bleached pulp. A final chapter surveys the properties and uses of pulp and the world pulp industry. Emphasis is on the physical and chemical processes involved rather than the purely technological aspects. The influence of process variables on yields and properties of pulps are demonstrated and analysed. The chemical reactions involved, the preparation and recovery of pulping chemicals, and the manufacture of organic byproducts are also dealt with.

71. Rydholm, S.A. 1966. **Wood quality and cost requirement for forest industries and dissolving pulp**. Proceedings of the Sixth World Forestry Congress: 3301-3302.

72. Sato, A; Kitamura, T; Higuchi, T. 1976. **Studies on wood phenolics (Part V). Chemical properties and NMR analysis of milled wood lignins**. Wood Research 59(60): 93-100.

Milled wood (Bjorkman) lignins of Metasequoia glyptostroboides, Fagus crenata and the bamboo Phyllostachys pubescens were analysed by nuclear magnetic resonance spectrometry, and some chemical properties of the lignins were also examined. The molecular weight of the milled wood lignins of the three species were 2610, 2700 and 1740 respectively.

73. Satyanarayana, G; Vaikuntam, K; Raghuveer, S. 1992. **Improved performances of evaporators and chemical recovery boiler with the increased utilisation of hard woods at ITC Bhadrachalam Paperboards Limited**. IPPTA 4(3): 121-122.

Adaptations were made to black liquor evaporators so that a mixture of bamboo and hardwood pulp (at a ratio of 70:30) could be processed as efficiently as bamboo.

74. Schwenzon, K. 1963. **The hydrotropic pulping of some plant materials**. Zellstoff Papier 12(10): 290-296.

75. Schwenzon, K. 1965. **The hydrotropic pulping of plants**. Zellstoff. Papier. 14(7): 199-201.

76. Singh, M.M. 1960. **Pressed boards from bamboo dusts**. Indian Pulp and Paper 15(3): 201-203.

77. Singh, M.M. 1989. **Raw materials for pulp and paper industry**. Paper presented in the Silver Jubilee International Seminar and Workshop on Appropriate Technologies for Pulp and Paper Manufacture in Developing Countries, September-October 1989, New Delhi: p35.

78. Singh, M.M; Madan, R.N; Dhawan, R; Kaira, K.K; Kaira, B.G. 1981. **Investigations on Andaman & Nicobar Islands woods for different grades of paper**. Indian Forester 107(6): 377-383.

Laboratory scale experiments were carried out on the production of wrapping, writing, printing and newsprint grade pulps from seven species by different pulping processes like sulphate, neutral sulphite, semi-chemical (N.S.S.C) and cold soda. Unbleached pulps suitable for wrapping paper were obtained in satisfactory yields and having satisfactory strength properties by using sulphate and (N.S.S.C) process. For writing and printing paper the pulps were bleached by CEH sequence. Bleached pulps in satisfactory yield and good strength properties were obtained. Pulps in high yield could be obtained by cold soda process, which when admixed with 28 bamboo sulphate pulp were considered to be suitable for newsprint. Comparative suitability indices of woods for wrapping and writing and printing papers were calculated. From the reults it can be concluded that all the seven species are suitable for wrapping, writing, printing and newsprint grade pulps.

79. Singh, M.M; Mukherjea, V.N. 1965. **Fibrous raw materials for the Indian pulp, paper and board industry**. Indian Forester 91(7): 505-529.

Data on fibre dimensions, proximate chemical analysis, method of pulping, yield of pulping, suitability of pulp for a varietis of paper, board and rayon of bamboos are provided.

80. Stevens, R.H. 1958. **Bamboo or wood**. Southern Pulp and Paper Manufacturer 21(3): 93-94, 108.

Work at the Harty Foundation has shown that bamboos can be pulped readily, with less chemical and power than wood, by the kraft and a 2-stage alkali process. Fresh culms and those cut for a year and protected against insect damage gave equally good results. Chemical composition of the culms and of the pulps was similar to that of pulpwood species and wood pulps respectively. Only minor differences were found between pulps of 21 bamboo species. The fibres are shorter than those of conifers and longer than those of hardwoods, and narrower than wood fibres used in papermaking. Properties of the pulps and papers are discussed.

81. Zhang, M; Kawai, S; Sasaki, H. 1994. **Production and properties of composite fibreboard**. Wood Research 81: 31-33.

Fibreboards were made from combinations of lauan (Shorea sp.), jute (Corchorus capsularis), bamboo (Phyllostachys pubescens) and bagasse and properties were investigated.

82. Zhang, M; Kawai, S; Sasaki, H; Yamawaki, T; Yoshida, Y; Kashihara, M. 1995. **Manufacture and properties of composite fiberboard II. Fabrication of board manufacturing apparatus and properties of bamboo/wood composite fiberboard**. Journal of Japan Wood Research Society 41(10): 903-910.

Bamboo/wood composites fibreboards were manufactured using bamboo and wood fibres as raw material at various fibre mix ratios. An apparatus for drying fibre with an adhesive blending device was set up and an apparatus for forming fibre mats was also made for this experiment. A carding machine was used to mix the fibres. The mixing ratios of bamboo to wood were 1/0, 3/1, 1/1, 1/3, and 0/1, and the target board specific gravities were 0.60 and 0.80. The amount of isocyanate resin added was 10 of the oven-dry weight of fibres. The MOR and MOE in both dry and wet conditions, internal bond strength, thickness swelling and linear expansion were determined. Increasing the ratio of bamboo fibre improved the MOR, MOE retention ratio and linear expansion after boiling.

Bamboo Resources and Distribution

83. **Bamboo resources - Andhra Pradesh - Status paper**. Proceedings of the National Seminar on Bamboos, 19-20 December 1990, Bangalore. Bamboo Society of India. 1992. Bangalore: 208-209.

Discusses briefly the state of bamboo resources of Andhra Pradesh. The species Dendrocalamus strictus grows extensively in the State. It is estimated that bamboo occurs over 9,883 sq. km. of the total forest area of 63,770 sq. km. and total growing stock is estimated as 38 lakh metric tonnes. Large scale pure bamboo plantations are raised by Andhra Pradesh Forest Department and Forest Development Corporation in various places. A survey conducted of the bamboo areas shows that the clump formation is completed by nine years and bamboo extraction can be taken up from ninth year.

84. **Bamboo supplies in India**. Indian Forester 39(11): 1913: p552.

The possibility of starting a paper manufacturing industry in Cochin is stated.

85. **Bamboo supplies for paper making**. Indian Forester 53(6). 1927: 349-351.

An editorial on bamboo supplies for paper making. It is a reprint of the article on bamboo supplies for paper making by Mr. W. Raitt of Forest Research Institute, Dehra Dun.

86. Bhat, A.S. 1970. **Economics of industrial plantations of Bambusa arundinacea**. Myforest 7(1): 57-64.

Discussed the economics of industrial plantations of Bambusa arundinacea for pulp and paper.

87. Chaudhari, R.R. 1960. **Bamboo surveys in the Bombay State**. Proceedings of the Ninth Silvicultural Conference, 7, 10-19 December 1956, Dehra Dun. Forest Research Institute and Colleges, Dehra Dun Vol.2: 205-215.

An account of a detailed systematic strip enumerations (involving clump analysis and problems of sustained yield) undertaken in the richer tracts of Dendrocalamus strictus and Bambusa arundinacea in the Kanara, Dangs and Vyara forests with a view to explore the possibilities of establishing pulp and paper mills in the State is given.

88. CSIR, India. 1948. **Bamboos**. Wealth of India, Raw Materials. Council of Scientific and Industrial Research, New Delhi. Vol.1: 145-155.

As per the information furnished, about 30 genera and 550 species inhabiting the humid tropical and extra-tropical regions are known. Of these, 136 species occur in India, 39 in Burma, 29 in Malaysia and the Andamans, 9 in Japan, 30 in the Philippines, 8 in New Guinea and a few in South Africa and Queensland. It also covers the varieties of bamboo, diseases and insect pests. Uses, including manufacture of paper-pulp and production of bamboo are discussed.

89. CSIR, India. 1966. **Neohouzeaua (Gramineae).** Wealth of India, Raw Materials. Council of Scientific and Industrial Research, New Delhi. Vol.7: 9-10.

A short description of the genus Neohouzeaua is given here. N. dullooa is a suitable raw material for paper pulp.

90. Deb, D.B. 1978. **Economic plants of Tripura State VII. Plants used for manufacture of paper and boards**. Indian Forester 104(9): 609-614.

Plants used for manufacture of paper and boards, which are found in the State are discussed in this paper. Eleven species of bamboo found in the State are reported to be suitable for the manufacture for pulp and paper.

91. Desai, B.P. 1980. **Management of bamboos in Chandrapur Circle, Maharashtra State**. Proceedings of the Third Southern Silviculturists and Forest Research Officers Conference, 3-5 March 1980, Dharwad. Karnataka Forest Department: 25-32.

The paper indicates the extent of bamboo resources available in Chandrapur Circle, Maharashtra highlighting the species and its distribution in various forest types. The importance of scientific management of bamboos and the demand for this raw material are discussed. The existing felling rules in the circle and the extent of exploitation for meeting the demands of the paper mills are presented.

92. Desai, B.P; Subramanian, K. 1980. **A note on bamboos in Maharashtra**. Proceedings of the Third Southern Silviculturists and Forest Research Officers Conference, 3-5 March 1980, Dharwad. Karnataka Forest Department: 39-60.

Three important species of bamboo occurring in Maharashtra are Dendrocalamus strictus, Bambusa arundinacea and Oxytenanthera monostigma. The first two are the principal species utilized as raw material for paper and pulp industries. The distribution of bamboos, their ecology, botany and silviculture are discussed. The achievements in creating man made bamboo forests by artificial regeneration upto 1978-79 are highlighted. Details of gregarious flowering are summarised. Management and utilization aspects are discussed.

93. Deshmukh, D.K. **Bamboo plantations by West Coast Paper Mills Ltd. Dandeli**. A new forest development strategy. West Coast Paper Mills, Dandeli: 5-17.

The West Coast Paper Mills with the cooperation of Mysore Forest Department launched a programme of raising bamboo plantation in Dandeli in 1964 with the objective of 1. Filling the natural gaps and improve the bamboo stocking 2. To convert low yielding bamboo areas into high yielding bamboo areas and 3. To hasten up the development of natural bamboo crop. Here discusses the soil type, climate of the area, vegetation type, selection of species, planting programme, natural regeneration, yield and financial aspect of raising such plantation.

94. Gamble, J.S. 1896. **The bambuseae of British India**. Annals of Royal Botanic Garden 7(1): 1-133.

An illustrated account of the bamuseae of India is given. Detailed information on the taxonomy, distribution, propagation of species are presented. Extensive notes on uses including rural dwellings and geotechnical applications are also given.

95. Gu, X.P; Xiao, J.H; Liang, W.Y; Lin, Y.F; Zhang, C. 1998. **The effects of N, P and K fertilizer applied in pulp bamboo stand**. Scientia Silvae Sinicae 34(1): 25-32.

A quadratic regression model was used to determine the effects of N, P and K fertilizers on relative growth rate of culms of Phyllostachys pubescens. The analysis of the principal effect of fertilizer shows that N, P and K have different effects on the increase of the output of P. pubescens stand, and the action order is: N > K > P in this test. 2-factor interaction analysis shows that there is a positive interaction between N and K to a certain extent, but there is no significant interaction between N and P, or P and K. Computer simulation showed that the optimum fertilizer combination is (within the confidence limits of 95): urea 325.5-413.5 kg/hm^2, superphosphate 208.5-295.5 kg/hm^2 and potassium chloride 198-267 kg/hm^2.

96. Guha, S.R.D. 1961. **Tour report of Dr. S.R.D. Guha to Culcutta and Luknow on February 1961**. File on Bamboo, Doc. Section, Forest Research Institute and Colleges, Dehra Dun.

97. Hasan, S.M; Skoupy, J; Vaclav, E. 1976. **Recent trends in Bamboo growing and use in Bangladesh**. Silvaeculture Tropica et Subtropica 5: 59-69.

In an assessment of the Bamboo resources of Bangladesh, it is pointed out that naturally occurring Bamboo species (the most common of which is Melocanna bambusoides) have thin-walled culms, whereas cultivated species, including Bambusa vulgaris, B. balcooa and B. nutans, have thick-walled culms. There are differences in utilization of the two groups of species, and cultivated species give higher yields for pulp production. Over-exploitation of accessible naturally occurring species has caused their disappearance from some areas and a decrease in yield. New management systems for growing Bamboo in plantations are suggested. Their introduction is dependent on the development of methods of propagation. Cultivated species are normally propagated by offsets and recently have been successfully propagated from 18- to 20-in-long branch cuttings with swollen basal nodes.

98. Hegde, N.G. 1993. **Scope for production of industrial raw materials through farmers**. Vaniki Sandesh 17(3): 1-23.

The introduction to this paper discusses the demand for wood in India, and gives data for wood consumption in 1985. A significant proportion of this consumption (42) is fuelwood, some 64 of which is collected free of cost by the poorer sections of society, and as such, offers no scope for commercialization. The next highest proportion of wood consumption is for the paper and paperboard industry (16.8), and the paper mainly concentrates on this industry, giving projected demands and production capacities (with some data for other overall wood demand and for wood for panelwood), and discussing sources of raw material (wood, bamboo, and agricultural residues), of which there is an anticipated shortage. Strategies for meeting industrial demand for pulpwood are outlined, and include afforesting degraded forest lands (which needs legislation to allow leasing to industry, and has met with environmental objections) and waste lands (some of which are either encroached or unsuitable). The available options are: (1) procuring wood from the Forest Department and Forest Plantation Corporation, from plantations on both forest and non-forest land; (2) leasing government and private lands to wood based industries for their own wood production; (3) leasing government land to farmers, with coordination of wood production by the industries concerned; and (4) the growing of trees by farmers on their own land, which is then procured by the wood based industries. The last option is considered to be the best, and theremainder of the paper discusses the involvement of farmers in industrial forestry, addressing profitability, and suitable species - the bamboos Bambusa arundinacea and Dendrocalamus strictus, and Eucalyptus spp. are those in most demand by the paper industry, but various other (multipurpose) species are also suitable for promotion under farm forestry and agroforestry systems. Steps to ensure profitability for the farmer include the selection of high yielding species and superior provenances, the use ofsuperior planting material (including micropropagated stock), improved silvicultural practices, improved harvesting and processing, and motivation and extension. Planning for product mix through farmers' organizations is also suggested.

99. Hodge, W.H. 1957. **Bamboos, their economic future in America**. Gdn. J. N.Y. Bot. Gdn. 7(4): 124-128.

A general note on the introduction and use of bamboos in the U.S.A., and on research in progress there on their utilization. The yield/acre/year of cellulosic material is 6 times that of Southern Pine, and some species yield regularly on a 5-year cycle.

100. Indian Council of Forestry Research and Education. 1991. **Bamboo: The poorman's timber**. ICFRE, Dehra Dun: 24p.

101. Jha, Y.P. 1964. **A short note on the management of bamboos (Dendrocalamus strictus) with special reference to its exploitation and mode of leasing out to paper mills in Daltonganj South Division, Bihar**. All India Bamboo Study Tour and Symposium 1963-64, Dehra Dun. Forest Research Institute, Dehra Dun: 166-174.

A short note on the management of bamboos (Dendrocalamus strictus) in Daltonganj South Forest Division, Bihar is given. The mode of leasing out bamboos to paper mills, the manner in which the leases are granted in the past and present, the minimum royalty, method of calculation of royalty are discussed briefly.

102. Kaitpraneet, W; Suwannapinant, W; Thaiutsa, B; Sahunalu, P. 1978. **Management of bamboo forest for pulp and paper industry**. Research Note, Faculty of Forestry, Kasetsart University 26: 9p.

The results of a study in a pure stand of Thyrsostachys siamensis at Hin Lap, Changwat Kanchanaburi, Thailand in 1974-77. Plots of 15X15 m were treated by clear felling or selection felling with or without the application of mixed [NPK] fertilizer, and the numbers of new culms recorded for 3 yr. The greatest number of new culms was in the selection system plots (av. 239/plot without NPK and 220 with NPK). Clear felled plots had an average of 94 new culms without NPK and 103 with NPK.

103. Kandelaki, T.E. 1976. **The economics of utilizing bamboo**. Lesmoe Khozyaistvo No. 12: 61-62.

Describes investigations in Soviet Georgia on the technical and economic feasibility of utilising home-grown bamboos as raw material in the pulp and paper industry. Data are given on the chemical composition of the wood of 3-year-old culms of three species of Phyllostachys, and literature data on plantation yields and management from Georgia and other countries are discussed. It is concluded that selective harvesting of 3-year culms is appropriate, and that P. edulis gives the best yields; the mean number of culms harvested per year in a high-yielding plantation is 2520 culms/year. The total yield from 1 ha of P. edulis plantation over a period of 80 years is 4218 t (as against only 360 t for a fir plantation and 440 t for Alder). The cost of 1 t bamboo free-at-mill is calculated at 11.77 roubles, vs. 44 roubles for conifer pulpwood grown in Georgia. The pay-back period (break-even point) for a P. edulis plantation is 7 years from establishment.

104. Karnik, M.G. 1956. **Varieties of paper**. Indian Forester 82(1): 203-205.

In this article important varieties of paper like 1. writing, 2. printing, 3. newsprint, 4. wrapping and 5. speciality paper are described along with the raw materials and method of preparation.

105. Khristova, P; Gabir, S; Khristov, T. 1981. **Raw material resources for obtaining fibrous semiproducts for pulp and papermaking in Sudan**. Sudan Silva 4(24): 6-10.

Eucalyptus camaldulensis from Sudanese plantations and the indigenous bamboo Oxytenanthera abyssinica were studied to see whether they were suitable for pulp production. They were pulped by the 'high temperature shock' chemithermomechanical process. Pulping was successful with both soda and sulphate liquors, E. camaldulensis gave a yield of 80-83 and O. abyssinica 70-74. The pulps are suitable for the manufacture of cardboard. The eucalyptus pulp is best mixed with 30 of long-fibre pulps to give it better strength properties.

106. Lakshmana, A.C. 1992. **Bamboo: A potential employment generator; Its present status and future prospects**. Proceedings of the National Seminar on Bamboos, 19-20 December 1990, Bangalore: 75-81. Bamboo Society of India, Bangalore.

The suitability of bamboo species for social forestry programmes is highlighted. Discusses bamboo yield in Karnataka, the type and extent of its use and its high capacity to generate employment and income especially among tribal people, marginal farmers and others living in the vicinity of forests. The estimated bamboo forest in Karnataka is about four lakhs hectares, out of which the annual production is about 100,000 tonnes of bamboo. The estimated demand for bamboo for selected few items in the State is 646,000 tonnes. Thus a short supply of 546,000 tonnes of bamboo is reported. Recommendations are made to increase the production of bamboo in the State.

107. Madhav Gadgil; Narendra Prasad, S. **Conservation of bamboo resources of Karnataka: Report on the State-wide availability of bamboo resources**. Centre for Theoretical Studies, Bangalore: 13p.

The report deals with the status of bamboo resources of Karnataka State and the impact of the industrial consumption on the resources. The need for raising bamboo plantations by paper mills is stressed.

107a. Martin, M. 1996. **Where have the groves gone?** Down to Earth, June 15: 27-31

108. McCormac, C.W. 1987. **Economics for bamboo forestry research: Some suggested approaches**. In: Rao, A.N, Dhanarajan, G and Sastry, C.B (Eds.). Recent Research on Bamboos: Proceedings of the International Bamboo Workshop, 6-14 October 1985, Kangshou, China. Chinese Academy of Forestry, Beijing and IDRC, Canada: 370-377.

109. Mohanty, A.P. 1959. **Bamboo resource of Orissa**. Indian Forester 85(2): 115-118.

A survey is carried out in Orissa to estimate the quantity of bamboo available for paper making. The method adopted for the survey and the results obtained are briefly discussed in this paper.

110. Mooney, H.F. 1959. **A report on the bamboo forests of Wallega Province (Abyssinia) with a view to their possible utilisation for paper and pulp**. British Middle East Division, Addis Ababa: 8p.

A descripion of ca. 2200 sq. miles of forest Oxytenanthera abyssinica. Assuming a yield of 5 tons air-dry culms per acre and a 4-year cutting cycle 24,000-30,000 acres would provide the 30,000 tons required for 10,000 tons of paper. With water also plentiful, the project is recommended for serious exploration.

111. Moulik, S. 1997. **The Grasses and Bamboos of India**. 2 Vols. Scientific Publishers, Jodhpur: 700p.

112. Nair, K.S. 1980. **A base paper on bamboos in Kerala**. Proceedings of the Third Southern Silviculturists and Forest Research Officers Conference, 3-5 March 1980, Dharwad. Karnataka Forest Department: 131-141.

The paper deals with forest types of Kerala and the distribution of bamboos. Details about indigenous and exotic species, silviculture and agronomy, crop associations and regeneration, seed production and growth, natural regeneration and management, utilization, pests and diseases etc. are given.

113. Nicholson, J.W. 1922. **Report of the bamboo forests of the lower Mahanadi basin**. Indian Forester 48(11): 607-608.

A survey of the bamboo resources of the Angul Division and the neighbouring states is made to ascertain whether sufficient supplies of bamboo can be made available to the paper-pulp factory to be set up at Cuttack. The results of the survey are reported here.

114. Ohrnberger, D. 1999. **Bamboos of the World**. Elsevier, The Netherlands. 585p.

115. Pesantes Rebaza, M.A. 1985. **Study on the possibilities to establish bamboo plantations for pulp and paper production in Pucallpa**. Lima: 93p. Universidad Nacional Agraria, Lima, Facultad de Ciencias Forestales.

116. Prasad, J. 1948. **Silviculture of ten species of bamboo suitable for paper manufacture**. Indian Forester 74(3): 122-130.

A general description, distribution, habitat, growth, development, cultivation, felling methods, extraction, flowering, seeding and supplies of ten Indian bamboos, suitable for paper manufacture are presented. The species described are Dendrocalamus strictus, D. hamiltonii, D. longispathus, Bambusa polymorpha, B. arundinacea, B. tulda, Melocanna bambusoides, Neohouzeaua dullooa, Ochlandra travancorica and Oxytenanthera nigrociliata.

117. Sagreiya, K.P; Khan, M.A.W; Chacko, V.J. 1961. **Bamboo potential surveys**. Proceedings of the Tenth Silvicultural Conference, 15-25 November 1961, Dehra Dun. Forest Research Institute and Colleges, Dehra Dun. 2: 840-843.

For the full utilisation of the bamboo resources of the country and also for a planned development of paper-pulp industry, an investigation of the resources of bamboo is planned on all India basis. Here describes the techniques, procedure and objectives of the survey.

118. Seethalakshmi, K.K; Kumar, M. 1998. **Bamboos of India: A Compendium**. Kerala Forest Research Institute, Peechi, Kerala, India and INBAR, Beijing, China: 342p.

In this book 128 bamboo species found in India are described. In the introduction part, the bamboo is dealt with in general. There after 18 genera naturally occuring and cultivated in India are described. Morphology, flowering and fruiting, distribution and ecology, antomy and fibre characteristics, chemistry, silviculture and management, pests and diseases, physical and mechanical properties, natural durability and preservation and uses are given whereever information is available. Illustrations and photographs are profusely given.

119. Shanmughavel, P; Francis, K; George, M. 1997. **Plantation Bamboo**. International Book Distributors, Dehra Dun, India: 191p.

This book addresses techniques for bamboo cultivation in South and South East Asia. It is arranged in 13 chapters, and includes separate colour plates and a section at the end providing tables of data on various aspects of bamboo plantations and use. The first 5 chapters are introductory: (1) Introduction; (2) Distribution; (3) Taxonomy; (4) Ecological requirements; and (5) Growth characteristics. The remaining 8 chapters address plantation establishment, management and use: (6) Establishment and management - mostly sowing and planting stock production, with a small section on management; (7) Growth and development; (8) Biomass and yield; (9) Felling cycle and fertilizer application; (10) Introduction of social forestry - strip planting,community forestry, limitations, agroforestry, rehabilitation of degraded forest, afforestation, reclamation of waste land; (11) Need for raising bamboo plantation - with reference to use as raw material for the pulp and paper industry; (12) Problems andprospects of bamboo plantations - with regard to cultivation and socioeconomic aspects; and (13) Utilization - consumption pattern in India, and uses as parquet, laminates, in aircraft, concrete reinforcement, growing in artificial shapes, and as raw material for phytosterols.

120. Sharma, Y.M.L. 1977. **Random notes on bamboos of Asia and the Pacific**. Forest News for Asia and the Pacific 1(2): 34-35.

Author discusses briefly the important role of bamboo in the rural economy. The species of bamboo used much by the people and in paper industry are also listed.

121. Sharma, Y.M.L. 1982. **Some aspects of bamboo in Asia and the Pacific**. RAPA, Bangkok, Thailand: 56p.

122. Singh, S. 1973. **The cheapest, quickest and surest way to solve raw material shortage problem for pulp and paper industries in India**. Indian Pulp and Paper 27(12/9): p20.

Draws attention to the declining yield of bamboo (Dendrocalamus strictus) from successive felling cycles in many of the Indian deciduous hardwood forests and to the consequent increasing shortage of raw materials for pulp and paper manufacture in India, and suggests silvicultural measures for achieving a rapid improvement in bamboo recruitment.

123. Surendran, P.N. **Status paper on Kerala man-made forests**: 5p.

124. Tewari, D.N. 1992. **A Monograph on Bamboo**. International Book Distributors, Dehra Dun, India: 172p.

This book provides a comphrehensive review and bibliography of all aspects of bamboos with particular emphasis on India and is presented in 13 chapters: (1) Introduction - including brief accounts of the current status of bamboo utilization and of proposed research programmes; (2) Distribution of bamboos in the world; (3) Bamboos in India; (4) Bamboo taxonomy; (5) Silviculture and management of bamboos in India; (6) Genetic improvement; (7) Growth, yield and economics; (8) Utilisation of bamboos; (9) Bamboo products; (10) Pulp and paper manufacture; (11) Insect pests of bamboos; (12) Diseases and decay of bamboo; and (13) General bibliography on bamboo. A subject index is included.

125. Uppin, S.F. 1964. **A note on Bambusa arundinacea in the leased area of the West Coast Paper Mills Ltd; Dandeli in Kanara Northern Division, Mysore State**. All India Bamboo Study Tour and Symposium 1963-64, Dehra Dun. Forest Research Institute, Dehra Dun: 187-196.

A note on the bamboo Bambusa arundinacea in the leased area of the West Coast paper Mill, Dandeli of Mysore state is given in this paper. Some of the observations made on the flowering pattern of the species are also presented. Cost of planting bamboo seedlings is calculated.

126. Venkatappa Setty, K.R. 1962. **Management and Exploitation of Bamboos** (Paper for the Diploma of Associate of Indian Forest College, Dehra Dun). Indian Forest College, Dehra Dun: 84p.

A brief account of silviculture, management and exploitation of bamboos with reference to Mysore State is given. Bambusa arundinacea, Dendrocalamus strictus, Oxytenanthera monostigma, Ochlandra travancorica and Oxytenanthera stocksii are the species reported from the State. To meet the local demand as well as the requirement of paper industries it is suggested to save bamboo forests departmental working of the bamboo forests is to be encouraged. The influence of bamboo flowering on the supply of bamboos for paper mills is also discussed. Bamboos from the forests are exploited by various agencies like department, contractors, permit holders, etc. and a comparative study of the working of bamboo by these agencies are studied. A working scheme for supply of bamboos for the West Coast Paper mills, Dandeli is worked out.

127. Waheed khan, M.A. 1972. **Creation of bamboo forests for paper industry in Madhya Pradesh**. IPPTA Seminar, Dehra Dun: p4.

National Newsprint and Paper Mills, Nepanagar and Orient Paper Mills, Amlai are the main pulpwood consuming industries in Madhya Pradesh. Large scale bamboo plantations are raised around Nepanagar by the Forest Department for meeting the demand for raw material. The author suggests here necessary changes to be made in raising bamboo plantations for the mills in the State.

128. Waheed khan, M.A. 1972. **Management of bamboo forests in Madhya Pradesh as producers of raw material for pulp and paper industry**. IPPTA Seminar, Dehra Dun: p5.

It is predicted that the bamboo areas will become totally unproductive if the present system of protection and management continues unchecked and unattended. Measures to be taken to halt degradation of bamboo forests and to revive their full production are suggested.

129. Yang, X.S; Shi, Q.T; Huang, Y.C; Liang, W.Y; Lin, Y.F. 1999. **The effect of silvicultural management on the production of moso bamboo plantations for pulp-making**. Forest Research 12(3): 268-274.

A series of tests on pulpwood production in moso bamboo (Phyllostachys pubescens) stands were conducted systematically in Anji County (Zhejiang Province), Shaowu County (Fujian Province) and Fengxin County (Jiangxi Province) in China. The silvicultural practices established were used in establishing a 20 hm2 high-yield model stand of moso bamboo for pulpwood production. The productivity of moso bamboo stands was determined by habitat and management, with significant differences found between different management regimes, site qualities or status of the original bamboo stand. A bamboo forest in an undesirable state on a poor site could be guided towards an ideal or normal state by using measures such as loosening the soil, fertilizing, felling, adjusting stand structure, etc. A management model is proposed which involves suiting silvicultural measures to local conditions and classifying management actions to improve stand economics/yields.

130. Yuan, Y.P; Xiao, J.H; Chen, H.L; Zhu, W.S. 1999. **New management type of Phyllostachys pubescens forest**. Journal of Zhejiang Forestry College 16(3): 270-273.

Bamboo for Pulp, Paper and Rayon

131. Adkoli, N.S. 1992. **Bamboo in pulp production**. Proceedings of the National Seminar on Bamboos, 19-20 December 1990, Bangalore. Bamboo Society of India, Bangalore: 45-52.

The present availability of the raw material bamboo for production of pulp and paper is assessed and an attempt is made to analyse the proposals made in the revised forest policy of 1988 regarding the supply of raw material to industries. Availabilityof wastelands for bamboo plantations, investments and efforts needed to raise such plantations are described.

132. Adkoli, N.S. 1994. **Bamboo in Indian pulp industry**. Bamboo in Asia and the Pacific. Proceedings of the Fourth International Bamboo Workshop, Chiangmai, Thailand. (FORSPA Publication: 6) International Development Research Centre and FORSPA, Bangkok, Thailand, Canada: 250-254.

Author presents an overview of the raw material, bamboo in Indian pulp industry. The annual output of bamboo is estimated about 4.6 million tonnes of which about 1.9 million tonnes is reported to be used by pulp industries. Three main species of bamboos, Dendrocalamus strictus, Bambusa arundinacea and Melocanna baccifera are reported to constitute 83 percent of the total growing stock. Bamboo is reported to be used for pulp and paper since 1936. Use of bamboo for pulping is reported to be declined from 73.5 percent in 1952 to 26.53 percent in 1988. One rayon-grade pulp mill uses bamboo as part of raw material. Shortage of about 20.28 million tonnes of raw material by the year 2015 for pulp and newsprint production is predicted. Bamboo yield can be increased 4 to 5 times in about 5-6 years if scientific harvesting, protection to clumps from fire, grazing and biotic influences, silvicultural tending of clumps are taken care of. The need of raising bamboo plantations in wastelands for increasing the supply of bamboo for various purposes including pulp industries is stressed.

133. Azzini, A. 1980. **Agronomic aspects of industrial production of bamboo**. Papel 41: 87-95.

Bamboo is examined in detail with regard to:botanic classification; anatomical and agronomic characteristics; vegetative propagation; flowering and fruiting; sexual propagation; production (effect of spacing, cutting system and fertilizer application); potential as a raw material for paper making (fibre dimensions and kraft pulp yields and strength properties); chemical composition; and potential as a source of alcohol.

134. **Bamboo for paper mills**. Myforest 12(2). 1976: 88-90.

Allotment of bamboo forests for paper mills of Karnataka is discussed and estimated the yield of bamboo from the bamboo forests.

135. Beri, R.M; Karnik, M.G; Pharasi, S.C. 1967. **A note on Dowga bamboo wax**. Indian forester 93(3): 188-189.

Dowga bamboo, Bambusa arundinacea Willd. West Coast Paper Mills Ltd at Dandeli uses Dowga bamboo as a supplementary raw materials for paper making. They find this species contains a certain amount of waxin which makes the bamboo difficult to cut in to uniform chips during the culling action and does not permit proper penetration of chemicals during cooking.

136. Bhargava, M.P. 1945. **Bamboo for pulp and paper manufacture. Part I - III**. Indian Forest Bulletin (N.S.) Utilization 129.

Part I gives an account of investigations from 1860 to 1944 and an outline of future investigations. Part II deals with the digestion of bamboo, and part III with its proximate chemical analyses. A series of appendixes give data on semi-commercial pulping tests, strength properties of kraft pulps, annual Indian production of papers, and proximate chemical analyses of the following species:- Dendrocalamus strictus(of 8 provenances and various stages of development), D. hamiltonii, D. longispathus, Melocanna bambusoides, Bambusa arundinacea, B. polymorpha, B. tulda, Ochlandra travancorica, Oxytenanthera nigrociliata and Teinostachyum dullooa.

137. Bhargava, M.P; Chattar Singh. 1942. **Interim report on the pulping qualities of crushed and uncrushed bamboo chips**. Indian Forest Bulletin (N.S.) Utilization. 112: 13p

Samples of chips from Dendrocalamus strictus, (1) crushed, (2) partially : crushed, and (3) uncrushed, were tested for uniformity, bleachability and pulp yield under the same conditions of digestion. The most satisfactory in every way was (1), but from a practical point of view, thorough or even partial crushing of Bamboo stems has the disadvantages that power consumed is high, and size of crushed chips is more irregular and uneven that that of chips obtained by oblique chipping. An ideal method would be to cut the Bamboo into more or less uniform chips and crush the chips, so that the bundle sheaths of the fibro-vascular bundles would be loosened and separated out from the ground tissues and their rigidity reduced, thus giving an easier and quicker penetration of the cooking liquors. It is doubtful, however, whether such a method is practicable.

138. Bourdillon, T.F. 1899. **More information about bamboos**. Indian Forester 25(4): 152-154.

This article is a continuation of author's earlier comments on the article Indian bamboos by D. Brandis which presents some useful information like growth and flowering of bamboos and its use for pulp and paper.

139. Chang, F.J; Duh, M.H. 1978. **Utilization of bamboo residue for pulp and paper making**. Quarterly Journal of Chinese Forestry 11(3): 51-68.

140. Chen, W.L. 1958. **Newest kraft pulp and paper mill in Formosa uses bamboo**. Paper Trade Journal 142(36): 40-46.

Describes the preparation of raw material, layout, equipment and methods at the mill of the Longlived Pulp and Paper Corp. Ltd., at Chu Nan. Species successfully used are Phyllostachys retuculata, P. edulis, Bambusa stenostachya and Dendrocalamus latiflorus.

141. Ciaramello, D. 1970. **Bamboo as a papermaking raw material: Study of processes for cooking material from Bambusa tuldoides Munro**. Bragantia 29(2): 11-22.

142. Ciaramello, D; Azzini, A. 1971. **Bamboo as a raw material for paper**. Papel 32: 33-40.

Compare Bambusa vulgaris, B. var. vittata, and B. oldhami for kraft pulping. B. oldhamii had the shortest fibres, but was the best suited to kraft pulping, giving the highest yields and pulps with the lowest permanganate number.

143. Correa de A; Luz, C.N.R; Frazao, F.J.L. 1977. **Papermaking characteristics of the bamboos of the State of Acre, Brazil**. Acta Amazonica 7(4): 529-550

The bamboos, known locally as tabocas, comprise Guadua angustifolia, G. glomerata, G. morim, G. superba and Nastus [Cenchrus] amazonicus. Data are given on the physical characteristics of the woods and on the properties of chemical, semichemical, chemimechanical and mechanical pulps derived from them. It is concluded that Acre bamboos can be used to make pulp and paper, especially for the manufacture of paperboard.

143a. Despande, P.R. 1953. Indian Pulp and Paper 8(3): 167.

144. Dhondiyal, S.N; Bahadur, O; Mathur, G.M. 1973. **Pulping of freshly flowered bamboo**. Forestry Product Conference, Dehra Dun.

145. Dobriyal, P.B; Satish Kumar. 1991. **Utilization of bamboo in pulp and paper**. Vigyanik.

146. El Bassam, N; Jakob, K. 1996. **Bamboo - A new source for raw materials**. First experimental results. Landbauforschung- Volkenrode 46(2): 76-83.

147. Escolano, J.O; Semana, J.A. 1970. **Bag and wrapping papers from Kayuan - Kiling (Bambusa vulgaris Schrad)**. The Philippine Lumberman 16(5): 36-40.

Kauayan-kiling (Bambusa vulgaris Schrad) pulped by the sulfate process, using an active alkali of 15.6 gave a screened yield of 41.4 and permanganate No. of 15.0. The pulp produced was characterized by very high tearing resistance but low bursting strengh. The folding and tensile strengths were within the range of imported commercial kraft pulps which were tested and used as standards. The experimental bag and wrapping papers, produced from this pulp were higher in tearing resistance but lower in burst, folds and tensile strengths, compared with those of commercial papers tested at the Institute. However, when beater adhesives such as starch, guar gum and locust-beam gum were incorporated in pulp furnishes, the burst, folds and tensile strengths were considerably improved, producing high quality bag and wraping papers.The resulting papers gave strength properties superior to those of the commercial papers tested, and exceeded the U.S. Federal Specifications.

148. Forest Products Research and Development Institute. 1962. **Bamboo for pulp and paper making**. FPRDI, Philippines. Technical Note No. 28: 5p.

149. Frison, E. 1951. **Bamboo and the problem of paper manufacture in the Belgian Congo**. Bull. Agric. Congo Belg. 42(4): 965-986.

Discusses (1) the suitability of Bambusa vulgaris and Oxytenanthera abyssinica for pulp manufacture, and (2) possible supplies of bamboo and hardwoods for pulp manufacture in the Belgian Congo.

150. Fukuyama, G; Kawase, K. 1955. **Production of furfural from `Sasa'. II. Production of furfural and plup from `Sasa'**. Research Bulletin of Experimental Forestry, Hokkaido University, Japan 17(2): 383-438.

(1) The highest yield of furfural obtained (11.6%) in these tests was when 100g. of Kumazasa [Sasa albo-marginata] were autoclaved with 1 litre of 1.5 % H_2SO_4 at 80 lb./sq. in. for 3 hours. (2) When 200 g. of chips were autoclaved with 1 litre of 0.5 % H_2SO_4 under various conditions, 58-65% of the residue was found suitable for pulp. When the extraction liquor, adjusted to 1.5 % H_2SO_4, was autoclaved at 80 lb./sq. in. for 3 hours, a yield of furfural 5.4-6.7% of the oven-dry weight of the chips was obtained.

151. Garg, R.K; Sharma, R.K; Kothari, R.M. 1998. **Some insight on the death of bamboo after flowering**. Indian Forester 124(5): 342-346.

After vegetative growth from rhizomes for a period of 50-80 yr, clumps of the bamboo Dendrocalamus strictus in a particular area undergo flowering, setting free enormous quantities of seeds and die synchronously. Changes in some major chemical constituents (alpha-cellulose, hemicellulose, reducing sugars, starch, lignin, moisture and ash) of stems were monitored at different stages of the flowering process in specimens from 5 compartments of the Fulchera area of Bhamragarh Forest Division, Maharashtra, in March (at the start of flowering) and May (after flowering) 1994. This was done because there is some evidence in the literature that plant composition may be related to bamboo mortality after flowering. The analyses suggested that bamboo death may have been caused by excessive deprivation of reducing sugars and moisture content, leading to loss in vitality and osmotic shock along with toxicity generated by an enormous increase in lignin content.

152. Guha, S.R.D. 1960. **Bamboo for pulp and paper manufacture - a summary of investigation at the Forest Research Institute Dehra Dun**. ECAFE-FAO-BTAO Conference on Pulp and Paper Development in Asia and the far East, October, 1960.

153. Guha, S.R.D. 1960. **Bamboo pulping in India**. ECAFE-FAO-BTAO Conference on Pulp and Paper Development in Asia and the far East, 17-31 October 1960.

154. Guha, S.R.D. 1961. **Bamboo as a raw material for paper and board making**. Indian Buyer 1(2).

155. Guha, S.R.D. 1962. **Bamboo for pulp and paper manufacture**. A summary of the investigations at the Forest Research Institute, Dehra Dun. In: FAO Pulp and Paper Prospects in Asia and the far East Vol.2.

156. Guha, S.R.D. 1962. **Bamboo pulping in India**. In: FAO, Pulp and Paper Prospects in Asia and the far East Vol.2.

157. Hunter, I.R. 2002. **Writing on bamboo**. INBAR News Magazine 9(1): p14.

158. International Network for Bamboo and Rattan. 1977. **Bamboo for pulp and paper**. INBAR News Magazine 5(3): p29.

159. Istas, J.R; Heremans, R; Raekaelboom, E.L. 1956. **The paper making qualities of some bamboos grown in the Belgium Congo**. Bulletin Agriculture Congo belge 47(5): 1299-1325.

Tabulates the mineral, cellulose and lignin composition and the fibre dimensions of 10 exotic bamboos, from culm samples of different age and, in one species, from 3 different soils. Also tabulated are the properties of the pulps and papers prepared from some of them, using 3 methods of cooking. Good sulphate pulps are obtainable but, except in tearing strength, the resulting papers are inferior to those of a medium-quality kraft. It is possible that pressure-impregnation cooking would improve quality. Bambusa vulgaris and its var. striata gave the best pulps. Sasa kurilensis and S. japonica do not appear suitable for unbleached pulp. Three months of water storage did not reduce Dinoderus attack. Though one-year culms are usable, it is better to use older ones. Soil affects paper quality and more investigations of the effect of site are required. In addition to those mentioned, the samples included Dendrocalamus strictus, Gigantochloa ater, Ochlandra travancorica (for all of which pulp and paper data are presented), Dendrocalamus longispathus, Gigantochloa apus and G. varticillata.

160. Istas, J.R; Raekaelboom, E.L. 1962. **A biometric, chemical and paper making study of Congo bamboos**. Publ. Inst. Nat. Etude Agron. Congo (Ser. Tech.) No. 67: 53p.

Gives data on wood density, fibre characteristics, chemistry, cooking schedules and pulp and paper properties of (a) Bambusa vulgaris, (b) Oxytenanthera abyssinica, (c) Arundinaria alpina, and (d) Gigantochloa aspera, with general notes on production, storage, addition of hardwood or softwood pulp to improve pulp quality, etc. The best papermaking pulps were got from (a) which can be cut, on a 2-year cycle to produce 50 tons of culms/ha. A good yield of pulp, inferior in quality to that of the other species is obtained from (b); (c) appears best suited for the (weaker) bleached pulps, and (d) gives pulps similar in quality to those of (a).

161. Jamaludin K; Jalil A.A; Abd. Latif Mohmod. 1993. **Pulp and papermaking properties of 1-, 2- and 3-year old Gigantochloa scortechinii**. Bamboo and its Use. International Symposium on Industrial Use of Bamboo, 7-11 December 1992, Beijing, China. Inernational Tropical Timber Organization, Beijing: 264-273.

The effects of age, active alkali and beating revolutions on the pulping characteristics of one to three years old Gigantochloa scortechinii were determined and the results are discussed in this paper. The proximate chemical analysis and fiber morphology are also determined. The fibers of the bamboo are long about 3.0 - 3.7 mm with thick cell wall of 7μ m. It is reported that the high Runkel and low flexibility ratio which imply to its unsuitability for papermaking can be compensated by the high slenderness ratio and high holo-cellulose content. The low ash content in G. scortechnii is beneficial to the pulping process. Pulp properties of one to three year old bamboo shows satisfactory strength properties.

162. Joglekar, M.H; Donofrio, C.P. 1951. **Disolving pulp from bamboos**. TAPPI Journal 34(6).

163. Kiang, T; Lin, W.C. 1978. **A research on bamboo resources in Sabah [including potential uses and processing facilities]**. Quarterly Journal of Chinese Forestry 11(3): 17-33.

164. Kitamura, H; Sakamoto, I; Nagashima, T. 1974. **On the quadrangular bamboo culms - Forms of culms and the anatomy, with special reference to their fibres and vascular bundles**. Bulletin of the Utsunomiya University Forests No. 11: 71-86.

Bamboo square in section can be grown artificially; in Japan Phyllostachys heterocycla f. pubescens is usually chosen because of the thickness of its culm. Square culms of P.h.f. pubescens were produced by placing a wooden frame round each sprout and forcing it to grow inside. The form of the culms, the size of the vascular bundles and the characteristics of the fibres and parenchyma cells were investigated in comparison with normal culms. Internode length was shorter than in a normal culm. Vascular bundles with values of <1.0 for the ratio tangential-diameter/radial-diameter across the culm wall were more numerous in square culms than normal culms at a given height above the ground. The metaxylem in the square culms consisted of two large vessels with an intercellular space between, originating from the primary xylem in a typical vascular bundle. Both fibre length and internode length were relatively shorter at the base of a square culms, longer in the middle and short again at the top. At a given height, fibre length was shorter than at the same height in a normal culm. Parenchyma cells were mostly thin-walled and very variable in size and shape, especially length.

165. Ku, Y.C. 1971. **Pulping properties on Chu- Piew bamboo (Bambusa beechyana Munro. var. pubescens (Li.) Lin.)**. Bulletin of Taiwan Forest Research Institute No. 22: 6p.

166. Ku, Y.C. 1978. **Pulping of bamboo tops and branches**. Bulletin, Taiwan Forestry Research Institute No. 311: 10p.

167. Ku, Y.C; Wang, Y.J. 1990. **Pulping of bamboo in Taiwan**. Forest Products Industries 9(1): 115-122.

Results are presented for the pulping of Phyllostachys makinoi, P. pubescens, Dendrocalamus latiflorus, Bambusa stenostachya, B. dolichoclada, B. oldhamii, B. beecheyana var. pubescens bamboos and compared with those for wood of Chamaecyparis formosensis, Pinus luchuensis, Acacia confusa, and Leucaena leucocephala.

168. Li Yuanzhong; Zheng Qingyan; Huang Jingsheng. 1992. **Studies on techniques for flourishing growth of moso bamboo (Phyllostachys pubescens) forest for paper pulp use**. Jiangxi Forestry Science and Technology 6: 5-10.

168a. Liese, W. 1980. **Preservation of bamboos**. In: Lessard, G. and Chouinard, A. (Eds.), Bamboo Research in Asia. IDRC, Canada: 165-172.

169. Ma Naixun. 1996. **Study on the culm-cutting techniques for pulp-making in Phyllostachys pubescens stands**. Forest Research 9(6): 593-597.

170. Maheshwari, S. 1982. **Pulp and paper making characteristics of bamboo twigs and branches**. IPPTA 14(2).

171. Maheshwari, S; Meshramkar, P.M; Jaspal, N.S. 1976. **Pulping and papermaking studies on nodes and internodes of bamboo (Bambusa arundinacea)**. IPPTA 13(1): 67-71.

Although nodal portions give poorer kraft pulp, it is reported not feasible to separate nodes and internodes before digestion and the reduction in yield and quality of whole bamboo pulp due to the nodal portions is regarded as insignificant.

172. Maheshwari, S; Satpathy, K.C. 1983. **Paper making characteristics of top, middle and bottom portions of bamboo**. Indian Pulp and Paper 38(2).

173. Maheshwari, S; Satpathy, K.C. 1984. **Pulp and papermaking characteristics of bamboos of different age**. Indian Pulp and Paper 38(4).

174. Maheshwari, S; Satpathy, K.C. 1984. **Studies on pulp and paper-making characteristics of bamboo of different ages**. Indian Pulp and Paper 38.

175. Maheshwari, S; Satpathy, K.C. 1988. **Pulp and papermaking characteristics of nodes, internodes and culm of bamboo, Dendrocalamus strictus**. IPPTA 25(1): 15-19.

This paper deals with the evaluation of nodes and internodes of D. strictus and comparison of their pulp and paper making properties. The study reveals that nodal and internodal portions of bamboo culm differ in their chemical constituents. Internodal portion of bamboo has higher holocellulose and lower pentosions, extractives, ash and lignin compared to nodal portion. The pulp yield is lower with more rejects in case of nodal portion. The chemical requirement and bleachability are same under the identical conditions. The bleached pulp viscocity is lower in case of pulp from nodal portion. The fibre morphological characters and Bauer Mc Nett classification results show that pulp from nodal portion has comparatively lower fiber length than internodal portion. The strength properties of bleached pulp of nodal portion are comparatively lower. As such bamboo culm show the intermediate trend in all the properties.

176. Maheshwari, S; Satpathy, K.C. 1988. **The efficient utilization of bamboo for pulp and paper making.** In: Bamboos: Current Research. Proceedings of the International Bamboo Workshop, 14-18 November 1988, Cochin, India (edited by Rao, I.V.R., Gnanaharan, R., Sastry, C.B), Kerala Forest Research Institute, Peechi and IDRC, Canada.

The pulping characteristics of (a) bamboo of different ages (b) different portions of the culm and (c) a few common varieties of bamboo are studied and the results are discussed. Effective methods of proper handling and storage of bamboo are also suggested.

177. Mai-Aung, U; Fleury, J.E. 1960. **Breakthrough in bamboo pulping**. Pulp and Paper International 2(5): 21-23.

178. Matsui, Z. 1963. **On the ecological and silvicultural treatment of Sasa bamboo and its industrial utilisation in Hokkaido**. Annul Report of Forest Experimental Station, Hokkaido, Japan: 186-229.

On account of the importance of Sasa bamboo (including Sasa, Sasamorpha and Neosasamorpha) for forestry in Hokkaido. It is estimated that 70 of the forest undergrowth is composed of Sasa s.l. The larger species (e.g. Sasa kurilensis) provide a raw material for pulp and chipboard, yielding 50-60 tons/ha. when clear-cut before afforestation. Smaller species (e.g. S. nipponica) are used as fodder. Utilization costs are tabulated. All species supress the regeneration of useful trees: the power of regrowth of different species after weeding and other control methods under experimental conditions is recorded.

179. Mazzei, F.M; Rediko, B.V.P. 1967. **Pulp for paper making from bamboo**. Publicacao, Instituto de Pesquisas Technologicas, Sao Paulo, No. 796: 7p.

Describes trials in the sulphate pulping of 1- to 5-year-old culms of Bambusa vulgaris, B. vulgaris var. vittata, and B. tuldoides, the most common Bamboos found in southern Brazil. Preliminary results indicate that high yields and pulp of good quality, especially as regards tearing strength, can be obtained. One-year-old culms gave the best results.

180. McGorovern, J.N. 1967. **Progress and problems in production of pulp from bamboo**. Paper Trade Journal 151: 33-35.

181. Medina, J.C; Ciaramello, D. 1965. **The effect of culm age on the paper making qualities of Bambusa vulgaris**. Bergantia Compinas 24(32): 411-435.

Culms (from 15 years-old clumps at Campinas, Brazil) ranging from 1 to 4 years in age were pulped by the soda process. The effect of culm age on pulp yield was singnificant at the 5 level for 2-year-old culms only. No effect on tearing, tensile, or folding strength could be attributed to culm age.

Paper from 2-year-old culms; however, had a significantly higher bursting strength. Pulps were in general highly porous. B. vulgaris can produce paper in tearing strength. From the industrial standpoint no advantage is gained by selecting culms of a particular age.

182. Mukherjea, V.N. 1967. **Utilisation of bamboos for cheap grade paper**. Indian Pulp and Paper 22(3): 181-186.

Discusses an investigation on the efficiency of a binary pulping process (patented) for bamboo (Dendrocalamus strictus). The chips (dry or steamed) are disintergrated by a kollergang or a refiner, and separated by screening into (a) prosenchymatous and (b) parenchymatous tissues. These tissues are pulped separately, (a) by the sulphate process and (b) mechanically. The pulps are then mixed to obtain the maximum yield of paper of acceptable strength. It is concluded from the results (tabulated) of 10 different experimental treatments of (a) and (b) that: a yield of satisfactory pulp of up to 75 (based on oven-dry chips) is obtainable; pulping procedures that give yields of ca. 40-45 bleached chemical pulp from (a) and ca. 29-25 mechanical pulp from (b), enabling pulp mixtures with >50 chemical pulp to be used, are recommended; chips should be steamed; and a refiner is more suitable than a kollergang, both for disintegrating chips and for grinding (b).

183. Nomura, T. 1999. **Bamboo utilization in Myanmar**. Wood Research No. 86: 9-18.

The role of bamboo in Myanmar, smoke drying and use in pulping and charcoal manufacture are outlined.

184. Ono, K. 1996. **Tropical bamboo for remarkable pulp resources**. Nippon Nogeikagaku Kaishi 70(4): 469-474.

Including brief data on Gigantochloa apus, Bambusa vulgaris, G. nigro-ciliata, G. verticillata.

185. **Papers from the First National Bamboo Symposium-Workshop**, 27th February and 1st March, 1989. Sylvatrop 13(1/2). 1988: 93p.

Ten papers are presented in this symposium-workshop which was sponsored by the Philippines Bamboo Research and Development Project. The project was started in 1987 by the Philippines Ecosystems Research and Development Bureau (formerly the Forest Research Institute), assisted by UNDP, and with FAO as the executing agency. The primary function of the 5-yr project is experimental/pilot plantation establishment and associated research, and the aims are to create new sources of employment and income inrural areas of the country.

186. Pearson, R.S. 1912. **Note on the utilization of bamboo for the manufacture of paper-pulp**. Indian Forest Records: 4(5): 159-277

An investigation is carried out to see the possibility of manufacturing pulp from bamboos. The report deals with areas from which bamboos could be exploited easily for the purpose of manufacturing pulp in Burma and West Coast of India. The places are inspected and figures of yield are also given. Possible sites for bamboo paper-pulp mills in the Bombay and Madras presidency are also given. A history of work carried out with a view of ascertaining the possibility of manufacturing paper-pulp from bamboo is also given. General conditions necessary for the successful establishment of a paper-pulp mill and the mode of growth and the possible outturn are also discussed. Flowering, felling, cost of extraction and cost of manufacturing bamboo paper-pulp are also briefly discussed. Cost of plant required for a mill and the chemicals available are also discussed.

187. Pearson, R.S. 1920. **The utilisation of bamboo for the manufacture of paper-pulp**. Indian Forester 46(12): 603-631.

Suitable areas for extracting bamboos for pulp and paper in India and Burma are recorded in this paper. Descriptions of the bamboo forests, means of transporting the extracted bamboo, cost of cutting and extraction and possible factory sites are also discussed.

188. Pearson, R.S. 1920. **The utilization of bamboo for the manufacture of paper-pulp**. Indian Forester 46(11): 547-561.

A brief review of pre-and post-war conditions of the utilisation of bamboo for the manufacture of paper-pulp is given by the author. Descriptions of some of the bamboo areas in Burma and India are also given.

189. Seabra, L-de. 1954. **Bamboos in the pulping industry**. Estude Ensaios e Dpcum. Junta Invest. Ultramar, Lisboa 13: 91p.

Presents some general information on the characteristics of bamboo compared with other paper-making species (viz. size and shape of fibres, chemical properties of the wood and cellulose, and the industrial value of bamboo pulps) and gives the results of preliminary trials with Oxytenanthera abyssinica from Mozambique and Guinea to determine its suitability for commercial pulping. The investigations deal with the dimensions of the fibres, the chemical properties of the sawdust and of pulps, and the physical and mechanical properties of the pulps. It is concluded that pulps from these African bamboos have properties equal or superior to Indian bamboo pulps, but more data is needed before they can be recommended for commercial production.

190. Shanmughavel, P. 1995. **Bambusa bambos - an ideal species for commercial plantation**. International Tree Crops Journal 8(4): 203-212.

Over-exploitation and shrinkage of their natural habitats is depleting the bamboo resource in India at an alarming rate. Sustained availability can be ensured only by plantations. This paper describes the establishment, growth and biomass production of a trial plantation of Bambusa bambos at Kallipatty, Tamil Nadu. This proved to be an ideal species for large-scale plantations. Pulp characteristics including proximate chemical analysis data for 1-6 yr old culms, utilization and economic aspects, costs and returns from a 6-yr-old plantation are discussed.

191. Sheikh, M.A. 1983. **The environmental aspects of using bamboo in the manufacture of pulp and paper in Bangladesh**. Industry and Environment 6(1): 14-17.

192. Sindall, R.W. 1909. **Bamboo for Papermaking**. Marchant Singer & Co, London: 59p.

An account of the results of the experimental work done for the conversion of bamboo into paper is given here. It reports that the utilization of bamboo as a regular source of supply for paper pulp was initiated in 1870. It attempts to collect the available data on bamboo pulping and present it in a condensed form. It is also discussed the habit and growth, flowering, propagation of bamboos and the supply of the material to the paper mills. Bamboo is found to be suitable for paper making as it is capable of standing considerable wear and tear. A small plant capable of making 8-12 tons of bamboo pulp is erected and the method of working of this plant is described. Table is provided to show the behaviour of bamboo paper when compared with an ordinary super-calendered printing of similar quality. Plant required for a paper mill having a weekly output of 200 tons of unbleached pulp is also discussed.

193. Singh, S.V; Bhandari, S.S; Singh, S.P. 1989. **Organosolve pulping of Dendrocalamus strictus and Eucalyptus tereticornis with aquous ethanol**. Paper presented in the IPPTA Silver Jubilee International Seminar and Workshop on Appropriate Technologies for Pulp and Paper Manufacture in Developing Countries. 1989, New Delhi.

194. Singh, S.V; Guha, S.R.D. 1981. **Indian experience of papermaking from bamboo**. Proceedings of Bamboo Production and Utilization XVII IUFRO World Congress, 6-17 September 1981, Kyoto, Japan. Wood Research Institute, Kyoto University, Kyoto: 33-38.

This paper gives a brief account of various kinds of bamboos occurring in India and of the chemical and morphological characteristics of major species used for paper making. Research carried out on pulping and bleaching, effect of morphological characteristics and sheet properties, beating properties and decay on storage and its effect on pulp properties are reviewed. A brief description about industrial paper making is also given.

195. Stracey, P.D. 1957. **The rational utilisation of India's cellulosic raw materials with particular reference to Assam**. Indian Forester 83(4): 253-259.

Author brings out the importance of the vast untapped reserve of bamboos in Assam in the light of the country's potential requirements.

196. Suleiman, K.M. 1994. **Bamboo as a source of long fiber pulp in Pakistan**. Pakistan Journal of Forestry 44(3): 130-135.

Three bamboo species (Dendrocalamus hamiltonii, D. strictus, Bambusa tulda) were pulped successfully by the soda process. D. hamiltonii gave the highest yield and best tearing strength properties - which were comparable to those of kraft pulp from Pinus roxburghii and imported Southern pine kraft pulp. However, the bonding properties of bamboo pulp were inferior to those of softwood kraft pulp. The advantages of using bamboos for pulpwood production and pulping are outlined.

197. Susuki, S. 1977. **The range of the genus Sasa Makino et Shibata, S. quelpratensis and S. chartacea**. Hikobia 8(1/2): 165-167.

Septate fibres were found to occur in Dendrocalamus latiflorus, Phyllostachys edulis, Schizostachyum brachycladum and Oxytenanthera abyssinica. Their characteristics and fine structure are described and illustrated with electron micrographs.

198. Tissot, M. 1970. **Bamboo as raw material for the Indian paper industry**. Bios. For. Trop. 129: 21-45.

Discusses the problems of making pulp and paper from bamboo on the basis of a study of four Indian mills at which bamboo (mainly Dendrocalamus strictus) is being successfully used, although the pulps have relatively poor mechanical properties. The cooking processes used (kraft, sulphate and neutral sulphite) are reviewed, details of the bleaching and refining procesures are given, and the solutions devised to overcome problems of blade wear and the presence of Si are described. Data on costs of the raw material and pulps are included.

199. Tshiamala T. 1984. **The technology of bamboo as raw material for the paper industries and fermentation industries**. Gembloux, Belgium. Faculte des Sciences Agronomiques de l' Etat, Gembloux: 174p.

200. Tshiamala, T; Mottet, A; Fraipont, L; Thonart, P; Paquot, M. 1985. **The Bamboo: Raw material for Paper Industries or Fermentation Industries**. Energy from biomass: 3rd E.C. conference, held Venice 25-29 March 1985. Elsevier Applied Science Publishers, London, UK: 1122-1125.

A summary of published work including the characteristics of pulps produced by sulphate, sulphite, lime and thermomechanical methods.

201. Tutiya, M; Hukuhara, S; Kato, Y. 1941. **Bamboos in Taiwan as a raw material for pulp. Part V**. Journal of Agric. Chem. Soc. Japan 17: 479-482.

202. Tutiya, M; Imai, M. 1940. **Researches on bamboo in Taiwan as a raw material for pulp. Part IV**. On the ashes and some characters of pulps and alpha-cellulose obtained by different digesting methods. Journal of Agric. Chem. Soc. Japan 16: 126-129, 755-760.

203. Ukil, T. 1961. **Bamboo and its paper making value**. Zellstoff 4. Papier 10(4): 149-151.

204. Villavicencio, E.J. 1990. **Process for making a pulp from bamboo**. Makati, Metro Manila, Philippines, Philippine Patents Office. Process Evaluation and Development Corporation, Dallas, Texas, Delaware: 18p.

Bamboo can be formed into a suitable pulp if prior to digestion, it undergoes a process of shredding, washing, and wet depithing. The fibers are then chemically digested preferably by a process which uses rapid pressure drops to open the fibers using the energy contained in the wet superheated fibers.

205. Vincent, H. 1911. **Bamboo pulp as the paper material of the future**. Indian Forester 37(11): 627-630.

The advantages of using bamboo pulp as the paper material are pointed out by the author.

206. Virtucio, F.D; Uriate, M.T; Uriate, N.S. 1992. **Pulp yield and physico-mechanical properties of six Philippine bamboo species and the implications on optimal harvesting age**. Proceedings of the Second National Bamboo Research and Development Symposium, College, Laguna 14th December 1990. Ecosystems Research and Development Bureau, College, Laguna, United Nations Development Programme, Makati, Metro Manila, Food and Agriculture, Manila: 78-92.

The effect of culm age on pulp yield and some physico-mechanical properties of six important bamboo species: kauayan tinik (Bambusa blumeana), bayog (B. blumeana var. luzonensis), grant bamboo (Dendrocalamus asper), bolo (Gigantochloa levis), buho (Schizostachyum lumampao) and kauayan kiling (Bambusa vulgaris) were studied. The study revealed that there was considerable variation with regard to specific gravity, shrinkage, compressive strength, stress at proportional limit, modulus of rupture, modulusof elasticity, and pulp yield among the six bamboo species relative to culm age. In general, the maximum physico-mechanical properties and pulp yield were attained between pulp ages of 2 to 5 years-old which could provide a vital information in determining the optimum culm age for harvesting which vary among the six bamboo species.

207. Waheed Khan, M.A. 1972. **Sporadic and gregarious bamboo flowering in relation to pulpwood production and management**. IPPTA Seminar, Dehra Dun: 2 p.

The paper discusses sporadic and gregarious flowering of bamboos and the methods of management of the flowered areas.

208. Wai, N.N; Murakami, K. 1983. **Papermaking characteristics of Burmese bamboo Bambusa polymorpha fiber in comparison with wood fiber**. Journal of the Japan Wood Research Society 29(10): 708-715.

209. Wilson, J; Hayes, M.H.B; Schallinger, K.M. 1983. **Bamboo, grown on blanket peats, as a raw material for cellulosic pulp**. Proceedings of the Second International Symposium: Peat in Agriculture and Horticulture. Hebrew University of Jerusalem, Rehovot, Israel: 223-239.

The bamboo varieties Arundinaria anceps and A. japonica can be grown on Blanket peats to provide economic yields of pulp appropriate for paper manufacture. A. anceps provided the higher quality pulp and was more suitable for mechanical harvesting. Bamboo grown on relatively poorly humified Blanket peat will incur plasmolysis when supplied solely with soil-applied commercial fertilizers. Applications of slow release fertilizers, and of boron and copper avoids plasmolysis while supplying N, P and K, and confers resistance to frost and to flowering, respectively. Proposals are made for the preparation of Blanket peats to support bamboo stands, for the management of the stands, and for the selection of improved varieties.

210. Witkoski, C.J. 1964. **Bamboo in pulp and paper manufacture**. ATCP 4(2): 122-129.

211. Ye, K.L. 1993. **The characteristics and industrial utilization of bamboo**. Wood Industry Beijing 7(2): 33-36.

An outline of the characteristics and uses of bamboo in structural applications and for pulping in China is given.

212. Zhang, Q.S; Luo, L.F; Wu, H.Y; Lin, J.H; Tian, X.P. 1998. **Pleioblastus amarus - an elite cash bamboo**. Journal of Bamboo Research 17(4): 51-53.

The shoots of Pleioblastus amarus, a Chinese bamboo species, are edible, with a good taste, and have medicinal properties (antipyretic and detoxifying). The species can also be used for pulp and papermaking and other wood products, including silk umbrellas for tourists, folding fans, curtains, musical instruments, and chopsticks. It is, therefore, of high economic value and suitable for increased exploitation in the Chinese bamboo industry.

213. Zhang, W.Y; Zhou, D.S; Ma, N.X; Yi, C.Q; Cao, D.Y; Zhang, H.M. 1997. **A propagation test with culm nodes of sympodial bamboo species for pulping**. Forest Research 10(4): 425-428.

The vegetative propagation 5 bamboo species suitable for pulpwood production (Bambusa textilis var. fasca, B. multiplex, B. gibba, B. chungii, Neosinocalamus affinis) was investigated using culm node cuttings. Of the 3 planting methods tested, flat planting was better than slanted or vertical planting. There were significant differences in survival of cuttings between between species and node ages, but no significant differences between growing seasons (March or May). The results of tests with cuttings of different thickness (2.5 and 4.6 cm in diameter), from different positions (higher and lower), and with single- or double-internodes suggested that survival rates were better with cuttings taken from thinner culms, a higher position, and with doublThe possibility of growing endemic species of rattan (Calamus spp.) under rubber in Sri Lanka as a secondary crop for production of handicrafts is briefly discussed with reference to the success of such operations in Malaysia.

214. Zhang, X. 1995. **Fibre and paper-making properties of the main bamboo species in Guizhou**. Journal of Bamboo Research 14(4): 14-30.

The fibre and paper-making properties of 22 bamboos species are described.

215. Zhen-xing,S; Tian-jian, H; Guang-zhi, Z; Shao-nan, C. 1990. **Development of a bamboo base and its use as a raw material in the paper industry**. Bamboos: Current Research. Proceedings of the International Bamboo Workshop, 14-18 November 1988, Cochin, India. Kerala Forest Research Institute, Peechi and IDRC, Canada: 283-285.

The importance of replacing wood with bamboo for paper-making is emphasized. A case history of raising bamboo plantation as a joint effort between a big paper industry and government is illustrated.

Species Suitability for Pulp and Paper

216. **Bamboos in Siam suitable for pulp**. Indian Forester 52(4). 1926: p146

Bamboos Cephalostachyum pergracile, Bambusa polymorpha and Bambusa arundinacea which are suitable for making pulp are reported from Siam.

217. Bhargava, G.G; Dwivedi, R.P; Mohan, S.M. 1985. **Pulping studies on bamboos (Assam green bamboo and old bamboo) hard woods (sal scantling and salai), mixed bamboos + mixed hard wood (70: 30) and mills chips**. IPPTA 22(3): 12-18.

Assam green bamboo, old bamboo, mixed bamboo (A), sal scantling, salai, mixed hard wood (B), mixed bamboo (A) + mixed hard woods (B) (70:30) and mill chips are evaluated for chips classification, bulk density, proximate chemical analysis, kraft pulping, bleaching and physical strength properties. It is reported that hardwoods need higher alkali than bamboo for producing bleachable grade pulp. It is also reported that the pulps in higher yield can be produced by separate digestions and separate bleaching of bamboos and mixed hard woods instead of mixed digestion of these two raw materials of heterogenous nature. Mixed hard woods used upto 30 per cent in the mixed furnish has no detrimental effect on pulping quality and the physical strength properties.

218. Bhola, P.P. 1976. **Pulping studies of hill jati bamboo (Bambusa tulda) from Cachar Hills**. Indian Forester 102(4): 242-246.

Proximate chemical analysis and fibre dimensions of Hill Jati Bamboo growing in Cachar Hills (Bambusa tulda) are given. The paper present results of pulping and bleaching studies. It is suggested, based on the results, that this species of bamboo issuitable for manufacturing wrapping, writing and printing papers.

219. Istas, J.R; Hontoy, J. 1952. **The chemical composition and paper making qualities of some bamboos harvested in Belgium Congo**. Publ. Inst. Nat. Etude agron Congo belge (Ser. Tech) No. 41: 23p.

Gives the results of chemical analyses and pulping and paper-making tests of Sasa japonica, S. kurilensis, Bambusa hoffii, B. vulgaris, Gigantochloa asper and Ochlandra travancorica.

220. Istas, J.R; Raekaelboom, E.L. 1960. **Paper making from a mixture of M. smithii and B. vulgaris**. Bulletin of Agriculture. Congo Belge 51(2): 393-402.

221. Kala, R.P. 1973. **Flowering of bamboo in relation to paper manufacture**. Northern Forest Rangers College Magazine 27: 5p.

The phenomenon of flowering is described with particular reference to bamboo species used for paper manufacture. The difficulties experienced by paper mills in exploitation of the flowered bamboos are described and solutions to these problems are suggested.

222. Kang, Z.Y; Hwang, S.G; Kang, T.Y; Huang, S.K. 1975. **Adaptability study on Bambusa beecheyana var. pubescens grown in Taiwan**. Bulletin, Taiwan Forestry Research Institute 264: 7p.

This variety is the fastest-growing Bamboo in Taiwan and has the thickest culm wall; it is recommended for pulping. The results of 5-year-old trials (begun in 1965) on three contrasting sites in S. central Taiwan are reported. The yield of culms was considerably greater on a good lowland site (Chia-Yi) than on a fairly poor hill site (Lien-Hua-Chi); however, the size of the culms and the total weight of rhizomes varied relatively little between sites.

223. Kedharnath, S; Chatterji, R.N. 1966. **A valuable exotic bamboo (Phyllostachys bambusoides) in Himachal Pradesh**. Indian Forester 92(6): 428-431.

The bamboo collected from Himachal Pradesh is identified as Phyllostachys bambusoides, a valuable exotic bamboo. It is tested and found good for paper manufacture. Descriptions of the species are also given.

224. Ku, Y.C; Pan, T.T. 1975. **Experiments on using shoot-sheath of bamboo for pulping and papermaking**. Quarterly Journal of Chinese Forestry 8(4): 101-107.

At present, bamboo shoot-sheath (BSS) is not utilized in Taiwan. After steam treatment of BSS, [from Sinocalamus latiflorus], av. fibre length was 1.6 mm, equal to or longer than values for hardwoods, rice straw or bagasse. Pulps produced by soda pulping in the laboratory, and by neutral sodium sulphite pulping in a paper mill, were found suitable for making good-quality printing paper and corrugating medium, or for blending with other pulps. However, the yield of chemical pulp was low (25 oven-dry BSS). The bulkiness and short storage life of BSS also present problems for its use on a commercial scale.

225. Maheshwari, S. 1981. **Pulp and paper making characteristics of Dendrocalamus strictus from Karnataka, Madhya Pradesh, Orissa and Andhra Pradesh**. Indian Pulp and Paper.

226. Maheshwari, S. 1982. **Studies on some aspects of pulp and papermaking characteristics of Orissa bamboo.** Ph.D Thesis. Sambalpur University.

227. Maheshwari, S; Jaspal, N.S; Bhargava, R.L. 1976. **Pulping and paper making characteristics of North Kanara (India) bamboos**. IPPTA 13(4): 299-306.

Data are presented on stand characteristics, physical and chemical properties, fibre morphology and pulping characteristics of Bambusa arundinacea, Dendrocalamus strictus and Oxytenanthera monostigma.

228. Maheshwari, S; Satpathy, K.C. 1990. **The efficient utilization of bamboo for pulp and paper making**. Bamboos: Current Research. Proceedings of the International Bamboo Workshop, 14-18 November 1988, Cochin, India. Kerala Forest Research Institute, Peechi and IDRC, Canada: 286-290.

The pulping characteristics of (a) bamboo of different ages (b) different portions of the culm and (c) a few common varieties of bamboo are studied and the results are discussed. Effective methods of proper handling and storage of bamboo are also suggested.

229. Mishra, N.D; Nagaiah, K; Kumar, P.P; Parekh, M.C. 1979. **Pulping properties of bamboo from Assam, Orissa and Bhadrachalam areas of Andhra Pradesh**. Indian Pulp and Paper 33(6): 13-15.

230. Pakotiprapha, B; Pama, R.P; Lee, S.L. 1979. **Study for bamboo pulp and fibre cement composites**. International Journal for Housing Science and its Applications 3(3): 167-190.

Important characteristics of bamboo fibre reinforced composites are presented. Benefical effects of bamboo pulp in imporving the first crack strength of the composite and of bamboo fibres in providing post cracking ductibililty are identified. Results of experiments to evaluate the performance of the composites under service conditions (as per ASTM requirement for building boards) are also presented.

231. Raitt, W. 1912. **Report on the investigation of bamboo as material for production of paper pulp**. Indian Forest Records 3(3): 26p.

232. Raitt, W. 1929. **The Burma bamboo pulp survey**. Indian Forest Records (Economy series - Paper pulp) 14(1) : 48p.

The report sums up the information available on the subject of areas considered suitable for pioneer enterprise in bamboo pulp production in Burma. It is the result of the survey made by the author through the districts Arakan of North and South Forest Divisions, Tavoy Forest Division and Mergui Forest Division. It is found that a secured supply of bamboos exist in Burma, but the problem is in getting the supply to the mill. Also include the report of Robertson, W.A, Conservator of Forests on tour inTavoy and Mergui Divisions.

233. Razzaque, M.A; Das, P; Sayeed, M; Chowdhury, A.R; Das, S.C. 1981. **Age factor influencing the pulping characteristics of some bamboo species of Bangladesh**. Bano Bigyan Patrika 10(1/2): 49-58.

Fibre analysis, chemical analysis, pulping and pulp testing experiments were conducted on Muli, Mitinga, Kali, Orah and Dalu bamboos of ages ranging from 6 to 36 months. No appreciable change in chemical composition, fibre dimensions, pulp yields and physical strength properties of pulps could be monitored with increasing age. The results indicate that probably these bamboo species attain their maturity during the first year of growth. For pulping purposes, these species seems to be suitable for a twelve months cutting cycle.

234. Sekyere, D. 1994. **Potential of bamboo (Bambusa vulgaris) as a source of raw material for pulp and paper in Ghana**. Ghana Journal of Forestry 1: 49-56.

Laboratory studies were carried out to determine the pulping characteristics of a local variety of Bambusa vulgaris. The fibre length of 2.65 mm and Runkel Ratio of 1.03 suggest that bamboo fibres might be suitable for pulping and paper-making. The bamboo with a lignin content of 26.8 and cellulose content of 61.2 was cooked with 18 active alkali for 90 mins to obtain a yield of 54.2 and kappa number of 48.2. The pulp evaluations showed that it is not necessary to separate the node from the internode during pulping. The physical and strength properties of the pulp produced also showed that the bamboo can make good papers.

235. Shanmughavel, P. 1997. **The optimum age for felling of plantation bamboo (Bambusa bambos) for pulp and papermaking**. Journal of Tropical Forest Products 2(2): 286-288.

236. Singh, S.V; Mantri, T.C; Deb, U.K; Ghosh, D; Kulkarni, A.G; Murthy, K.S; Bharathi, S; Sude, Y; Kapur, S.K; Roy, T.K. 1977. **Properties of ETA reed pulps**. Research Report No. 1, FRI & Colleges, Dehra Dun, India.

237. Singh, S.V; Rai, A.K; Singh, S.P. 1988. **Aspects of pulping and papermaking from bamboos.** Indian Forester 114(10): 701-710.

A brief account of the chemical and morphological characteristics of major species of bamboo used for paper making in India is given in this paper. Research carried out on (a) pulping and bleaching, (b) effect of morphological characteristics on sheetproperties, (c) beating properties and (d) decay on storage and its effect on pulp properties is reviewed and discussed. A brief description of industrial pulping and papermaking is given.

238. Tamolang, F.N; Lopez, F.R; Semana, J.A; Casin, R.F; Espiloy, Z.B. 1980. **Properties and utilization of Philippine erect bamboos**. Bamboo Research in Asia. Proceedings of a Workshop, 28-30 May 1980, Singapore. IDRC, Ottawa: 189-200.

Of the 48 bamboo species in the Philippines, 29 are erect and the rest are climbing. Of these 10 species have been studied for their anatomic structure, pulp and paper making characteristics, fibre morphology, chemical composition, edibility of theirshoots, physical and mechanical properties, new industrial uses, seasoning and preservation aptitudes. The results of these studies are presented in this paper. The studies on the properties and the utilization of bamboos in Philippines by the Forest Products Research and Industries Development Commission are not comprehensive. Areas which require further investigation are indicated.

239. Ujiie, M; Kawase, K; Imagawa, H. 1986. **Studies of utilization of Sasa-bamboos as forest resources III. Pulp from soft young culms by the alkaline process**. Mokuzai Gakkaishi Journal of the Japan Wood Research Society 32(1): 28-33.

Young culms, 1.5-2.0 m long, of Sasa kurilensis were pulped easily with 1 NaOH. The pulp had a good quality and high strength, comparable with that of sulphate pulps of full-grown culms.

240. Wu, Z.H; Xu, Q.F. 1987. **Paper making with bamboo and its economic benefit in the world**. Journal of Bamboo Research 6(1): 46-53.

241. Xia, N.H. 1989. **Studies on the pulping properties of bamboo**. Acta Botanica Austro Sinica No. 4: 207-217.

Chemical constituents and fibre length were determined for 8 bamboo species, including moso bamboo (Phyllostachys pubescens). Samples (1 kg) of each species were processed under identical pulping conditions. The average unbleached pulp yield was 49.76 (Kappa number 28.3). Pulp strengths were satisfactory. Based on the unbleached pulp yield and strength properties, Schizostachyum funghomii exhibited the best qualities and Bambusa textilis and B. pervariabilis were ranked second and third. Under thesecriteria P. pubescens was ranked last. The pulping properties of bamboo of different ages were investigated. It was found that 1- to 2-yr-old bamboos were suitable for pulping.

242. Xie, J.H; Fu, M.Y; Chen, J.Y; Zhang, A.L; Li, R.G. 1999. **Study on high-yield structure of Moso bamboo pulp stands**. Proceedings of the First International Seminar on Technologies of the Cultivation, Processing and Utilization of Bamboo in the '99 Bamboo Cultural Festival of China. Journal of Bamboo Research 18(4): 65-72.

The structures of two types of high-yield Moso bamboo (Phyllostachys pubescens) pulpwood stands were studied in Anji County, Zhejiang Province, and in Jianyang County, Fujian Province, from 1991 to 1995. Aspects investigated included stand density, culm age components, and tree components. The best high-yield structure for pure Moso stands was a standing density of 3000 culms/ha, and culm age proportions of 1-2 year old to 3-4 year old of 7:3. Stands of this structure will produce a new culm yield of 31.1 t/ha every 2 yr. A model for calculating new culm yield was also established, based on the nonlinear relationship between new culm yield, and bamboo stand density and culm age components. In mixed Moso and broadleaved tree stands, the most importantstructural factor influencing productivity was the bamboo and tree [density] ratio, and the second most important the bamboo standing density. In this trial, the best bamboo/tree ratio was $\sum DB^2{:}\sum DT^2$ thin=thin 8:2 [where D is density], and a bamboo standing density of 2100 culms/ha. This structure of Moso/broadleaved tree mixed stand will produce 22.8 t/ha of new culms every 2 yr.

Anatomy and Chemical Constituents

243. Chen, Y.D; Quin, W.L; Li, X.L; Gong, J.P; Ni, M.A. 1985. **Study on chemical composition of ten species of bamboo**. Chemistry and Industry of Forest Products 5(4): 32-39.

Results are presented of chemical analyses of 10 species from Guangdong and Zhejiang provinces. Phyllostachys heteroclada contains larger amounts of holocellulose and less lignin than the other species and appears to be useful for chemical utilization. Chemical components change with age of the bamboo, amounts of holocellulose and alpha-cellulose decreasing after 1 yr and amount of lignin increasing slightly or remaining unchanged. Prolonging the growth period of bamboos is not desirable for chemical utilization purposes.

244. Fengel, D; Shao, X. 1984. **A chemical and ultra structural study of bamboo species Phyllostachys makinoi Hay**. Wood Science and Technology 18(2): 103-112.

A culm sample of Phyllostachys makinoi was investigated by analysis of its chemical composition, and by electron microscopic observations of the cell wall structure before and after extraction and degradation procedures. Quantitative determination of the components resulted in 2.6 extractives, 25.5 lignin, 45.3 alpha-cellulose, and 24.3 polyoses. The main polyose was an arabinoxylan with a Xyl: Ara ratio of about 17:1. The electron micrographs show a lamellar deposition of lignin and polyoses within the secondary walls. Lignin was soluble by parts in alkaline as well as in acidic reagents. Sodium hydroxide solution removed cell wall aubstance mainly from the secondary walls, whereas trifluroacetic acid removed substance from compound middle lamellae.

245. Fujii, Y; Azuma, J; Marchessault, R.H; Morin, F.G; Aibara, S; Okamura, K. 1993. **Chemical composition change of bamboo accompanying its growth**. Holzforschung 47(2): 109-115.

An immature culm of a moso-bamboo (Phyllostachys pubescens) 6 m in height was divided into six 1-m portions; their chemical composition was analysed and compared with results for an edible bamboo shoot (2 m high). In immature bamboo, the content of cellulose (and its crystallinity), and hemicelluloses and lignin content were higher in the lower portions. Similar changes were observed in uronic acid, acetyl group content, phenolic acid and phenolic aldehyde. Protein, starch and ash contents were higher in the upper portions. About 90 of the phenolic acid was composed of p-coumaric acid and ferulic acid, both being exclusively in the trans form, but their distribution profile was different:p-coumaric acid increased from the top to the bottom of the culm in relation to lignin content, while the reverse relation was observed for ferulic acid. Sixteen free amino acids were detected of which\small-cap\L-tyrosine was predominant.\small-cap\L-Tyrosine content was highest at the top and decreased rapidly in the middle portion of the immature bamboo culm where lignin biosynthesis was progressing rapidly. 13C-NMR spectroscopy was found to be useful for analysing the distribution of\small-cap\L-tyrosine. The results indicated that 6 m high immature bamboo could appropriately be used to study growth and development.

246. Ghosh, S.S; Negi, S.S. 1958. **Salient anatomical structure of Dendrocalamus strictus Nees and Bambusa arundinacea Willd. used for paper manufacture**. Symposium on Cellulose Research.

247. Giri, S.S; Janmejay, L.S. 1991. **Studies on the cell wall components of plain and hill bamboos of Manipur**. Advances in Plant Sciences: 235-243.

An analysis of the variations in the contents of fibre and it components such as cellulose, hemicellulose and lignin in bamboos collected from plain and hill areas is carried out and the results are presented. Six samples such as base internode, middle internode, top internode, base node, middle node and top node from plain and hill grown bamboos are studied. The fibre contents are reported higher in plain bamboos than in hill ones. The weakness of the hill bamboo culms is reported due to the lower percentage of fibre. A decrease in the contents of cellulose and hemicellulose from the base to top both in node and internode is reported.

248. Gomide, J.L; Vivone, R.R; Vilar, R. 1985. **Effect of parenchyma cell content on characteristics and properties of kraft pulp from Bambusa vulgaris with an optimum**

degree of delignification. ABCP 18th annual meeting held during paper week, 18-22 November, Paulo, Brazil. ABCP, Sao Paulo, Brazil. Vol. 1: 139-147.

Different amounts of parenchyma cells (0, 11.8, 23.6 and 35.4) were added to the fibre fraction of kraft pulp and the characteristics of the pulp were assessed. Pulp of high strength was obtained with B. vulgaris; presence of parenchyma cells generally reduced pulp strength.

249. Hwang, J.S; Chiang, P.Y. 1998. **Studies of the changes of texture and chemical compositions of Ma-Bamboo shoots (Dendrocalamus latiflorus) during cooking**. Journal of Agricultural and Forestry 47(2): 89-100.

The effect of heat treatment on the texture, chemical composition and observed microstructure was investigated in Ma-Bamboo shoots. Pectic substances tended to increase after being heated between 40 and 80^{o}C for 100 min. Pectic substances decreased sharply from 880 to 505 mg by heating to 100^{o}C for 200 min, however, cellulose hemicellulose, lignin changed slightly. The change in chemical composition and cell microstructure was slight and the cell wall kept shape, even during dehydration and construction of cells. It is concluded that during heating, the loss of pectic substances simultaneous resulted in the softeing and the contraction and deformation of cell walls.

250. Liese, W; Weiner, G; Chapman, G.P. 1997. **Modifications of bamboo culm structures due to ageing and wounding. The bamboos**. Proceedings of an International Symposium, London, 25-29 March 1996. Academic Press for the Linnean Society of London, San Diego, USA: 313-322.

Structural modifications that can occur during the life span of a bamboo culm due to wounding and ageing are described. A bamboo culm grows for only a few months with minor anatomical differences within the internode and along the culm length. Structural modifications occur within a maturation period of 1-2 years, followed by further changes in older culms due to ageing, such as cell wall thickening of fibres and parenchyma. In order to ensure long-term competent physiological functioning, any damagecaused by culm injury has to be blocked off, especially as the secondary meristem cannot provide new pathways. Protective mechanisms include formation of slime substances, tyloses, phenolic compounds and lignification. Special features of wound responsesin comparison to hardwoods are suberinization and additional wall lamellae.

251. Lin, J.G; Dong, J.W; Fan, X.F; Lin, S.D. 2000. **The variation tendency of chemical composition contents in Dendrocalamus latiflorus culm-wood**. Journal of Plant Resources and Environment 9(1): 55-56.

Variation in the chemical composition of Dendrocalamus latiflorus culm wood were systematically analysed using samples from different sites (3), ages (1, 2 or 3 yr old), planting methods (3, transplants from the maternal bamboo, and cuttings from mainor secondary branches), and planting positions (2, horizontal or vertical) in [Fujian Province], China. Components analysed were ash, hot water, NaOH and benzene/alcohol extractives, nitric acid/alcohol cellulose, pentosans and Klason lignin. The resultsshowed that age and bamboo planting position are the main factors which affect wood chemical composition, while site and planting mode are insignificant.

252. Madan, R.N; Vijan, A.R. 1995. **Physico-chemical properties of Dendrocalamus giganteus kraft spent liquor**. Proceedings of the international seminar on 'Management of MFP', 13-15 November 1994. Journal of Non Timber Forest Products 2(3/4): 160-164.

253. Montalvao, Filho, A; Gomide, J.L; Conde, A.R. 1984. **Variability in chemical constitution and dimensional characteristics of Bambusa vulgaris fibres**. Revista Arvore 8(1): 12-27.

A study of holocellulose, pentosan, lignin and ash contents, solubility in various solvents and fibre dimensions of stem and branch samples of 6.5-yr-old plants grown in plantations in Bahia.

254. Parameswaran, N; Liese, W. 1977. **Occurrence of warts in bamboo species**. Woodscience and Technology 11(4): 313-318.

Warts have been observed on the walls of wood cells(under SCM and TEM) in several bamboo species; they can be presented not only in vessel members and fibres, but also in the highly lignified parenchyma cells, especially in those of the elongated type. Among the 34 species studied only

Melocanna bambusoides possessed warts in all three cell types. The sizes of warts lie with in the range observed for dicots and gymnosperms. There is no recognizable correlation between the occurrence of warts and the taxonomic grouping of bamboos. It has been suggested that the development of warts is associated with the lignification of the cell wall.

255. Paremeswaran, N; Liese, W. 1981. **The fine structure of bamboo**. Proceedings of Bamboo Production and Utilization XVII IUFRO World Congress, 6-17 September 1981, Kyoto, Japan. Wood Research Institute, Kyoto University, Kyoto: 178-183.

The fine structural aspects of the diverse cells like fibres, parenchyma, metaxylem vessels, protoxylem and phloem are briefly discussed. Special emphasis is laid on the wall construction as realated to the physical properties of the culm.

256. Patnaik, J.K; Rao, P.J.M; Gantayet, R.G; Bhargava, K.S. 1984. **Effect and utilisation of bamboo pin chip**. IPPTA 21(3): 20-23.

With the increase of the cost of bamboo, efforts are made to utilise bamboo at the maximum for pulping. A study was conducted on the cooking of pin chips, which are removed as bamboo dust during the screening of the chips. Studies show that the small quantity pulp obtained from separate cooking of pin chips can be mixed with normal kraft pulp for the manufacture of the kraft paper without any significant effect on the physical strength properties of paper. It is reported that by mixing small quantity(5 percent) of pin chips with the usual chip the quality of pulp does not deteriorate much.

257. Samapuddhi, K. 1959. **A preliminary study in the structure of some Thai bamboos**. Royal Forest Department, Ministry of Agriculture, Bangkok: 13p.

Results of a preliminary study made on the anatomical structure, silica content, fibre length and starch content of some Thai bamboos are presented.

258. Sekhar, T; Balasubramanian, A. 1994. **Structural diversity of culm in Bambusa vulgaris**. Journal of the Indian Academy of Wood Science 25(1/2): 25-31.

Bambusa vulgaris is one of the valuable and much used bamboos for structural purposes and in the paper industry. The variations in the fibro-vascular bundle organization, mechanical tissue distribution and the fibre charcterestics in in culm internodes were used for the identification and delimitaiton of of Bambusa vulgaris and its varieties viz. B. vulgaris var. striata and B. vulagaris cv. wamin. The significance of the structural diversity of the culm wall in taxonomy is discussed and the elevation of the above varieties to the species level is supported.

259. Shin, D.S; Jung, T.M. 1962. **Studies on the chemical components of bamboo produced in Korea-(1)-On the chemical composition of kat-tae**. Research Bulletin of Chinju Agricultural College 1: 31-34.

260. Tomazello, Filho, M; Azzini, A. 1987. **Anatomical structure, fibre dimensions and basic density of Bambusa vulgaris culms**. IPEF 36: 43-50.

Examination of sections of 3-yr-old culms showed a decrease in fibre length from internal to external culm layers at all culm heights. Fibre length increased longitudinally upto 25-75 culm height and then decreased towarse the apex. Basic density increased from internal to external layers and from the base to the apex.

261. Tono, T. 1963. **Chemical studies on bamboo fibre as a raw material for pulp**. Bulletin of the University of Osaka Prefecture Ser. B. 14: 127-161.

262. Varshney, M.C. 1965. **The effect of anatomical characteristics of bamboo on pulping**. Sirpur Industries Journal 4(2): 116-118.

263. Vijan, A.R; Madan, R.N. 1996. **Study on the chemistry of Dendrocalamus giganteus lignin**. Van Vigyan 34(1/2): 43-49.

With a view to possible utilization of kraft lignin as a byproduct, lignin was isolated from the spent liquor left from pulping by the kraft process, using bamboo samples from sound and flowered specimens of D. giganteus. Data are tabulated on the C, H, O and S contents of the lignins, on the contents of Klason lignin and functional groups (methoxyl, hydroxy and carboxylic) and correlations between them, and on the relative retention time and percentage of alkaline nitrobenzene oxidation products of the lignins. The results indicate clear differences in structure between lignin isolates from sound and flowered bamboos.

264. Wu, S.C; Sheng, H.J; Liou, J.L. 1996. **The anatomical properties of some bamboo species grown in mainland China (III)**. Quarterly Journal of the Experimental Forest of National Taiwan University 10(2): 37-59.

The middle internode of a bamboo culm was cut from each of 23 species belonging to 7 genera (Brachystachyum [Semiarundinaria], Clavinodum [Arundinaria], Indocalamus, Oligostachyum [Arundinaria], Phyllostachys, Pseudosasa and Sinobambusa), native to Zhejiang. Sectioning, maceration and computer image analysis were used to investigate their anatomical properties. The characteristics recorded were: vascular bundle size; number of vascular bundles/mm2; culm wall thickness; distribution of small and large diameter vessels; fibre length, diameter and cell wall thickness; diameter, length and type of parenchyma; and the proportion of various anatomical elements.

Cellulose, Hemicellulose and Lignin

265. Ahmad, N; Karnik, M.G. 1944. **A technical survey of cellulose bearing materials of India**. Journal of Scientific and Industrial Research 2: 275-290.

The chief object of this investigation was to determine the alpha-cellulose content of the cellulose-bearing materials of India under the optimum conditions of Kier boiling and bleaching. The materials tested included Bamboos, grasses, straws, fibres, and the tree species Fir, Spruce, Salai (Boswellia serrata), Karai (Sterculia urens). Four processes were used-soda, sulphate, sulphite, and sodium sulphite; the last of these gave the best results. Addition of sodium aluminate as an auxiliary was found to increase the alpha-cellulose content of the pulp, but also increased the ash content. The Fir and Spruce samples gave good results and seem to be promising raw materials for the rayon industry. Salai and Karai did not give satisfactory results; the pulp obtained consisted of short fibres and had a low alpha-cellulose content. The results of the experiments on all types of materials are given in tabular form. The Bamboos include Dendrocalamus strictus. Bambusa arundinacea, and Eetta Bamboo.

266. Azzini, A; Arruda M.C.Q. de; Ciaramello, D; Salgado, A.L de B; Tomazello Filho, M. 1987. **Combined production of cellulose fibres and ethanol from bamboo**. Bragantia 46(1): 17-25.

In a study using 1-, 3- or 5-yr-old Bambusa vulgaris culms, shredded and treated with dilute H_2SO_4, fibre yield for paper making was higher in younger culms. Potential ethanol yield (by fermentation of glucose) and glucose and starch contents were higher in samples from the middle and upper portions of the culms. Density did not vary with age but was higher in the middle and top portions of the culms. Combined production of ethanol and fibres was considered to be feasible.

267. Azzini, A; Arruda M.C.Q. de; Tomazello Filho, M; Salgado, A.L. de B; Ciaramello, D. 1987. **Variation in cellulose fibre and starch contents in bamboo culms**. Bragantia 46(1): 141-145.

In a study of 3-yr-old Bambusa vulgaris culms, density was lowest in the basal portion of the culm and in the inner parts of the culm wall. Cellulose fibre and starch contents did not vary significantly along culm length, although higher fibre contentwas found in the outer portion of the culm. The highest starch contents were found in the inner portion of the culm.

268. Bawagan, P.V. 1968. **Studies on bamboo (Bambusa vulgaris Schrad. ex. Wendl.) cellulose and its isolation by analytical and industrial methods**. Philippine Lumbermann 14(11): 18-24, 32, 34.

The results suggested that the prehydrolysis/sulphate process may be the only effective means of removing the pentosan from the Bamboo chips (though at a cost of considerable loss of alpha-cellulose) and thus enabling a dissolving-grade pulp to be obtained.

269. Bhat, R.V; Guha, S.R.D. 1952**. Indigenous cellulosic raw materials for the production of pulp, paper and board. Part IV**. **Writing and printing paper from paper mulberry (Broussonetia papyrifera).** Indian Forester 78(2): 93-99.

Experiments conducted in Madras State and Travancore-Cochin State indicate that paper mulberry (Broussonetia papyrifera, Vent.) can be easily raised in plantations from seeds. The species reproduces itself naturally and is a fast grower and a good coppicer. The bast fibre is used in Japan for the preparation of extremely strong and high quality papers. Laboratory experiments as well as pilot plant trials carried out in this Branch indicated that the wood of this species is a useful raw materials for the production of writing and printing papers. Since the chemical pulp from this wood is short-fibred, an addition of about 25 of long-fibred pulp such as bamboo pulp in the furnish improves the strength properties of the paper.

270. Bhat, R.V; Guha, S.R.D. 1953. **Indigenous cellulosic raw materials for the production of pulp, paper and board. Part XV**. **Chemical pulps and writing and and printing paper from Albizzia stipulata Bolvin**. Indian Forester 79(9): 475-483.

Laboratory experiments on the production of chemical pulps by the sulphate process from the wood of Albizzia stipulata are described. The wood was obtained from forests of Bihar. Results of four pilot plant experiments on the preparation of writing and printing papers from this wood are also included. This investigation has shown that chemical pulps in satisfactory yields can be prepared from this wood. The whiteness of the bleached pulps was good. Although the average fibre length of the pulps was only 1.02 mm., writing and printing papers made on the pilot plant from the furnish containg entirely the pulp from this wood were characterised by good strength properties. The formation of the papers was satisfactory.

271. Bhat, R.V; Guha, S.R.D; Pande, S.P. 1952. **Indigenous cellulosic raw materials for the production of pulp, paper and board. Part VIII**. **Writing and printing papers from Boswellia serrata Roxb**. Indian Forester 78(4): 169-175.

Laboratory experiments carried out in this Institute on the production of bleached chemical pulp from Boswellia serrata (salai) are described. The results of pilot plant experiments are also included. Two samples of printing paper made from mixtures of Boswellia serrata pulp and bamboo pulp are appended. These experiments have shown that writing and printing papers with suitable strength properties can be prepared from Boswellia serrata using 25-40 of bamboo pulp in the furnish. As the chemical pulp from Boswellia serrata is short-fibred, it is essential to add bamboo or other long-fibred pulp to the furnish.

272. Bhat, R.V; Jaspal, N.S. 1957. **Indigenous cellulosic raw materials for the production of pulp, paper and board. Part XXX**. **Wrapping papers from castor stem (Ricinus communis Linn.).** Indian Forester 83(10): 614-620.

Laboratory experiments on the production of wrapping papers from castor stem (Ricinus communis Linn.) of the annual variety are described. Wrapping papers were made on the pilot plant of the Forest Research Institute from 100 castor stem pulp and also from a mixture of 70 of this pulp and 30 bamboo kraft pulp. These papers were characterised by good formation and satisfactory strength properties. The utilization of castor stalk for the manufacture of wrapping papers will depend upon the price at which it can be made available at the mill site.

273. Bhat, R.V; Viramani, K.C. 1957. **Indian Forest Leaflet No. 123**. FRI & Colleges, Dehradun.

274. Bhowmick, K; Mian, A.J; Akhteruzzaman, A.F.M. 1994. **The kinetics of delignification in low sulphidity kraft anthraquinone and soda anthraquinone pulping of muli bamboo (Melocanna baccifera)**. IPPTA.

275. Bist, D.P.S; Singh, S.V; Singh, M.M; Guha, S.R.D. 1974. **Oxidation of bamboo- dioxane lignin by alkaline potassium ferricyanide**. Indian Pulp and Paper 29(4): p3.

276. Bist, D.P.S; Singh, S.V; Singh, M.M; Guha, S.R.D. 1975. **Oxidation of dioxane and soda lignins of bamboo by alkaline cupric sulphate**. Indian Pulp and Paper 29(6): p17.

277. **Cellulose yield of bamboo**. Myforest 2(1)1965: 51-52.

A note on the visiting of Mr. John Wilson the various bamboo areas of Mysore State. It is reported that the cellulose yield of bamboo is 4 to 5 times more per acre, per year than that obtained from the best managed southern pines in U.S.A.

278. Dhawan, R; Singh, S.V. 1982. **Chemical characterization of hemicelluloses isolated from three species of bamboo - Dendrocalamus strictus, Dendrocalamus hamiltonii and Melocanna baccifera**. Journal of the Indian Academy of Wood Science 13(2): p62.

GLC hemicelluloses showed that xylose is the main constituent (80-92 of hemicellulose in all 3 species. Glucose, arabinose, rhamnose and glusuronis acid were also found in small amounts. The yield of sugars was highest for D. strictus, whereas the yield of pentosans and methoxyl compounds were highest for D. hamiltonii, M. baccifera had the lowest content of sugars, pentosans and methoxyl compounds.

279. Doat, J. 1967. **Bamboos: A possible source of cellulose for Africa**. Bios. For. Trop. 113: 41-59.

280. Espiloy, Z.B. 1982. **Silica content in spiny bamboo Bambusa blumeana Blume ex Schultes**. NSTA Technology Journal 7(4): 38-43.

Determination of silica, which affects the pulping quality in the species, Bambusa blumeana is dealt with in this paper. It is reported that a positive correlation exists between specific gravity, cell wall thickness and silica content in the bamboo.

281. Faix, O; Jakab, E; Till, F; Szekely, T. 1988. **Study on low mass thermal degradation products of milled wood lignins by thermogravimetry-mass-spectrometry**. Wood Science and Technology 22(4): 323-334.

Thermogravimetry-mass-spectrometry (TGMS) as a sophisticated analytical technique is described for the thermal analysis of milled wood lignins from spruce (Picea abies), beech (Fagus sylvatica), and bamboo (Bambusa sp.). The samples were heated on thethermobalance in an inert gas atmosphere (Ar) with 20°C/min heating rate. The weight loss curves (TG) and their 1st derivatives (DTG) were recorded. The evolution of 10 low mass degradation products with m/z below 44 was monitored as a function of temp. by means of a quadrupol mass spectrometer; their intensity profiles were recorded and interpreted in terms of lignin structure and the course of carbonization. The results are in agreement with the results of differential scanning calorimetry and pyrolysis-gas-chromatography mass-spectrometry of the phenolics.

282. Faix, O; Lange, W; Beinhoff, O. 1980. **Molecular weights and molecular weight distributions of milled wood lignins of some wood and Bambusoideae species**. Holzforschung 34(5): 174-176.

Mol. wt. measurements were made on milled wood lignins from spruce, beech, aspen [Populus spp.], birch, dabema [Piptadeniastrum africanum], bamboo and rattan using high pressure liquid chromatography. The yields of milled wood lignin were between 1.7 and 5.9 and considerable differences in their molecular properties were found between species.

283. Faix, O; Meier, D. 1989. **Pyrolytic and hydrogenolytic degradation studies on lignocellulosics, pulps and lignins**. Holz als Roh und Werkstoff 47(2): 67-72.

Wood and milled-wood lignin from beech, Norway spruce and bamboo, as well as teak wood and teak HCl-lignin, were subjected to analytical pyrolysis using the off-line approach, and to hydrogenolysis. Gas chromatography-mass spectrometry was used for product identification and assignment as derivatives from 4-hydroxyphenylpropane, guaiacylpropane and syringylpropane basic units, followed by capillary gas chromatography for quantitative determination of the phenolics. The results are compared with thoseof nitrobenzene oxidation and quantitative non-degradative FTIRspectroscopy. Pyrolysis-GC and hydrogenolysis-GC studies were also used for the characterization of residual lignins in kraft and alkaline-sulphite-anthraquinone-methanol (ASAM) pulps from beech, pine and sugar cane bagasse. It is concluded that analytical pyrolysis of biomass, in both on-line and off-line approaches, is well suited for lignin classification even without previous lignin isolation; hydrogenolysis is more suitable for the characterization of residual lignins in pulps.

284. Fengel, D; Shao, X. 1985. **Studies on the lignin of the bamboo species Phyllostachys makinoi Hay**. Wood Science and Technology 19(2): 131-137.

Milled wood lignin (MWL) isolated from Phyllostachys makinoi was investigated by chemical and physical methods. The bamboo lignin was rich in syringyl units which is indicated by a high methoxyl content and respective bands in the IR spectrum. The distinct absorption bands for aromatic ring vibrations were attributed to final p-coumaryl ester groups. In the UV spectrum the extinction maximum in the range of 280 nm is shifted to longer wavelengths compared with those of wood lignin. With NaOH and trifluoroacetic acid (TFA) mainly an arabinoxylan with a Xyl :Ara ratio of 14:1 was extracted from bamboo saw dust. The lignin proportion in the NaOH extract, which is derived mainly from the secondary walls, has a lower methoxyl content; the lignin proportion in the TFA extract, which is derived from the compound middle lamellae, has a higher methoxyl content compared with MWL.

285. Guha, S.R.D; Pant, P.C. 1967. **Hemicelluloses from bamboo (Bambusa arundinaceae)**. Indian Pulp and Paper 21(7): p14.

286. Han, H; Zu, Z.W; Zhang, J.W; Ma Naixun; Ma, L.F. 1996. **Ash and lignin contents for 76 species of bamboo wood**. Journal of the Zhejiang Forestry College 13(3): 276-279.

The ash content and lignin content for 76 species of bamboo wood from Guangxi and Zhejiang were determined. The ash content ranged from 0.88 to 7.23, averaging 2.65, and the lignin content ranged from 2.36 to 30.4, averaging 24.95.

287. Hasegava, T; Ito, M. 1959. **The behaviour of xyloses during hydrotropic pulping**. Journal of Chemical Society of Japan, Industrial Chemical Section 62(9): 1435-1438.

288. Higuchi, T. 1958. **Studies on the chemical properties of the lignin of bamboo-stalk**. Journal of Biochemistry 45(9): 675-685.

Results of an investigation made on the lignin of bamboo are described in this paper. It is conclued from ethanolysis and hydrolysis of stalks of Phyllostachys edulis that a part of the lignin is formed by oxidative condensation of beta-guaiacyl ethers of guaiacyl-, syringyl-, and p-hydroxyphenyl-propanes.

289. Higuchi, T; Kawamura, I. 1966. **Occurrence of p-hydroxy phenylglycerol-B-aryl ether structure in lignins**. Holzforschung 20(1): 16-21.

Describes experiments which showed that this structure is not specific to the lignin of gramineous plants but also occurs in various other lignins, the amount being almost the same in conifers and gramineous plants, and a little less in broadleaved trees.

290. Higuchi, T; Tanahashi, M; Sato, A. 1972. **Acidolysis of Bamboo lignin. I. Gas-liquid chromatography and mass spectrometry of acidolysis monomers**. Mokuzai Gakkaishi Journal of the Japan Wood Research Society 18(4): 183-189.

Milled wood lignins from Phyllostachys pubescens and from four tree species were subjected to acidolysis in dioxan/water containing 0.2N HCl. Examination of the products showed that guaiacyl- and syringyl-glycerol- beta -aryl ethers are present in approximately equal amounts in the Bamboo lignin, and that these two components account for 50-60 of the phenylpropane units of the lignin.

291. Higuchi, T; Tanahashi, M; Nakatsubo, F. 1973. **Acidolysis of Bamboo lignin III. Estimation of arylglycerol- beta -aryl ether groups in lignins**. Wood Research 54: 9-18.

The concentrations of both condensed and uncondensed forms of arylglycerol- alpha, beta -diaryl ether groups in Phyllostachys pubescens, Fagus crenata and Thuja standishii were estimated by gas/liquid chromatography and spectral analysis. Results arecompared and discussed.

292. Idei, T. 1981. **D.P [degree of polymerization] and crystallinity of cellulose in the different growth stage of bamboo culms.** Bulletin, Utsunomiya University Forests 17: 59-73.

Including data on chlorophyll and lignin contents in Phyllostachys heterocycla var. pubescens [P. pubescens].

293. Ingle, T.R; Bose, J.L. 1969. **Nature of hemicelluloses of bamboo (Dendrocalamus strictus).** Indian Journal of Chemistry 7: 783-785.

Two hemi cellulose fractions are isolated from Bamboo (Dedrocalamus strictus) powder, and holocellulose prepared from it. The behaviour of some of these fractions towards water and potassium hydroxide is studied. The main hemicellulose fraction from holocellulose is found to be a glucuronoxylan of molecular weight of 6600, containing D-xylose and D-glucuronic acid units in the molar preportion of about 9:1.

294. Jamaludin K; Abd. Latif Mohmod. 1993. **Variability of specific gravity, fibre morphology and chemical properties in three Malaesian bamboos.** BIC India Bulletin 3(2): 7-13.

The paper discusses physical properties like specific gravity and fibre morphology and chemical properties of three commercialy imporatant bamboo species in Peninsular Malaysia, namely Bambusa vulgaris. B. heterostachya and Gigantochloa scortechinii. Specific gravity is reported increase from basal to top portion. The fibre properties especially the fibre diameter and fibre cell wall thickness are reported increase with the increasing height.

295. Kapoor, S.K; Guha, S.R.D. 1984. **Infrared studies on wood lignin of eta-reed (Ochlandra travancorica).** IPPTA 21(3): 24-28.

Presents the results of an investigation carried out to elucidate the chemical character of milled wood lignin isolated from Ochlandra travancorica which is proved to be a very good raw material for chemical pulping.

296. Karnik, M.G. 1960. **The nature of hemicelluloses from bamboo (Dendrocalamus strictus). Part I. Preliminary investigations.** Indian Pulp and Paper 14(9): 427-429.

Reports the results of a study of the nature of hemicelluloses in bamboo following chemical analysis of 0.25 mm. x 2.5 cm. air-dried shavings from 3-year-old culms. The material was found to contain 64.8 of holocellulose (oven-dry wt. basis), 10.6 of "hemicellulose A" and 3.77 of "hemicellulose B". The higher value of the "hemicellulose A" fraction indicates that bamboo contains more hemicelluloses of a lower degree of polymerization, which are likely to be dissolved and destroyed in the process of alkaline pulping, resulting in the production of a pulp of low hemicellulose content. Data from chemical analysis of the holocellulose, alpha-cellulose, and hemicelluloses isolated from the bamboo, showed that of the 21 of pentosans present in holocelluloses ca. 2.73 are alkali resistant and retained in alpha-cellulose. Hemicellulose B contained 20.9 more pentosans than hemicellulose A. The high pentosan content of both fractions indicated that the bamboo hemicelluloses contained more pentosans than hexosans.

297. Karnik, M.G; Morak, A.J; Ward, K. 1963. **Hemicelluloses and dissolving pulp from Indian bamboo (Dendrocalmus strictus).** TAPPI Journal 46(2): 130-134.

A more quantitative treatment of Karnik's preliminary investigation into the hemicelluloses of D. strictus, in which the main hemicellulose of the bamboo would seem to be consistent with the structure of 4-0-methylglucuronoarabinoxylan (though the only basis for this so far is analogy with the wood hemicelluloses).

298. Kawase, K; Sato, K; Imagawa, H; Ujiie, M. 1986. **Studies on utilization of Sasa bamboos as forest resources. 4. Pulping of young culms and histological change of cell structure of the culms in growing process.** Research Bulletins of the College Experiment Forests, Hokkaido University 43(1): 73-97.

Young culms of S. kurilensis (up to 4 yr old) were pulped by boiling with 1-2 KOH. This produced pulps suitable for folk art paper, because of the presence of thin-walled fibres, unlike the

sclerenchymatous adult fibres. Underground buds and culms <1yr old were examined using SEM, and the vascular bundles and parenchyma cells are described and illustrated.

299. Kuroda, H; Shimada, M; Higuchi, T. 1981. **Roles of bamboo O-methyltransferase in the lignin biosynthesis**. Wood Research, Kyoto University 67: 17-28.

O-methyltransferase (OMT) extracted from Phyllostachys pubescens was characterized and its role in lignin biosynthesis studied. Bamboo OMT was shown to be a single enzyme catalyzing the methylation of both caffeic to ferulic acid (FA) and 5-hydroxyferulic to sinapic acid (SA). Km (Michaelis-Menton constant) values were 5X10-5 and 10-5M respectively, and the methylation process was competitively inhibited by the subsequent phenolic substrate. Two possible mechanisms by which OMT controls lignin biosynthesis are considered, viz. feedback inhibition, and apparent conformational changes in the enzyme as suggested by changing SA/FA ratios. The av. SA/FA ratio of about 1 is characteristic of the Gramineae.

300. Maekawa, E. 1976. **Studies on hemicellulose of bamboo**. Wood Research No. 59(60): 153-179.

Reviews world literature on the isolation and structure of a xylan as the predominant component of Bamboo hemicellulose, and gives results of (1) experiments on the isolation and purification of hemicellulose from culms of Bamboo (Phyllostachys reticulata) (2) structural studies on a Bamboo xylan, and (3) an experiment on the isolation from Bamboo of a xylan containing native acetyl groups. In general the results show that Bamboo xylan has properties similar to those of hardwood xylans, although in having arabinose residues it resembles softwood xylans; it is therefore concluded that in structural characteristics Bamboo xylan is likely to be intermediate between hardwood and softwood xylans.

301. Maekawa, E; Koshijima, T. 1983. **Wood polysaccharides dissolved in the liquor in the process of preparing holocellulose by using peracetic acid**. Journal of the Japan Wood Research Society 29(6): 415-421.

302. Maekawa, E; Koshijima, T. 1988. **An analytical method for the determination of acidic sugars in wood hemicelluloses by gas-liquid chromatography**. Mokuzai Gakkaishi Journal of the Japan Wood Research Society 34(4): 359-362.

The method was used to analyse acidic sugars from beech [Fagus crenata] and bamboo hemicelluloses.

303. Mahanta, D. 1989. **Adsorption of cationic polyacrylamide and alum onto cellulose fibres at different pH of the medium**. Journal of the Japan Wood Research Society 35(4): 336-341.

304. Maheshwari, S. 1985. **Peroxide delignification of bamboo sulfate pulp**. Indian Pulp and Paper XL(2).

305. Martin, F; Saiz Jimenez, C; Gonzalez Vila, F.J. 1979. **Pyrolysis - gas chromatography - mass spectrometry of lignins**. Holzforschung 33(6): 210-212.

Milled wood lignins from spruce, beech and bamboo were pyrolysed. The high-boiling products of pyrolysis were studied by GLC and mass spectrometry. The 43 products identified provide information on the structural units of lignin.

306. Monteiro, R.F.R. 1949. **Ochlandra abyssinica, an African bamboo: Contributions to a knowledge of its value in the cellulose industry**. Agron. Angol. No.2: 59-73.

307. Mukherjea, V.N; Guha, S.R.D. 1971. **Production and studies of cellulose from bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 25(9/12): 535-541.

308. Nakatsubo, F; Tanahashi, M; Higuchi, T. 1972. **Acidolysis of Bamboo lignin II. Isolation and identification of acidolysis products**. Wood Research 53: 9-18.

Acidolysis products of milled wood lignin of Phyllostachys pubescens were fractionated by gel filtration on Sephadex, and individual compounds in both monomeric and dimeric fractions were identified by infra-red, nuclear-magnetic-resonance and mass spectrometry. The results confirmed those of the earlier study, showing that the Bamboo lignin is a mixed polymer of guaiacyl and syringyl propanes and a small amount of p-hydroxyphenylpropane connected by linkages similar to those found in spruce lignin.

309. Negi, J.S. 1969. **Chemical composition of hemicellulose of bamboo (Dendrocalamus strictus).** Ph.D Thesis, Agra University, Agra, India.

310. Negi, J.S. 1970. **Effect of hemicellulose on paper making properties of bamboo (Dendrocalamus strictus) sulphate pulp**. Indian Pulp and Paper 24(8): p347.

311. Pant, R; Singh, M.M; Guha, S.R.D. 1975. **Studies on bamboo lignins**. Journal of the Indian Academy of Wood Science 6(2): 61-71.

Lignins were extracted from Dendrocalamus strictus by several methods, and analysed in several ways. The results indicate that there are 2 main fractions present: (A) amounting to 52, with a higher methoxyl value, easily extracted by organic acids andin which guaiacyl and syringyl repeating units dominate and (B) with a lower methoxyl value, extractable with more drastic treatment (periodic and sulphuric acid) and in which there are more p-hydroxy-phenyl propane units.

312. Rita Dhawan; Singh, S.V. 1982. **Chemical characterization of hemicelluloses isolated from three species of bamboo Dendrocalamus strictus, Dendrocalamus hamiltonii and Melocanna baccifera**. Journal of the Indian Academy of Wood Science 13(2): 62-66.

A comparison of the chemical composition of hemicelluloses (Beta 17-20 percent yield) from three bamboo species viz. Dendrocalamus strictus, D.hamiltonii and Melocanna baccifera is reported. The gas liquid chromotography (GLC) of hemicelluloses indicated that xylose (=82-92 percent yield) is the main constituent of the hemicelluloses from all the three species. Glucose, arabinose, rhimnose and glucuronic acid were also found to be present in small amounts in all the hemicelluloses. The yield of sugars was highest in case of D.strictus, whereas pentosans and methoxyl content were the highest in the case of D.hamiltonii. M.baccifera had the lowest yield of sugars, pentosans and methoxyl content.

313. Sabharwal, H.S; Singh, S.V; Singh, M.M; Guha, S.R.D; Jain, K.D. 1962. **Chlorination of bamboo protolignin**. Indian Pulp and Paper 31(1): p13.

314. Schowing, A.G; Johansson, G. 1965. **Determination of acid soluble lignin in semichemical bisulphite pulps and in some wood and plants**. Syensk Paperstard 68(18): 607-613.

315. Shimada, M. 1972. **Biochemical studies on Bamboo lignin and methoxylation in hardwood and softwood lignins.** Wood Research No.53: 19-65.

Gives a detailed account of research on the mechanism governing the biochemical formation of lignins in higher plants, based on an extensive review of world literature and on the author's studies of lignin from Bamboo (Phyllostachys sp.), Pine (Pinus thunbergii) and Ginkgo biloba.

316. Singh, M.M; Bhola, P.P. 1978. **Chemical nature of soda lignins and pulp sheet properties of Indian bamboos**. Indian Forester 104(6): 438-449.

The difference in the lignin content of different species of Indian bamboo is very negligible (24+-3) percent. The carbon and hydrogen content of these lignins are 59.7 percent with a variation of 3 percent respectively. The number of c9 units varies from 12 to 21 with an average of 14 indicating that the structure of carbon lignin skeleton is more similar to hardwoods than conifers. The I.R. spectra is similar and show bamboo lignin composed of polymer. There is a correlation between the number of c9 units of different bamboos and breaking length of the beaten pulps.

317. Singh, M.M; Mathur, G.M; Jain, K.D. 1974. **Isolation of carbohydrates and preparation of alphacellulose from bamboo (Dendrocalamus strictus) to study alkali resistance of hemicelluloses**. Indian Pulp and Paper 24(4/5): 19-21.

318. Singh, S.V; Singh, S.P; Bhandari, S.S; Saini, B.K. 1987. **Chemical modification of lignin in high yield pulps - A new approach to improve strength properties and bleachability**. IPPTA 24(1): 27-31.

The paper gives an account of the improvement achieved in strength properties and bleachability of high yield pulps through chemical modification of their lignin. Soda thermo mechanical (STM) and soda-sulphite thermomechanical (SSTM) pulps of bamboo are modified using chlorine sodium sulphite and hypochlorite.

319. Takei, T; Kato, N; Iijima, T; Higaki, M. 1995. **Raman spectroscopic analysis of wood and bamboo lignin**. Mokuzai Gakkaishi, Journal of the Japan Wood Research Society 41(2): 229-236.

Fundamental conditions to record near-infrared excited Fourier-transform Raman spectra from wood meal samples were studied. Favourable Raman spectra were obtained at 150-200 mW of laser power with more than 100 scanning. The size of meal samples, in the range of 20-200 mesh, had no influence on the spectra. Under these conditions Raman spectra were recorded from meal samples of Fagus crenata, Cryptomeria japonica and Phyllostachys pubescens as typical hardwood, softwood, and bamboo species, respectively. On F. crenata, a weak Raman band at 1740 cm and a strong one at 1330 cm were observed, whereas on C. japonica no Raman band at 1740 cm and a weak one at 1330 cm were observed. In addition, on C. japonica, the relative intensity at 1600 cm, which was assigned to the lignin, was stronger than on F. crenata. On P. pubescens, extremely strong bands, which were assigned to the lignin and phenolic acids, were observed at 1630 cm and 1604 cm. Upon delignification of F. crenata and C. japonica meal samples,the Raman band intensities decreased at 1660 cm, 1600 cm, 1460 cm, 1330 cm, 1030 cm and 800 cm. In the case of P. pubescens, the same bands as F. crenata and C. japonica, except 1660 cm, and the bands at 1630 cm decreased as a result of delignification. These results indicate that the Raman bands decreased by delignification are assigned to lignin. By recording Raman spectra from meal samples, the information on native-state lignin may be obtained directly and easily.

320. Yoshinaga, A; Fujita, M; Saiki, H. 1989. **Evaluation of the varieties of lignins in wood and bamboo cell walls by Maule colour reaction coupled with microscopic spectrophotometry**. Bulletin of the Kyoto University Forests No. 61: 276-284.

Variations in lignin structure were compared for hinoki (Chamaecyparis obtusa), makanba (Betula maximowicziana), buna (Fagus crenata), mizunara (Quercus crispula), hinoki compression wood, and the bamboo mousouchiku (Phyllostachys pubescens). Fibre walls of makanba and mizunara, rich in syringyl lignin, stained red and showed light absorption at 510-520 nm. Walls of makanba vessels, mizunara earlywood vessels and hinoki tracheids, rich in guaiacyl lignin, were stained yellow-brown with no absorption at 510-520 nm. Amount of cell wall syringyl lignin decreased in the order: fibre > fibre/tracheid > tracheid = vessel. Compression wood tracheids and some bamboo cells stained dark brown, and exhibited light absorption at 300-400 nm, perhaps due to the presence of p-hydroxyphenyl propane and p-coumaric acid. Results suggest that cells rich in syringyl lignin act as mechanical or physical supports rather than as water conductors.

321. Yoshizawa, N; Idei, T. 1980. **Sugar composition of bamboo hemicellulose**. **On the fractionation of the mannan-containing hemicellulose**. Bulletin, Utsunomiya University Forests No. 16: 57-64.

It samples from 1-yr-old Phyllostachys heterocycla var. pubescens P. pubescens.

322. Zafar, S.I; Abdullah, N. 1987. **Bamboo wood delignification by Coriolus versicolor**. The Malaysian Forester 50(1): 121-123.

Coriolus versicolor is found to degrade lignin in bamboo. The study deals with the bamboo - C. versicolor solid state fermentation interaction. Contents of lignin, cellulose and water soluble substances, before and after the bamboo wood degradation by C. versicolor as well as organic matter loss during the solid state fermentation period of 14 days are presented in a table. Bamboo wood lignin content fell from 36.5 to 29.9 per cent which represents 18.1 per cent degradation of lignin in 14 days.

323. Zeng, M.C; Xiang, Y.M. 1987. **Study on bamboo cellulose triacetate**. Journal of Bamboo Research 6(2): 39-49.

The quality of bamboo cellulose triacetate (CTA) and ultrafiltration membranes produced from it was equal to or better than that of cotton CTA and membranes.

Fibre Morphology and Characteristics

324. Abdul Latif Mohamod; Khoo, K.C; Jamaludin, K; Jalil, A.A. 1994. **Fibre morphology and chemical properties of Gigantochloa scortechinii**. Journal of Tropical Forest Science 6(4): 397-407.

325. Alvin, K.L; Murphy, R.J. 1988. **Variation in fibre and parenchyma wall thickness in culms of the bamboo Sinobambusa tootsik**. IAWA Bulletin 9(4): 353-361.

In order to elucidate whether perceptible anatomical changes occur with aging, 3 culms whose ages were estimated to be less than 1 yr, between 1 and 2 yr, and more than 2 yr, were cut from a plant in greenhouse cultivation in the UK and the middle 1 cm portions of the 6th and 12th internodes were examined. There were significant increases in av. cell wall thickness of the fibres and ground tissue parenchyma with age. Of the 4 different tissues examined, only the cortical parenchyma remained unchanged. The basic density of the culms also increased with age. There was clear evidence of the persistence of living protoplasts in fibres and parenchyma with the possible exception of the thickest walled fibres. Progressive thickening of the cell walls with time is consistent with the reported increase in mechanical strength of bamboo culms over a period of time. It is stressed that these observations need to be verified using accurately aged culms of a range of species growing naturally.

326. Chu, W.F; Yao, H.S. 1964. **Studies on the fibre structure of 33 Chinese bamboos available for pulp manufacture**. Sci. Silvae, Peking 9(4): 311-327.

A detailed study (with 2-page English summary) of fibre length, cell-wall thickness, percentages of fibres and other elements, and density. Of the 33 species examined, 21 are listed as promising for yielding high-quality pulp.

327. Foelkel, C.E.B; Barrichelo, L.E.G; Manfredi, V; Fazanaro, R. 1976. **Quantitative analysis of cellulosic fibres**. Papel 37: 59-64.

Microscopic analyses of cellulose fibres were made to determine weight factors and 'coarseness' of papermaking pulps commonly encountered in Brazil (unbleached kraft pulps from Araucaria angustifolia, Bambusa vulgaris, Eucalyptus saligna, Pinus elliottii and Joannesia princeps; bleached kraft pulp from E. saligna; bagasse soda pulp; NSSC, thermomechanical and chemimechanical pulps from eucalypts; and mechanical pulp from A. angustifolia). The determination of the quantitative composition of fibre mixtures in commercial pulps and papers from weight factors is outlined.

328. Hu, C.Z; Zhou, J.Y; Lan, X.G; Yang, L.P. 1986. **Changes in nutrient composition of bamboo shoots of different ages**. Journal of Bamboo Research 5(1): 89-95.

M.c. and fibre content increased with age in Phyllostachys pubescens, while proteins, amino acids, fats, sugars, inorganic salt contents, P, Ca and Fe concentration decreased.

329. Huang, L.Y; Zhu, L.F; Hu, A.Q. 1992. **Study on the fibre length and culm properties of five bamboo species in Hunan, China. Bamboo and its Use**. International Symposium on Industrial Use of Bamboo, 7-11 December 1992, Bejing, China. Chinese Academy of Forestry and International Tropical Timber Organization: 129-132.

The length of fibre, amount of vascular bundles and properties of physical mechanics have been determined for Indosasa levigata, Phyllostachys kwangsiensis, P. bambusoides, P. heteroclada and P.

virdis in Yiyang, Hunan. The results show that the length of fibre is variation in different parts of the bamboo culm, such as the fibre of tabashir is longer than that of green skin at the base of culm, no any difference in the middle and shorter at the top. The thickness of culm wall is thicker at the base and thinner at the top. The internodes are longest in the middle of culm and the amount of vascular bundle is maximum at the top. The five species are excellent ones.

330. Jamaludin K; Jalil, A.A. 1994. **Fiber and chemical properties of Bambusa vulgaris Schrad.. Bamboo in Asia and the Pacific**. Proceedings of the Fourth International Bamboo Workshop, Chiangmai, Thailand. IDRC, Canada and FORSPA, Bangkok: 218-229.

The paper discusses the variation of fiber and chemical properties of different portions of Bambusa vulgaris. A significant effect of bamboo portion, location position on cell wall thickness, fibrelength, slenderness ratio, holocellulose and ash content is reported. A significant effect of bamboo portion, location on specific gravity and 1 percent NaOH solubility is also shown. Fibre and chemical properties are found to have significant effect. The base portion is reported to have the longest fibrelength 3.51mm), highest slenderness ratio (245.0), lowest holocellulose content(70.8 percent) and highest one percent NaOH solubility(26.5 percent) as compared to the middle and top portions.

331. Jamaludin K; Jalil A.A; Abd. Latif Mohmod; Khoo, K.C. 1994. **A note on the proximate chemical and fibre morphology of Bambusa vulgaris**. Journal of Tropical Forest Science 6(3): 356-358.

Data on the proximate chemical composition and density and fibre dimensions are tabulated and briefly discussed based on an analysis of 50 mature culms of Bambusa vulgaris from Malaysia, as part of a study of the suitability of the species as a pulping material.

332. Kitamura, H. 1962. **Studies on the physical properties of bamboo. IX. On the fibre content**. Journal Japan Wood Research Society 8(6): 249-252.

Tabulates data on the variation of fibre content of 1- to 6-year Phyllostachys reticulata after pulping by the soda process. Age played no significant part, but fibre content was found to increase with culm height and to decrease from the outer to the inner parts of culms.

333. Krishnagopalan, A. 1973. **Paper forming properties of bamboo in relation to its fiber characteristics**. MSc Thesis. University of Maine at Orono.

334. Ku, Y.C; Chiou, C.H; Chiu, C.H. 1972. **Tests on fibre morphology and composition of important bamboos in Taiwan**. Co-operative Bulletin, Taiwan Forestry Research Institute with Joint Commission on Rural Reconstruction No. 20: 8p.

Tables with English caption give the results of measurements of fibre length and width, and of proximate chemical analyses(by TAPPI standard method Tllm-59) of the wood, of Bambusa beecheyana var. pubescens, B. stenostachya, Lelebba dolichoclada, L. oldhamii, Phyllostachys edulis, P. makinoi and Sinocalamus latiflorus.

335. Li, Q. 1984. **On the relation between internode length and fibre length of Pseudosasa amabilis and Bambusa pervariabilis**. Journal of Bamboo Research 3(1): 89-94.

For P. amabilis, correlation coefficients between internode and fibre length in inner- middle- and outer- parts were respectively 0.725, 0.337 and 0.574 and generally greater than the critical value of 0.381. For B. pervariabilis they were respectively 0.629, 0.638 and 0.618 and the critical value was 0.361. It is suggest that the linear correlations between internode and fibre length are marked and that fibre stretch is one of the causes of internode stretching; when intercalary meristems devide, there derivative cells stretch fully before secondary thickening, resulting in simultaneous internode stretching.

336. Liese, W; Grosser, D. 1972. **Investigations on the variability of the fibre length in bamboo**. Holzforschung 26(6): 202-211.

Published information on the fibre dimensions of 78 species of bamboo is assembled in a table. The variations in fibre length and width within one internode has been investigated in five species. Generally, the fibre length increases across the wall from the periphery and decreases again towardse the center, but the longest fibres are some times found in the outer zone. The fibre width does not follow a similar pattern. A considerable variation exists longitudinally within one internode, the shortest fibres occuring at or near the nodes. A small decrease in fibre length occurs with increasing height in culm.

337. Ma, L.F; Zhu, L.Q. 1990. **Fibre forms and tissue percentage of six species of sympodial bamboos in Zhejiang Province**. Journal of the Zhejiang Forestry College 7(1): 63-68.

Fibre length (L) width (W), L/W, cell wall thickness (T), lumen diameter (D), T/D and the percentage of fibre tissue were recorded for Lingnania wenchouensis, L. chungii, Bambusa oldhamii, B. textilis var. fusca, Sinocalamus (Dendrocalamus) latiflorus and S. (D.) beechayana. Fibre lengths were gratest in the middle of the bamboo shaft, while w decreased from ground level upwards. The percentage of fibre tissue decreased from the outside of the stem inwards and from the top of the stem downwards.

338. Monsalud, M.R. 1965. **Fibre characteristics of bamboo species in the Philippines**. Conference on Pulp and Paper Development in Africa and Near East Cairo.

Fibre characteristics of thirteen bamboo species of Philippines are discussed.

339. Murphy, R.J; Alvin, K.L. 1992. **Variation in fibre wall structure in bamboo**. IAWA Bulletin 13(4): 403-410.

The degree of polylamellation in the fibre cell walls of Phyllostachys virideglaucescens was investigated. The extent of polylamellation was found to be influenced by position of the vascular bundle in the culm wall, in certain positions by age of the culm and, most strikingly, with position within the vascular bundle. The number of wall lamellae was variable but tended to the greatest in fibres adjacent to either vascular elements or ground tissue at the periphery of the fibre bundles. A similar pattern of variation in fibre wall lamellation was also observed in two other species of bamboo.

340. Murphy, R.J; Alvin, K.L. 1997. **Fibre maturation in the bamboo Gigantochloa scortechinii**. IAWA Journal 18(2): 147-156.

Fibre maturation, which has been shown in a number of bamboos to be a process extending over a long period after the culm has reached its full height, was investigated in comparable internodes (6th above ground level) in culms of Gigantochloa scortechinii up to three years old, with special reference to the fibres constituting the free fibre strands immersed in the ground tissue. The possession of such strands is characteristic of this pachymorph species. The fibres of the free strands were notable more heterogeneous in terms of their diameter than those of the fibre cape adjacent to the vascular tissues. It is in some of the larger fibres of the free strands that wall thickening is longest delayed, so that, even after three years, many still remain comparatively thin walled, especially in the inner region of the culm wall. Fibres retain a living protoplast and appear to undergo progressive septation.

341. Murphy, R.J; Alvin, K.L; Chapman, G.P. 1997. **Fibre maturation in bamboos. The bamboos**. Proceedings of an International Symposium, London, 25-29 March 1996. Linnean Society Symposium Series No. 19. Academic Press for the Linnean Society of London, San Diego, USA: 293-303.

Cell diameter, cell wall thickness, degree of cell wall lamellation, development of lignification and culm density were studied in Phyllostachys viridi-glaucescens and Sinobambusa tootsik cultivated at the Royal Botanic Gardens, Kew, and in Gigantochloa scortechinii from a natural stand in peninsular Malaysia. Maturation of fibres was extremely heterogeneous and influenced by height in the culm, location of the vascular bundle across the culm wall and location of the fibres within vascular bundles. Fibres which matured earliest in development occurred in the lower internodes around the periphery of the culm wall and immediately adjacent to vascular tissue. In middle and inner parts of the culm wall, fibre maturation was observed to take place over at least 3 growing seasons with progressive cell wall thickening and lignification of the newly formed wall material. These findings are discussed with reference to mechanical properties of bamboos.

342. Nomura, T; Yamada, T. 1977. **On the discrete diffraction of small angle X-ray scattering of bamboo (Phyllostachys mitis)**. Wood Research No. 62: 11-18.

Discrete diffraction depending on periodically recurring elements (interparticle interference) was observed both parellel and perpendicular to the fibre direction. Crystallite length and width were calculated to be about 11μ m and 4.8 μ m respectively.

343. Ota, M. 1955. **Studies on the properties of bamboo stem. Part II: On the fibre-saturation point obtained from the effect of the moisture content on the swelling and shrinkage of bamboo splint**. Bulletin Kyushu University Forestry 24: 61-72.

Full research report on the subject mentioned in the title. Full statistical analysis is provided. Contains eleven tables and three figures.

344. Paremeswaran, N; Liese, W. 1976. **On the fine structure of bamboo fibres**. Woodscience and Technology 10: 231-246.

The ultrstructure of bamboo fibres are investigated using various techniques. Studies are made on the following seven species, Cephalostachyum pergracile, Dendrocalamus latiflorus, D. strictus, Melocanna bambusoides, Oxytenanthera abyssinica, Phyllostachys edulis and Thyrsostachys oliveri.

345. Patel, M; Trivedi, R. 1994. **Variations in strength and bonding properties of fines from filler, fiber, and their aggregates**. TAPPI Journal 77(3): 185-192.

346. Pattanath, P.G. 1972. **Trend of variation in fibre length in bamboos**. Indian Forester 98(4): 241-243.

The trend in the variation of fibre length within a culm has been studied for twelve different species of bamboos. While the fibre length in the lower portion of the culm is more than at higher levels, the pat1tern of variation differ from species to species. Fibre length also does not show any consistent relationship with internode length in the species investigated.

347. Preston, R.D; Singh, K. 1950. **The fine strcture of bamboo fibres. I. Optical properties and X-ray data**. Journal of Experimental Botany 1(2): 214-226.

A detailed investigation is made on the fine structure of a wide variety of bamboo fibres. A combination of X-ray analysis, measurement of refractive indices in longitudinal view and of phase differences in transverse section has presented a complete picture of cellulose chain orientation. Attention is given to the general molecular architecture of bamboo fibres and particularly the relation of molecular structure to fibre dimensions.

348. Rajulu, A.V; Reddy, G.R; Chary, K.N. 1996. **Chemical resistance and tensile properties of epoxy-coated bamboo fibres**. Indian Journal of Fibre and Textile Research 21: 223-224.

The chemical resistance and tensile load at break of bamboo fibres (Dendrocalamus strictus) before and after coating with a high performance epoxy resin(Araldite LY 5052/Hardner 5052 system) have been studied. It is observed that the tensile load at break and chemical resistance of bamboo fibres increase on coating, indicating that epoxy resin and bamboo fibres are favourable materials for making the composites.

349. Sahu, A.K; Patel, M. 1996. **Effect of fibres on the optical properties of bamboo pulp**. IPPTA 8(1): 43-47.

350. Shanmughavel, P; Francis, K. 1996. **Trend of variation in fibre-length in an age series of Bambusa bambos**. Journal of Tropical Forestry 12(4): 208-211.

Analyses were made of fibre length and fibre classification in pulps prepared from chips of Bambusa bambos from plantations of ages ranging from 1 to 6 yr old. No appreciable change in fibre length and percentage content of +50, +65, +100 and -100 mesh fibres in both unbleached pulp and bleached pulps was found with increasing age. The results indicate this bamboo species attains maturity during the first year of growth, so that for pulping purposes, it is suitable for a 1-yr cutting cycle.

351. Shanmughavel, P; Francis, K. 1998. **Comparison of fibre-length of plantation grown bamboos with natural stand bamboos**. Van Vigyan 36(2/3/4): 125-127.

Comparisons between the fibre dimensions (length, diameter and wall thickness) of 10 bamboo species (3 Bambusa spp. including B. bambos, 4 Dendrocalamus spp., Melocanna baccifera, Schizostachyus dullooa [Schizostachyum dullooa], Ochlandra travancoricaPhyllostachys bambusoides) in [a] natural stand in [Tamil Nadu] India, and 2 species in plantations (Gigantochloa scortechinii, 3 yr old; and B. bambos, 1-6 yr old) showed no significant differences between them. There were no significant correlations between fibre length, diameter and wall thickness. There was only a minimal increase in fibre length with increasing age of plantation-grown B. bambos. However, there was a significant difference in fibre length across culms. The investigation was carriedout from the viewpoint of utilizing bamboos for pulpwood.

352. Siddique, A.B; Chowdhury, A.R. 1982. **Fibre dimensions of some wood, bamboo and green species with special reference to their usefulness in paper making**. Bano Bigyan Patrika 11(1/2): 56-62.

Fibre dimensions of various wood, bamboo and grass species and miscellaneous fibrous materials of Bangladesh were studied in the Pulp and Paper Division of the Forest Research Institute, Chittagong. The data from these studies are compiled in this review and the species graded as very good, good or poor for paper making on the basis of Runkel ratio. The other properties, viz, flexibility co-efficient and relative fibre length have also been determined, since these properties are reported to be correlated to the tensile strength and tearing resistance of paper. Out of the species studied, 33 wood, 3 bamboo, 2 grass and 4 miscellaneous species have been found promising for paper making.

353. Singh, M.M; Purkayastha, S.K; Bhola, P.P; Lal, K; Singh, S. 1976. **Fibre morphology and pulp sheet properties of Indian bamboos**. Indian Forester 102(9): 579-595.

Fibre morphology and pulp strength of twelve species of bamboos studied in two sets of pulps. In all species fibre dimensions and parenchyma properties varied widely. But there was no significant difference in respect of chemical composition and alkali consumed during pulping. In respect of strength properties there was marked difference between beaten and unbeaten pulps. No relationship could be observed between fibre characteristics and the pulp strength properties. The study revealed that fibre characteristics cannot be used as a criterion for selecting bamboos for pulp and paper production.

354. Singh, M.M; Purkayastha, S.K; Bhola, P.P; Lakshmi Sharma. 1971. **Influence of variation in fibre dimensions and parenchyma proportion on sheet properties in bamboo**. Indian Forester 97(7): 412-421.

The effect of variations in fibre dimensions on strength properties are studied by testing handsheets made from 32 mixtures of different fractions of pulp of Dendrocalamus strictus, beaten to 250 ml (CSF). Fibre length, determined from unbeaten pulpaccounts for 77 to 90 per cent of the variations in strength properties. Parenchyma proportion shows a high negative correlation with the sheet properties. Fibre length and parenchyma proportion together account for 94 percent of the variation in strength properties.

355. Tamolang, F.N. 1962. **Fibre dimensions of some Phillipine fibrous materials**. Philippine Journal of Forestry 18(1/4): 59-60.

Gives tabulated data for hardwoods, softwoods, palms, bamboos, agricultural crops and wastes, grasses etc. It seems likely that, as in India, Bamboos will become an increasingly important source of long-fibred paper pulps.

356. Wai, N.N; Murakami, K. 1984. **Relationship between fiber morphology and sheet properties of Burmese bamboos**. Journal of the Japan Wood Research Society 30(2): 156-165.

Fibre morphology and papermaking properties of whole and fines-free pulps were investigated for 6 major species of Burmese bamboo. Based on the distribution of the Runkel ratio of the fibres in a cross section of the tissue, the bamboo species used inthis study were placed in 3 groups: group A (Melocanna bambusoides) that contains a substantial number of thin-walled fibres; group B (Bambusa polymorpha and Dendrocalamus membranaceus) that contain a small number of thin-walled fibres; and group C (Cephalostachyum pergracile, B. tulda, and D. longispathus) that consist almost entirely of thick-walled fibres with very small lumen. It was found that this grouping is very useful in evaluating and explaining sheet properties. The influence of fibre morphology on sheet properties was much greater in the fines-free pulp sheets than in the whole pulp sheets. The sheets of group A pulp were denser and had significantly better sheet-strength properties, except for tear index, than the sheets of other pulp groups of the same beating levels. The small amount of thin-walled fibres contributed to the burst index and the folding endurance of the group B fines-free pulp sheets. The effect of the presence of fines on sheet properties is also discussed.

357. Wai, N.N; Nanko, H; Murakami, K. 1985. **A morphological study on the behavior of bamboo pulp fibers in the beating process**. Wood Science and Technology 19(3): 211-222.

Bamboo pulp fibres respond to beating more rapidly than do wood fibres; this is probably due to the difference in secondary wall structure between the fibres. In a study on the fibre morphology of Bambusa polymorpha, the secondary wall was seen to consist of alternately arranged broad and narrow layers. During the beating process, a number of transverse and concentric cracks are generated in the broad layers, which causes an internal fibrillation. The outer broad layers with their numerous cracks separate from the inner layers and swell greatly toward the outside. The outer secondary wall layer of bamboo fibres has a microfibril angle of about 20° with respect to the fibre axis which is much smaller than that of the S1 layer of wood fibres. As a result, this layer appears to offer little resistance to prevent the external swelling of the broad layers.

358. Xia, Y.F; Zeng, J. 1996. **Studies on the fibre morphology of Bambusa distegus of different ages**. Journal of Bamboo Research 15(1): 45-51.

This species is one of the main raw materials for papermaking in Chishui, Guizhou Province, China. Details are given of ranges found in fibre length, width, cell wall thickness and cavity diameter. Fibre length and cell wall thickness increased with age, while cavity diameter decreased.

359. Zamuco, G.I.T. 1972. **Fibre length variability in relation to the anatomical structure of bamboo**. Technical Note No. 115, Forest Products Research and Development Commission, Philippines: 4p.

Briefly discusses fibre-length variability in Bamboos, with particular reference to the species suitable for manufacturing pulp and paper that are grown in the Philippines.

Mechanical Pulping

360. Chao, S.C; Pan, T.T. 1963. **Studies on magnifite process for bamboo pulp and paper making**. Bulletin of Taiwan Forest Research Institute with Joint Commission on Rural Reconstruction No. 19: 10p.

Advantages of the process for pulping Dendrocalamus latiflorus were: increased pulp yield, a stronger pulp, shorter cooking times and reduced consumption of SO.

361. Chen, S.C; Lin, S.J; Lin, S.C. 1974. **The multistage digestion of Taiwan bamboo for pulping**. Bulletin of Taiwan Forestry Research Institute No. 242: 16p.

Pulps for printing papers were prepared from 5 species of bamboo by three pulping processes:(a) two-stage digestion with hot water (150^{o} C) followed by NaOH; (b) two-stage digestion with dilute NaOH (at 100^{o} C) followed by more concentrated NaOH; and (c) single-stage digestion with NaOH. In each trial the pulp was bleached in three stages before testing. Process (a) gave the highest yield and best physical properties of pulp and the lowest bleaching ratio, resulting in economical pulping. The pulps with the best physical properties were from Bambusa beecheyana var. pubescens and B. dolichoclada, followed by B. stenostachya and Dendrocalamus latiflorus; Phyllostachys makinoi was judged the least suitable. Since B. beecheyana var. pubescens can be grown on a 3-year rotation, its planting is recommended as a solution to the raw material supply problem in the Taiwan paper industry.

362. Eberhardt, L. 1968. **Hi-yield and mechanical type pulp from raw materials of India**. Indian Pulp and Paper 23(1): 49-51.

Tabulates and discusses the suitability of Indian materials, including tropical hardwoods, eucalypts and bamboo, for high-yield and refiner mechanical pulping.

362a. Lund, H. 1942. **Mechanical disintegrator of wood for production of fibres**. German Petant No. 720190, April 2, 1942.

363. Perdue, R.E; Kraebel, C.J; Kiang, T. 1961. **Bamboo mechanical pulp for manufacture of Chinese ceremonial paper**. Economic Botany 15(2): 161-164.

Total Taiwan production of this "joss" paper is 4500-5000 tons/year, a large proportion hand-made in 500 small mills from bamboo. Bambusa stenostachya, Dendrocalamus latiflorus, and E. oldhamii are chiefly used for the machine-made groundwood paper of the Kung-chin mill, the operation of which is described. Phyllostachys pubescens is chiefly used in the mainland.

364. Rao, M.S; Rao, B.Y; Agshikar, B.M. 1962. **Hand made paper from bamboo by cold soda process**. Indian Pulp and Paper 17(4): 261-263.

Chemical Pulping

365. Alam, M.R; Barua, I.B; Khan, A.B. 1997. **Innovation to the high yield alkaline semi chemical pulping of muli bamboo**. Bangladesh Journal of Scientific and Industrial Research 32(1): 79-83.

An experimental study was carried out to evaluate the possibilities of producing semichemical pulp for different end uses from muli bamboo (Melocanna baccifera) by cooking with white liquor from the recovery cycle, i.e. by adopting the kraft semichemical process. The yield and other pulping characteristics were encouraging and well within the acceptable range of for semichemical pulps. The physical strength properties and other characteristics of the pulp and hand-made sheets were tested. The strength properties of the semichemical pulps were relatively lower than those of conventional kraft pulp, but it was possible to produce an acceptable grade of pulp from under carefully chosen cooking conditions. The yield was higher (72-74) than that of conventional kraft pulp (45-48). The approximate cost of production of paper from this semichemical pulp was attractive. The investment and process modifications required to incorporate this type of pulping in the Karnaphuli Paper Mills at Chandraghona in Bangladesh were also not major.

366. Azzini, A. 1976. **Influence of dimensions of culms of Bambusa vulgaris Schrad. On the yield rejects percentage, kappa number and brightness of pulp obtained by the sulphate process**. Papel 37: 125-127.

The best overall results were obtained with chips of 6.0 x 0.8 x 0.6 cm. Most rejects, minimum brightness and highest kappa number were obtained with the largest size of chips studied (6.0 x 1.2 x 1.0 cm). Data are also given for density, void vol., fibre dimensions and chemical composition of the bamboo.

367. Azzini, A; Gondim, T.R.M.A. 1996. **Starch extraction from bamboo chips treated with diluted sodium hydroxide solution**. Bragantia 55(2): 215-219.

In culms of Bambusa vulgaris (1 and 5 years of old), the contents of starch fibrous materials and parenchymatous residue were determined using sodium hydroxide solution concentrations of 0.25, 0.50 and 0.75 for 5, 10 and 15 hours and shredding times of 30, 60 and 90 seconds. The contents of starch , fibrous materials and parenchymatous residue were not affected by sodium hydroxide concentration and treatment time. The highest starch quantity (75.22 g/kg) was obtained at the highest shredding time (90 seconds) from the 5 year bamboo culms. This study showed the starch extraction is feasible technically as a pretreatment of the bamboo chips employed to produce pulp and paper.

368. Azzini, A; Nagai, V; Ciaramello, D. 1979. **Alkaline monosulphite pulping of Bambusa vulgaris schrad [Bamboo: Fiber]**. Bragantia 38(14): 131-144.

369. Banthia, K.M; Mishra, N.D. 1968. **Recovery of bamboo dust and knotter rejects (nodes) in a bamboo kraft pulp mill**. Indian Pulp and Paper 23(2): 171-174.

369a. Banthia, K.M; Mishra, N.D; Rao, A.V; Rao, G.M. 1970. **Some studies on high yield pulping of Bamboo. Part I – Alkali penetration behaviour of bamboo (for chemical and semi-chemical pulp)**. Indian Pulp and Paper 25(1/6): 420-430.

370. Banthia, K.M; Mishra, N.D; Rao, A.V; Rao, G.M. 1972. **Some studies on high yield pulping of Bamboo. Part II - Alkali treatment of brown stock**. Indian Pulp and Paper 26(8/9): 101-113.

Describes laboratory studies on the use of mild alkali treatments on hard, moderately hard and normally cooked chemical and semichemical pulps of Bamboo [unspecified] to produce soft pulps with minimum loss of yield and properties.

371. Banthia, K.M; Mishra, N.D; Rao, A.V; Rao, G.M. 1972. **Some studies on high yield pulping of Bamboo. Part III - Pulp yield vis-a-vis a cooking system and re-use of wastes from Bamboo**. Indian Pulp and Paper 27(1/2): 16-25.

In continued work, the authors give results of a study of (1) factors affecting the relative yield of sulphate pulp obtainable from Bamboo (Dendrocalamus strictus) by two different cooking systems, and (2) the potential value of recovering and using Bamboo screenings from the clipping plant, and 'buntings' and branches from the forest, as additional pulping material. It is concluded that recovery of available wastes could contribute to a substantial increase in Bamboo pulp yield without much difficulty or extra expense.

372. Banthia, K.M; Mishra, N.D; Rao, A.V; Rao, G.M. 1972. **Some studies on high yield pulping of Bamboo. Part IV - Pulp yield versus bleaching variability for Bamboo pulp**. Indian Pulp and Paper. 27(3/4): 57-59, 61-67.

Describes promising results of attempts to devise a practical and economical procedure for improving the bleaching of Bamboo sulphate pulp without loss of pulp yield or quality. The procedure consists essentially of controlled hypochlorite bleaching followed by a mild H_2O_2/SO_2 treatment.

373. Barrichello, L.E.G; Foelkel, C.E.B. 1975. **Production of sulphate pulp from mixtures of wood of Eucalyptus saligna with small proportions of chips of Bambusa vulgaris var. vittata**. IPEF 10: 93-99.

Different blends were made of E. saligna chips with B.v. var. vittata chips, and sulphate pulping of the mixed material was studied. Pulps made from (a) blends containing 5 and 10 Bamboo (total chip weight basis) and (b) 100 E. saligna were compared. Pulp yield and tear strength of pulps made from (a) were significantly superior to those of pulp made from (b), while there was no difference between the pulps in beating time, hand-sheet density, tensile strength and burst strength.

374. Barrichello, L.E.G; Foelkel, C.E.B. 1975. **Rapid alkaline pulping for the production of chemical pulp from Bambusa vulgaris var. vittata**. IPEF No. 11: 83-90.

Briefly describes Kleinert's rapid alkaline pulping process and gives results of an experiment on the use of this method in the production of pulp from B. v. var. vittata grown in Sao Paulo. Pulp yields and strengths comparable with those obtained by the normal sulphate process were achieved, and there were savings in time and energy.

375. Bharatia, D.K; Veeramani, H. 1974. **Technical feasibility of vanillin production from bamboo black liquor**. Indian Pulp and Paper 29: 6-11, 13-16.

376. Bhowmick, K; Mian, A.J; Akhtaruzzaman, A.F.M. 1992. **Effect of anthraquinone in soda pulping of muli bamboo (Melocanna baccifera)**. IPPTA 4(4): 36-44.

Conventional soda pulping results in lower pulp yield and strength properties Anthraquinone (AQ) is used as an additive in soda pulping to overcome the problems. Laboratory studies on soda+AQ pulping of mill-cut mull bamboo (Melocanna baccifera) show that AQ accelerated delignification, improved pulp yield at a particular kappa number and reduced the active alkali dose or cooking time compared to normal soda cook. An addition of AQ as low as 0.05 on OD raw material lowered the alkali demand by 4 on OD bamboo. Such a low dose of the catalysis increased the pulp yield by 3 on OD bamboo. The yield was almost similar to the kraft control. Use of 0.10 AQ further increased the pulp yield to surpass the kraft control. But the gain in yield with 0.10 AQ was not as remarkable as with 0.05 AQ. The beating characteristics and strength properties of pulp improved by the addition of AQ during soda pulping. The soda+AQ pulp is almost equal to the kraft control. This investigation has shown that AQ is a promising additive in soda pulping of muli bamboo.

377. Biyani, B.P. 1966. **Nitric acid pulping of Bambusa arundinacea Willd**. Abstracts of Thesis. Forest Product Journal 16(11): p60.

378. Biyani, B.P; Gorbatsovisch, S.N; Lorey, F.W. 1967. **Nitric acid pulping of bamboo**. TAPPI Journal 50(1): 87A-91A.

Describes trials of this process at Syracuse, N.Y., for making paper-grade chemical pulps from Bambusa arundinacea. Highest screened-pulp yield (40.9) was obtained by cooking with 10 HNO_3 at 80^{o}C. For 6 hr. and extracting with 1 NaOH at 120^{o}C. for 1 hr. It is concluded that, in view of the low pentosan content of the pulps, the process is promising.

379. Bolker, H.I; Singh, M.M. 1965. **Delignification by nitrogen compounds. II. Pulping of spruce, birch, bamboo and bagasse with nitric - nitrous acid mixtures**. Pulp and Paper Magazine of Canada 66: T165-T170.

It is concluded inter alia that, under some economic conditions, the pulping of Bamboo [not specified] with HNO_3 may be worth commercial consideration.

380. Bose, S.K; Chowdhury, A.R; Akhtaruzzaman, A.F.M. 1998. **Neutral sulphite anthraquinone (NS-AQ) pulping of muli bamboo (Melocanna baccifera)**. Journal of Tropical Forest Products 4(1): 45-51.

Neutral sulfite (NS) anthraquinone (AQ) pulping of muli bamboo (Melocanna baccifera) was conducted in the laboratory. Normal NS and kraft pulping were also conducted for comparison. The total yield gain in the NS-AQ process was 6 to 7.9 units more than that of the kraft control at Kappa number 20. The Kappa number could not be lowered below 32 in the normal NS pulping. The use of 0.1 AQ was sufficient to give the desired effect. The strength properties of unbleached NS-AQ pulps were lower than those of kraft pulps.

381. Browning B.L. 1952. **The chemical analysis of wood**. In: Wise, L.E. and Jahn, E.C. (Eds.), Wood Chemistry. Vol. II, Part VII. Reinhold, New York.

382. Chang, F.J; Kuo, L.S. 1976. **Studies on manufacturing of dissolving pulp from bamboo Sinocalamus latiflorus and Bambusa stenostachya**. Quarterly Journal of Chinese Forestry 9(1): 97-106.

383. Chen, S.C; Lin, S.J; Lin, S.C. 1973. **Semichemical pulping of Taiwan Bamboos**. Co operative Bulletin, Taiwan Forestry Research Institute with Joint Commission on Rural Reconstruction No. 21: 16p.

Reports pulping trials on five Bamboo species by the cold-soda, neutral sulphite (NSSC) and sulphate processes. The NSSC pulps, although the lowest in yield, showed good strength (near that of imported Canadian kraft pulp) and were bleached to 72-88 GE brightness by the CEH (chlorination/alkali extraction/hypochlorite bleaching) sequence. The net yield of 48.3-53.2 for the bleached pulp was well above that obtained from fully cooked pulps. Bamboo NSSC pulps may therefore replace imported long-fibrepulps in high-grade papers. The sulphate pulps were darker and hard to bleach, but were strong enough for packaging products. It is concluded that the best properties where shown by pulps from Bambusa beecheyana var. pubescens, followedin order by Leleba dolichoclada, Bambusa stenostachya, Sinocalamus latiflorus and Phyllostachys makinoi, the last two being unsuitable.

384. Devi, N; Bhola, P.P; Singh, M.M; Guha, S.R.D. 1982. **Prehydrolysis of bamboo - Effect of pH**. Indian Forester 108(5): 342-353.

Studies in this paper have been carried out with a view in understand the effect of pH on prehydrolysis of bamboo (Dendrocalamus strictus). The bamboo chips have been cooked with 1 of H_2SO_4, H_2O and 10 of NaOH for 90 minutes and 150 minutes. The acidic, aqueous and soda lignins have been analysed. These results show that pulp yield decreases at higher pH and at more cooking time, and is also effected by the final pH of the prehydrolysates. The lignin yield from prehydrolysate decreases as the pH goes towards acidic side. The methoxyl content in isolated lignins decreases with the increase of lignin yield, while total-OH increases with the increase in lignin yield. The ratio of syringaldehyde to vanillin is less in lignins obtained at higher prehydrolysis time. The acidic and aqueous lignins are less condensed than soda lignin.

385. Dhawan, R. 1980. **Nitric acid pulping of Dendrocalmus strictus**. Indian Forester 106(2): 122-125.

Dendrocalamus strictus was pulped by nitric acid process. Air-dry chips were cooked with nitric acid and sodium nitrite. The residual wood was extracted with dilute solution of caustic soda. The material was washed disintegrated and screened. The yield of the pulps was determined. It was oberved that by the addition of sodium nitrite upto a certain extent, delignification was enhanced. Pulps were analysed for Kiason lignin content, pentosan content, nitrogen content, ash content and permanganate number. It was observed that the yield, Klason lignin content, pentosan content and permanganate number of pulps decrease with increase in concentration of nitric acid, cooking time and temperature.

386. Du, H.T. 1957. **Studies on the alkaline pulping of bamboo**. Bulletin of Taiwan Forestry Research Institute No. 47: 12p.

387. Escolano, J.O; Nicholas, P.O; Felix, G.T. 1964. **Pulping, bleaching and paper experiments on Kauayan-Tinik Bambusa blumeana Schlt.F**. Philippine Lumberman 10(4): 33-36.

Results of an investigation carried out to determine the suitability of Bambusa blumeana for pulp and papermaking. This species is reported easily digested by the single stage sulphate pulping process and the pulps produced responded well to standard three-stage bleaching process. It shows that good quality bond, airmail bond, onionskin, offset book, kraft wrapping and bag papers can be produced from this species of bamboo.

388. Fukuyama, G; Kawase, K; Satonaka, S. 1955. **(I) Alkaline (soda), (II) Kraft and (III) NSSC (Neutral sulphite semi-chemical) pulps from Sasa spp.**. Research Bulletin of Forestry, Hokkaido University, Japan 17(2): 321-381.

Details are given of the compositions and strengths of the pulps obtained by these 3 processes under varying conditions of cooking. The kraft process gave the strongest pulps. The NSSCP, when yield was 54-77%, produced fibreboards stronger than those from wood chips; pulps from this yield range were weaker than Birch NSSCP but showed excellent tearing strength and their alpha-cellulose content was 59.81 %. Both the kraft and NSSCP processes are recommended.

389. Gajdos, J; Farkas, J; Janci, J. 1971. **Bleaching of sulphate pulps from Bamboo**. Papir a Celuloza 26(6): 69-79.

Gives results of laboratory trials with pulps made from air-dry Bamboo with yields of 39-58. A comparison with typical pulps made from central European conifers and hardwoods shows that Bamboo pulps are more difficult to bleach and are generally inferior in mechanical properties.

390. Gonzalez, T; Escolano, J.O. 1965. **The fiber fractions of giant bamboo sulfate pulp and their strength properties**. Philippine Lumberman 11(6): 12-14, 16, 20.

391. Gremler, E.R; McGorovern, J.N. 1960. **Low-power cold soda pulping**. TAPPI Journal 43(8): 200A-205A.

Reviews briefly the history of cold soda pulping, emphasizing the various continuous methods used. Pulping data on Aspen, Birch, Oak, Bambusa polymorpha, and a hardwood mixture suggest that short impregnation periods and low h.p. result in completely defibrated pulp at high freeness. The principle of a new defibrating machine, the Chemifiner, and its contribution to the process described, are explained.

392. Guha, S.R.D; Dhoundiyal, S.N; Mathur, G.M. 1975. **Sulphate pulping of giant bamboo (Dendrocalamus giganteus)**. Indian Forester 101(5): 296-300.

The results of a comparative laboratory scale investigation of the pulping of Dendrocalamus giganteus and Dendrocalamus strictus are recorded in this paper. The results show that D. giganteus is a better raw material than D. strictus for both unbleached grade pulps and bleached grade pulps.

393. Guha, S.R.D; Jadhav, A.G; Sharma, Y.K. 1970. **Effect of wet end additives on bamboo pulp**. IPPTA 7(3): 235-240.

Investigations on the effect of sixteen natural gums available commercially, two varieties of commercial carboxymethyl cellulose, viz; Cellpro LSH and Cellpro LVE and six samples of seed gums on bleached bamboo pulp are reported in this paper.

394. Guha, S.R.D; Negi, J.S. 1972. **The alkali resistant pentosans in bamboo**. Indian Pulp and Paper 27(3/4): 69-71.

A study of alkali-resistant pentosans in bamboo (Dendrocalamus strictus) showed that treatment with alkali before chlorite treatment alone makes the pentosans non-resistant to alkali extraction, and that once pentosans are rendered non-resistant they cannot be converted into resistant pentosans. Fibre structure was found to play an important role in determining the alkali resistance of pentosans. Fragmentation of fibre permitted the removal of more pentosan.

395. Guha, S.R.D; Pant, P.C. 1961. **Bamboo pulps by neutral sulphite semi-chemical process**. Research and Industry 6(2): 49-51.

Pulps are made from cellulosic raw materials by the sulphate process. An investigation is carried out on the pulping of the bamboo, Dendrocalamus strictus by the neutral sulphite semi-chemical process with the aim of improving the yield and quality of the pulp and the results are presented in this paper. It is found that unbleached pulps (yield 56-68 percent) of satisfactory strength properties can be prepared from bamboo by NSSC process. When bleached, these pulps (yield 37-44 percent) are found to have satisfactory brightness and strength properties for the production of white papers.

396. Guha, S.R.D; Pant, P.C. 1966. **Sulphate pulping of Phyllostachys bambusoides**. Indian Forester 92(7): 467-468.

Bamboo, Phyllostachys bambusoides is tested for its suitability for paper pulp. The result shows that the yield, bleach consumption and strength properties of pulps obtained are comparable to those obtained from Dendrocalamus strictus except in the case of tear factor and folding endurance which are found lower in case of P. bambusoides. But the strength obtained is found sufficient for production of writing and printing papers. Results are tabulated.

397. Guha, S.R.D; Sharma, Y.K; Jain, R.C; Jadhav, A.G. 1966. **Chemical pulps for writing and printing papers from ringal (Arundinaria spp.)**. Indian Forester 92(10): 634-636.

Laboratory experiments on the production of chemical pulp from ringal (Arundinaria sp.) for production of writing and printing papers by sulphate process are described. The average fibre length of pulp was 1.01 mm and average fibre diameter was 11 microns. It is reported that bleaching pulps in satisfactory yields can be prepared under suitable conditions of digestion.

398. Guha, S.R.D; Singh, M.M; Mithal, K.C. 1966. **Sulphate pulping of mixture of bamboo and mixed hardwoods**. Indian Pulp and Paper 21(3).

Laboratory experiments are described on production of kraft papers from mixtures of bamboo chips and mixed hardwoods.

399. Isono, Z; Ono, K. 1967. **Desilicification of high silica containing kraft liquors. Part I. Desilicification of black liquor by carbon dioxide treatment**. Journal of Agricultural and Chemical Society of Japan 41: 220-225.

400. Isono, Z; Ono, K. 1968. **Desilicification of kraft green liquor by aluminium sulphate**. **Part II.** Journal of Agricultural and Chemical Society of Japan 42: 18-23.

401. Isono, Z; Ono, K. 1968. **Desilicification of kraft liquors high in silica. Part III. Desilicification of kraft black liquor by aluminium sulphate**. Journal of Agricultural and Chemical Society of Japan 42: 24-28.

402. Isono, Z; Ono, K. 1968. **Desilicification of kraft liquors high in silica. Part IV. Desilicification of kraft black liquor by magnesium sulphate and general consideration of the subject**. Journal of Agricultural and Chemical Society of Japan 42: 29-32.

403. Janci, J; Farkas, J; Gajdos, J. 1971. **Neutral sulfite semichemical Bamboo pulps**. Papir a Celuloza 26(12): 139-151.

The results of a laboratory study of these pulps (made from Bambusa vulgaris) showed that they were suitable as a basic material for the middle layer of corrugated paper.

404. Jauhari, M.B; Ghosh, P.C. 1984. **High yield alkaline sulphite-anthraquinone pulping of bamboo**. IPPTA 21(1): 45-50.

An improved approach to produce high yield bleached chemical pulps is described. Alkaline sulphite solution with and without anthraquinone (AQ) under high temperature and pressure produced pulp of 25 and 32 Kappa number with unbleached screened yield of 61 and 60 percent respectively. Addition of 0.1 percent AQ on chips offered the advantage of producing pulp of low Kappa number with high pulp yield and also enabled to carry out the cooking at a much lower maximum temperature compared to where no AQ was added. The pulps could be easily bleached in three stages of calcium hypochlorite bleaching to brightness of 78 and 76 per cent with bleached pulp yield of 59.4 and 57.4 percent respectively. The physical strength properties and opecity were matchingwith those of sulphate pulp in comparison with sulphate pulp. The alkaline sulphite -AQ pulp is obtained in about 7.7 percent greater pulp yield both in the unbleached and bleached state. The process offers advantages of higher unbleached/bleached pulp yield. Higher unbleached pulp brightness and greater ease of bleaching, are advantages over sulphate process for bamboo pulping.

405. Kadarisman, D; Silitonga, T. 1974. **Sulphate pulping of bamboo**. Bulletin Penelitan Tek Hasil Pertanian 40: 14-17.

406. Kar, S.K; Jena, S.C; Maheshwari, S. 1987. **Effect of variation of moisture in bamboo chips on pulp and paper making characteristics**. IPPTA 24(2): 49-54

The storage of bamboo, the conventional raw material for papermaking in India, is necessary for continuous supply of this raw material throughout the year. It has been observed that due to storage, particularly in summer season, the moisture content reaches a very low level, which adversely affects the pulp and papaermaking properties. The present study reveals that though it is not practicable to attain higher percentage of moisture in bamboo as such by soaking in water but chips can be brought to a desired level of moisture content by soaking for a very short period in water pond. With increasing moisture content active alkali requirement in pulping decreases while the uniformity and pulp quality improve. The physical strength properties have aslo shown increasing moisture content. However, it may adversely affect the black liquor characteristics which will be obtained in less concentrated form. It has been concluded that an optimum moiture content may be maintained so as to get the uniform pulping and better quality of the pulp.

407. Karim, M.S; Islam, M.A; Khalid ul Islam, M. 1994. **Studies on muli bamboo (Bambusa baccifera) [pulped] by soda process and laboratory evaluation of unbleached and bleached pulps**. Bangladesh Journal of Scientific and Industrial Research 29(1): 10-19.

Data are presented on the chemical composition of muli bamboo (Bambusa baccifera [Melocanna baccifera]) before and after pulping, and on pulp properties before and after bleaching. The bleached pulps were suitable for making good quality writing and printing paper, and the unbleached pulps for packing and wrapping papers.

408. Kato, F. 1955. **On the digestion of bamboo pulp. Part 1**. TAPPI Journal 9(3).

409. Kato, F. 1955. **On the digestion of bamboo pulp. Part 2**. TAPPI Journal 9(5).

410. Khanduri, S.C; Biswas, B. 1960. **Some observations on the cold caustic treatment of Ringal (Arundinaria jaunsarensis) bamboo**. Indian Pulp and Paper 14(10): 475-476.

Discusses the effect of alkali treatment of A. jaunsarensis at 30^{o}C. The ash, pentosan, and lignin contents of the soaked material were found to decrease with increases in cellulose content and in the concentration of alkali in the soaking liquor.

411. Mahanta, D; Chaliha, P.B. 1970. **Pulping of bamboo by nitric acid**. Chemical Age India 20(2).

412. Mahanta, D; Gohain, P.D; Rehman, A; Chaliha, P.B. 1979. **Non-sulphur pulping of bamboo**. Indian Pulp and Paper 34(1).

413. Maheshwari, S; Gopichand, K. 1990. **Studies on peroxide addition in extraction stage (CEpH) on optical properties of bamboo pulp**. Pulping Conference: Proceedings 2: 481-485.

414. McGorovern, J.N. 1962. **Semichemical and mechanical pulping**. In: Libby, C.E (Editor). Pulp and Paper Sicence and Technology Vol. I. McGraw - Hill, New York: 281-316.

415. Mishra, B.P; Joshi, R.C; Banthia, U.S; Singh, M.M. 1984. **Effect of sulfidity on alkaline pulping of bamboo, mixed hardwoods and a mixture of bamboo and mixed hardwoods**. Indian Pulp and Paper 39(3): 7-16.

Increasing sulphidity from 0 to 20 increased the yield, reduced the of rejects and the demand for bleach, and generally improved strength properties. The effects were greatest in the 60:40 mixture of bamboo and mixed hardwoods and least in bamboo only. Optimum sulphidity is 16 for bamboo, 20 for mixed hardwoods and 18 for bamboo/mixed hardwoods.

416. Mukherjea, V.N; Guha, S.R.D. 1965. **High-yield pulps by a hot caustic soda process**. Indian Pulp and Paper 20(2): 139-144.

417. Nafziger, T.R; Clark, T.F; Wolff, I.A. 1960. **Dissolving pulps from domestic timber bamboo, Phyllostachys bambusoides**. TAPPI Journal 43(6): 591-596.

418. Nafziger, T.R; Clark, T.F; Wolff, I.A. 1961. **Newsprint from domestic timber bamboo, Phyllostachys bambusoides**. TAPPI Journal 47(7): 472-475.

Culms of P. bambusoides of not more than15 years, from Savannah, Ga., were used in tests to prepare chemical, semichemical and mechanical pulps, for newsprint. Yields of 82 and 62% for cold soda semichemical and neutral sulphite pulps respectively were attained, but stone grinding with and without chemical pre-treatment failed to produce satisfactory pulps from the mature culms. Strength characteristics of experimental newsprint from a furnish comprising 80% cold soda and 20% neutral sulphite pulps, 1% alum, 0.05% rosin, and 7% clay, were comparable to those of a control paper from a similar furnish of 80% Aspen groundwood and 20% unbeaten softwood sulphite pulps. Blends of Bamboo and wood pulps gave sheets of inferior strength in all combinations tried. It is suggested that further study of treatment before grinding and of the use of green Bamboo, and of the variables in the preparation of both chemical and mechanical pulps and of machine furnishes, might indicate the best treatments and also lead to end products superior to those here reported.

419. Nicholas, P.M; Navarro, J.R. 1964. **Standard cold soda pulping evaluation of Philippine woods and bamboos**. TAPPI Journal 47(2): 98-105.

420. Nirankari Devi; Bhola, P.P; Singh, M.M; Guha, S.R.D. 1982. **Prehydrolysis of bamboo - effect of pH**. Indian Forester 108(5): 342-353.

The effect of pH on prehydrolysis of bamboo (Dendrocalamus strictus) is examined. Acidic aqueous and soda lignins analysed by cooking bamboo chips in a solution of one per cent sulphuric acid, water and 10 percent sodium hydroxide for 90-150 minutes. The result shows that pulp yield decreases at higher pH and at more cooking time. The lignin yield from prehydrolysate decreases as the pH goes towards acidic side. The methoxyl content in isolated lignin decreases with the increase of lignin yield, while total OH increases. The acidic and aqueous lignins are less condensed than soda lignin.

421. Oye, R; Mizuno, T. 1970. **Studies on bamboo dissolving pulp, reactivity of bamboo pulp for viscose**. Journal of Japan Wood Research Society 16(2): 92-96.

Examines the relation between pulping conditions and the reactivity of dissolving pulp prepared from bamboo (Melocanna bambusoides) by the prehydrolysis sulphate process. Bamboo pulp has lower resistance to mercerization than hardwood pulp made by a similar process, and has low resistance to sulphidation. Its filterability is similar to that of wood pulps. Figures and tables have English legends.

422. Oye, R; Mizuno, T. 1970. **Studies on dissolving pulp characteristics of the bamboo pulp**. Journal of Japan Wood Research Society 16(3): 135-139.

Properties of dissolving pulp prepared from bamboo (Melocanna bambusoides?) by the prehydrolysis sulphate process influencing its suitability for viscose manudfacture were determined. In comparison with wood pulp bamboo pulp has a higher rate of depolymerization during ageing, low cold-alkali but comparatively high hot-alkali solubility, and a similar degree of crystallinity, but a higher rate of acid hydrolysis and lower levelling-off DP.

423. Oye, R; Mizuno, T. 1972. **Prehydrolysis sulphate cooking of bamboo**. TAPPI Journal 26(7): 363-371.

424. Raitt, W. 1931. **The digestion of bamboo and grasses for paper making**. Crosby Lockwood & Son, London.

425. Sanyal, A.K; Devgan, R.C. 1964. **Use of elemental sulphur in soda cooking of bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 18(9): 521-523.

426. Semana, J.A. 1965. **Study of the variable in sulphate pulping of giant bamboo (Gigantochloa aspera Kurz.)**. Indian Pulp and Paper 20(6): 395, 397-399, 401, 403-406.

427. Singh, M.M; Sharma, Y.K; Pant, R. 1970. **High yield pulps - two stage pulping**. Journal of the Indian Academy of Wood Science 1(1): 39-42.

To increase the yield of pulp for the production of kraft papers from bamboo and Eucalyptus grandis, experiments were conducted by splitting the digestion into two stages with an intermediate refining stage and the results were presented. The yield of bamboo pulp was found increased from 47.1 to 53.3 percent without any significant effect on the strength properties of the pulp.

428. Singh, S.P; Joshi, H.C. 1988. **Plywood adhesives from black liquor of bamboo Dendrocalamus strictus**. Journal of the Indian Academy of Wood Science 19(1): 47-51.

Black liquor, a lignin-rich byproduct from the pulping of D. strictus, was used as a replacement for phenol (at 10-60) in the preparation of phenolic adhesives for plywood. The resulting adhesive (a phenol-lignin formaldehyde resin) was tested for use in making 3-ply plywood from veneers of Vateria

indica and Ulmus [Pinus] wallichiana. The boards were tested for glue adhesion strength in dry, hot wet, and mycological tests. The black liquor itself had 12.94 solids, 3.8 ash and pH 9.5. Replacement of phenol by black liquor progressively decreased the solid content of the adhesive, and the glue spread. At up to 50 of phenol replacement the adhesive met the strength requirements of Indian Standard IS:848-1974 for the BWR adhesive grade, but at 60 the BWR grade was not met with V. indica plywood.

429. Singh, S.V; Guha, S.R.D. 1975. **Kinetics of alkaline pulping of Bamboo**. Indian Pulp and Paper 30(3): 15-25.

Changes in yield, chemical composition and strength properties of chemical and semi-chemical pulps were determined during the kraft pulping of Dendrocalamus strictus, throughout the cooking cycle. Up to 70 yield, there was a linear correlation between lignin in pulp and pulp kappa number, and also between lignin to carbohydrate ratio and yield. Regression equations were developed from which kappa number, or lignin in pulp can be predicted for controlling the pulping process up to a yield of 70.

430. Singh, S.V; Guha, S.R.D. 1976. **The H factor of bamboo sulphate pulping**: A device to control pulp mill operation. IPPTA 13(1): 57-60.

The sulphate pulping of bamboo (Dendrocalamus strictus) is studied from beginning to the end of cook, applying the concept of representing the times and temperatures of the cooking cycle by Vroom' H factor. The experimental results showed that the Hfactor can be employed as a means of predicting compensating adjustments of cooking times and temperatures to give the same yield of pulp, kappa number and lignin content with varying cooking cycles. This indicated that the concept of H factor can suitably be applied as a guide for controlling sulphate pulping process of bamboo in mills by predicting times for a variety of temperatures or vice-versa to make necessary adjustments in the cooking cycle, so as to get equivalent pulp yield. For the experimental standard cooking cycle employed in this investigation (90 min. from 80 to 170 degree C and 90 min. at 170 degree C) the H factor was found to be 91982.

431. Tshiamala, T; Fraipont, L; Paquot, M; Thonart, P; Mottet, A. 1984. **Comparative study of different bamboo pulps**. Holzforschung 38(5): 281-288.

Sulphate, neutral sulphite, lime and thermo-mechanical pulps were prepared from Bambusa vulgaris, B. viridi, Gigantochloa apus and G. aspera. The chemical properties of the pulps were analysed in relation to their effect on paper properties. Neutral sulphite pulp gave the best results, with high yield and satisfactory paper mechanical properties.

432. Tsuji, H; Isono, Z; Ono, K. 1965. **Studies on the dissolving bamboo pulp**. Bulletin of the University of Osaka Prefecture, Sakai, 16B(January): 89-104.

Dissolving pulp can be prepared by pre-hydrolysis cooking at 160o or 165^{o}C for 4 hr., followed by sulphate cooking at 160^{o}C for 2 hr., with total NaOH 20, and sulphidity 20. With these pre-hydrolysis conditions, pentosans were <5. The average degree of polymerization compares favourably with that of similar pulps from wood, and the chemical properties and the filtrabilities of viscose show no great difference from those of wood. There should be openings in industry for this type of pulp, for which Bambusa bambos is superior to Phyllostachys reticulata in polymerization and yield.

433. Tsuji, H; Ono, K. 1966. **Studies on the silica removal by calcium oxide addition from black liquor of bamboo sulphate pulping**. Bulletin, University of Osaka Prefecture, Osaka 18: 37-46.

The high SiO_2 content of Bamboos and some other materials leads to the formation of a soluble silicate during pulping, which causes trouble at the chemical recovery stages. The addition of CaO to the black liquor was effective in reducing the SiO_2 content from 5.0-7.2 g./liture to 1.3-1.8 g./liture, and the precipitated Ca silicate was easily removed by filtration, without reducing the amount of organic matter and Na. A table lists the ash and SiO_2 content of 14 tropical bamboo species used for pulping.

434. Vroom, K. 1957. **The `H'- factor: A means of expressing cooking times and temperatures as a single variable**. Pulp Paper Magazine of Canada 58(3): 228-231.

435. Vyas, G.M; Bhat, R.V; Chowdhury, K.A. **A process for the treatment of bamboo to further its utilization in the manufacture of pulp, paper or the like**. Indian Patent No. 49054.

436. Vyas, G.M; Bhat, R.V; Chowdhury, K.A. **An improved process for the treatment of bamboo to further its utilization in the manufacture of pulp, paper or the like**. Indian Patent No. 57267.

437. Wang, H. 1981. **The application of anthraquinone in the pulping of bamboo waste**. Proceedings of Bamboo Production and Utilization. XVII IUFRO World Congress, 6-17 September 1981, Kyoto, Japan. Wood Research Institute, Kyoto University, Japan: 131-135.

438. Wang, H; Lirn, T.R. 1984. **Study on the high yield pulping of bamboo waste**. Forest Products Industries 3(1): 32-48.

Shavings and nodes of Dendrocalamus latiflorus, Phyllostachys edulis and P. makino [makinoi] were pulped using the neutral sulphite-anthraquinone process. Fibre dimensions were measured and chemical composition (ash, lignin, cellulose etc.) and mechanical properties were recorded. On av. fibres were 2.05-2.84 µm long and 15.1-21.2 µm wide, with length/width ratios of 135-162. D. latiflorus had the longest fibres. Ash and extractive contents of bamboo wastes were higher than those of wood. Lignin content was lower than that of softwood, but similar to that of hardwood. The lignin content of P. edulis was the highest. Yields and pulp strength (breaking length, burst and tear factors) are tabulated for varying total alkali, alkali ratio and anthraquinone in the pulping process.

439. Wang, K.T. 1982. **Alkaline sulphite pulping of Bambusa arundinacea with the addition of anthraquinone**. Bulletin, Taiwan Forestry Research Institute 378: 12p.

440. Yamagishi, K; Satonaka, S; Hanzawa, M. 1970. **Studies on pulping of Sasa with per acetic acid**. Research Bulletin on Experimental Forestry, Hokkaido University, Japan 27(2): 459-486.

Sasa Bamboo (S. senanensis etc.) is plentiful on high land in Hokkaido, where stands may contain ca. 700,000 stems/ha. with a weight of ca. 60 [metric] tons/ha.; this important forest resource has hitherto scarcely been used. Powdered wood meal of Sasa was effectively delignified by treatment with peracetic acid (PA) at 70°C., and the pulp yield was 57.3%. A high yield of pulp with a low lignin content was also obtained by pulping Sasa chips with PA; the brightness of this pulp was high but the pentosan content was >20%. As regards its strength properties, the PA pulp was markedly superior in breaking length and burst factor, and slightly superior in tear factor, to a semi-kraft pulp of similar yield and lignin content, while its folding endurance was satisfactory. The strength properties of a Birch (Betula platyphylla var. japonica) pulp obtained by PA pulping were, however, superior to those of the Sasa pulp. Microscopic observation of the latter revealed fibres with an intact structure, accompanied by many small parenchyma cells.

441. Yamaguchi, H; Nagamori, N; Sakata, I. 1991. **Applications of the dehydrogenative polymerization of vanillic acid to bonding of woody fibres**. Journal of the Japan Wood Research Society 37(3): 220-226.

Composite boards were made by treating thermomechanical pulp with vanillic acid that had been dehydrogenatively polymerized by a crude peroxidase prepared from madake (Phyllostachys bambusoides) bamboo shoots.

442. Yao, G.Y; Zou, Z.X. 1986. **The pulping of bamboo (Phyllostachys pubescens) with alkaline sodium sulfite-anthraquinone**. Journal of Nanjing Forestry University No. 4: 50-58.

Kraft Pulping

443. Alam, M.R; Barua, I.B; Islam, N. 1997. **To study the effect of sulphidity variation in kraft pulping of muli bamboo (Melocanna bambusoides).** Bangladesh Journal of Scientific and Industrial Research 32(1): 111-114.

The optimum limit of sulfidity in kraft (sulfate) pulping of muli bamboo (Melocanna bambusoides) was studied in the process used at Karnaphuli Paper Mills in Chandraghona, Bangladesh. About 17 sulfidity gave the best quality of pulp.

444. Bajpai, P; Bajpai, P.K. 1996. **Application of xylanases in prebleaching of bamboo kraft pulp.** TAPPI Journal 79(4): 225-230.

The effectiveness of 12 commercial enzymes was evaluated for prebleaching bamboo [Bambusa arundinacea and Dendrocalamus strictus] kraft pulp. Different xylanases varied in the maximum obtainable effect. The enzymes Bleachzyme F and Irgazyme 40S were able to decrease the active Cl_2 requirement in the first stage of bleaching by 20 or decrease the ClO_2 in the last stage of brightening by 4 kg/metric tonne of pulp in the CDEHD sequence. Alternatively, at the same chemical charge, it was possible to increase the final brightness approaching 89 ISO. The use of enzymes had no adverse effect on the pulp viscosity and strength properties.

445. Bhandari, K.S. 1981. **Kraft pulping of Oxytenanthera ritcheyi.** Indian Forester 107(7): 454-458.

Kraft pulps from Oxytenanthera ritcheyi are produced in laboratory at three different cooking schedule and chemical concentrations. On the basis of pulp evaluation for various strength properties kappa number and unbleached pulp yield, optimum pulping conditions are reported. Kraft pulp obtained at optimum conditions is bleached and bleaching conditions, bleached pulp yield, brightness and various strength properties of bleached pulp sheets are also reported. It is found that Oxytenanthera ritcheyi is a suitable raw material for the production of wrapping, writing and printing paper.

446. Bhargava, M.P; Chattar Singh. 1942. **Interim report on the manufacture of kraft paper from bamboos.** Indian Forest Bulletin (New Series) Utilisation 112: 13p.

Investigations are carried out at the Forest Research Institute, Dehra Dun to explore the possibilities of manufacturing kraft paper. It is established the suitability of bamboo as a raw material for the manufacture of kraft paper.

447. Bhowmick, K; Mian, A.J; Akhteruzzaman, A.F.M. 1991. **Anthraquinone as an aditive in kraft pulping of muli bamboo (Melocanna baccifera).** Forpride News 3(5).

448. Bhowmick, K; Mian, A.J; Akhtaruzzaman, A.F.M. 1991. **Effect of anthraquinone in low sulphidity kraft pulping of muli bamboo (Melocanna baccifera).** IPPTA 3(4): 26-33.

Low sulphidity kraft pulping of mill-cut muli bamboo (Melocanna baccifera) with anthraquinone (AQ) addition was studied in the laboratory scale. AQ acted as a pulping catalyst and increased the rate of delignification or decreased the alkali demand. The viscosity of AQ catalysed low sulphidity kraft pulps was almost equal to the kraft control and better than the pulp of 15 percent sulphidity. It was also observed that the burst, tear and tensile strength properties of the pulp increased on addition of AQ. The strength properties were almost same or better than the pulp obtained in normal kraft pulping. The use of AQ is beneficial at a low sulphidity level in preserving the pulp yield and improving the quality of the pulp. This will reduce the air pollution problems because of a lower sulphidity input in the cooling.

449. Bhowmick, K; Akhtaruzzaman, A.F.M; Mian, A.J. 1992. **Economic benefits of soda and kraft anthraquinone pulping of muli bamboo (Melocanna baccifera).** Bangladesh Journal of Forest Science 21(1/2): 13-19.

Results of a tentative economic analysis made on kraft and soda anthraquinone pulping of muli bamboo (Melocanna baccifera) are presented. It shows that compared to soda pulping better benefits can be achieved in soda + AQ pulping. Reports that a mill producing 30,000 tons of pulp annually can save TK 52.5 million by using soda + AQ process. Addition of AQ in low sulphidity kraft pulping is also reported profitable. Kraft 15 + AQ pulping of muli bamboo is capable of saving TK 30 million compared to kraft 15 without AQ and TK 7.6 million compared to normal kraft pulping. Addition of AQ in normal kraft pulping is reported not very encouraging where only TK 5 million is saved compared to normal kraft cook.

450. Bhowmick, K; Akhtaruzzaman, A.F.M; Jabbar Mian, A. 1994. **Soda-anthraquinone and low sulphidity kraft anthraquinone pulping of Muli bamboo (Melocanna baccifera) and mixed wood in a mixture in Bangladesh**. Bangladesh Journal of Forest Science, Bangladesh 23(1): 20-25.

Pulping of bamboo-hardwoods in a mixture showed that H-factor required in soda plus AQ and low sulphidity kraft plus AQ was slightly lower than the calculated value from the mixture of the components. The total pulp yield for kraft15 plus AQ was higher than the calculated value. But for soda plus AQ it was lower from the theoretical value. The tensile strength of the pulp obtained in soda plus AQ process was better upto 60 bamboo chips in the mixture. It showed superior quality with more than 60 bamboo in the component in low sulphidity kraft pulping. The bursting strength of the pulp decreased as the bamboo chips increased in kraft15 plus AQ pulping. The tear strength behaved almost linearly with any proportion of bamboo chips with wood chips.

451. Bose, S.K; Chowdhury, A.R; Akhtaruzzaman, A.F.M. 1988. **Influence of age on kraft pulping of Muli bamboo (Melocanna baccifera)**. Bano Bigyan Patrika 17(1/2): 41-45.

In this study an attempt has been made to find out the optimum cutting cycle for Muli bamboo (Melocanna baccifera) from the point of view of pulp yield and quality. The results show that bleachable grade of pulp is obtained at a lower cooking time with younger bamboos (9 months old) than those of higher age groups. The pulp yield at a given point of delignification is the highest with 21 months old bamboos. Physical strength properties of the pulp are independent of age. Thus, it seems that 21 months old Muli bamboo is better for pulping.

452. Chao, S.C; Pan, T.T. 1972. **Manufacture of kraft pulp from Taiwan Bamboos**. Co operative Bulletin, Taiwan Forestry Research Institute with Joint Commission on Rural Reconstruction 19: 10p.

Gives the results of sulphate pulping tests on Bambusa beecheyana var. pubescens, B. dolichoclada, B. stenostachya, Dendrocalamus latiflorus and Phyllostachys makinoi. All the pulps had good strength properties, and tearing strengths were especially high. Pulp yields varied with cooking conditions from 41 to 47. Results of bleaching tests are also given.

453. Chen, J.X; Yu, J.L; Zhan, H.Y. 1987. **Study on mechanisms of kraft and AS-AQ pulping of bamboo**. Cellul. Chem. Technol. 21(6).

454. Gomide, J.L; Colodette, J.L; Oliveira R.C. de. 1981. **Influence of active alkali and temperature on the kraft pulping of Bambusa vulgaris**. Revista Arvore 5(2): 181-193.

455. Goyal, P; Misra, N.D. 1980. **Economics of bamboo and mixed hardwoods pulping by AQ-catalysed kraft process**. Zonal Seminar on High Yielding and Pulping and Bleaching of Pulps, 20-21 September, Dehra Dun.

456. Goyal, P; Mishra, N.D. 1982. **Vapour phase kraft pulping of bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 37(3).

457. Guha, S.R.D; Om Bahadur; Mathur, G.M. 1980. **Production of kraft paper from bamboo (Melocanna baccifera) of Mizoram**. Indian Forester 106(8): 578-582.

To identify the appropriate bamboo species for the production of Kraft paper, Cellulose and Paper branch of FRI Dehra Dun, made a study on Melacanna baccifera which is the main species available in Mizoram. Investigations carried out, on the production of unbleached and bleached grades of pulps from M.baccifera (syn. M. bambusoides) by sulphate. Result of the experiments showed that M. baccifera was the suitable fibrous raw material for Kraft paper making.

457a. Guha, S.R.D; Singh, M.M; Sharma, Y.K; Gulati, A.S. 1966. **Wrapping, writing and printing papers from bamboo dust**. Indian Pulp and Paper 21(3): 187.

458. Jamaludin K; Jalil A.A; Abdul Latif Mohamod. 1993. **Kraft pulping of Bambusa vulgaris**. BIC-India Bulletin 3(1): 7-10.

The sutablility of Bambusa vulgaris as a raw material for pulp by the kraft process is examined. Pulp yield ranged from 45 to 53 percent. Results from this preliminary study indicate that B. vulgaris is a moderate to poor material for pulping.

459. Koorse, G.M; Veeramani, H. 1976. **Engineering properties of spent pulping liquors. I. Specific gravity of bamboo, bagasse and eucalyptus kraft black liquors**. Indian Pulp and Paper 31(1).

460. Koorse, G.M; Veeramani, H. 1976. **Engineering properties spents pulping liquors. II. Thermal conductivity of bamboo and bagasse and eucalyptus kraft black liquors**. Indian Pulp and Paper 31(4).

461. Kuang, S.J; Revol, J.F; Goring, D.A.I. 1985. **A comparison of the mercerization of kraft pulp from spruce and bamboo**. Cellul. Chem. Technol. 19(2).

462. Kulkarni, A.G; Kolambe, S.L; Mathur, R.M; Pant, R. 1984. **Studies on desilication of bamboo kraft black liquor**. IPPTA 21(1): 37-44.

An attempt is made for desilication by the method of lowering the pH of the black liquor by carbonation. The bamboo kraft black liquor usually contains silica in the range of 5-8 g/l as SiO_2}. It is tried to see the effect of pH and temperature on silica precipitation and also to achieve selective precipitation of silica. Studies revealed that temperature and pH are the two important parameters to be optimised. The pH range for silica precipitation is largely influenced by the temperature during carbonation. It is revealed that at all temperature and pH levels there was a coprecipitation of lignin. Studies are also made for achieving selective precipitation of silica. Treatment of sludge with calcium oxide or aluminium hydroxide at 80^oC helps in redissolution of coprecipitated lignin without dissolving silica portion. Leaf filter studies indicated that the carbonated black liquor could be filtered easily on 600 mesh nylon cloth under reduced pressure of about 0.3 kg/cm^2}.

463. Luo, C.C; Wang, Y.F. 1991. **A modified design to produce kraft liner board using bamboo pulp**. In: Selected Papers on Recent Bamboo Research in China. Chinese Academy of Forestry, Beijing and Bamboo Information Centre, China: 247-255.

464. Maheshwari, S. 1979. **Anthraquinone as additive in kraft pulping of bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 33(5).

465. Nazak, R.G; Handigol, M.P.H; Deb, V.K; Jaspal, N.S. 1979. **AQ as an aditive in kraft pulping of bamboo (Dendrocalamus strictus)**. Indian Pulp and Paper 33(5): p17.

466. Nazak, R.G; Handigol, M.P.H; Deb, V.K; Jaspal, N.S. 1979. **Studies on kraft pulping of mixed tropical hardwoods in the presence of AQ**. Paper presented in the IPPTA Seminar, March 1979.

467. Nepenin, N; Bang, D.S. 1969. **Obtaining kraft pulp from Vietnam bamboo**. Cellulose Chemistry and Technology 3(6): 681-700.

Laboratory studies have shown that by maintaining optimum conditions for sulphate cooking it is possible to obtain good-quality kraft pulp with a yield of 45 from old Neohouzeaua dullooa.

468. Pravin, G. 1987. **Improved process control strategy for liquid phase kraft pulping of bamboo (Dendrocalamus strictus)**. IPPTA 24(4): 41-47.

Conventional liquid phase kraft pulping of bamboo is studied to develop an improved process control strategy so as to produce pulp of uniform quality.

469. Rao, V.G; Murthy, N.V.S.R; Annam Raju, P.V; Sharma, G.S.R.P. 1983. **Effect of pulp extractives on sizing**. Journal of Wood Chemistry and Technology 3(3): 371-376.

The effect of specific extractive components of bamboo (Dendrocalamus strictus) and tropical mixed hardwoods kraft pulps on sizing is studied. It is found that the removal of the extractive components by diethyl ether improves sizing substantially, which may be attributed to the presence of oleic acid and its derivatives in the extractives. To substantiate this, the effect of added oleic acid and methyl oleate on sizing is also studied. The possible mechanism of action of these compounds is also postulated.

470. Rawat Rajesh; Sharma, G.D; Bhargava, G.G; Mohan, S.M. 1985. **Kraft anthraquinone pulping of bamboo + mixed hard woods (70:30) bamboo (100 percent) and mixed hard woods (100 percent)**. IPPTA 22(3): 39-47.

Laboratory scale kraft pulping studies are carried out at 17 percent sulphidity on bamboo + mixed hard woods (70:30) and compared the findings with bamboo (100 per cent) and mixed hard woods (100 per cent) using anthraquinone. It is reported that by adding different anthraquinone dosages (0.05 per cent to 0.25 per cent) the kappa no. of bamboo + mixed hardwoods (70:30) reduces. The bleach consumption of all the anthraquinone based pulps is lower and physical strength properties are superior to the pulps without anthraquinone additive. It is reported that anthraquinone in small dosage (0.05 per cent) is more effective in improving the yield of bamboo + mixed hard woods (70:30) digested at higher kappa no. than with lower kappa no. digested bamboo and mixed hardwoods.

471. Semana, J.A; Escolano, J.O; Monsalud, M.R. 1967. **The kraft pulping qualities of some Philippine bamboos**. TAPPI Journal 50(8): 416-419.

The kraft pulping properties of Gigantochloa levis, G.aspera, Schizostachyum lumampao, Bambusa vulgaris, B. vulgaris var.striata and B.blumeana are studied. These bamboos are reported to have higher range of ash and silica contents than those ofother Asian species but lower lignin contents than those of Indian species. The Philippine bamboos are easily digested and bleachable pulps with permanganate numbers from 13.0 to 18.2 and screened pulp yield from 41.3 to 48.0 are obtained. The bamboos gave pulp with higher tearing resistance but lower folding endurance bursting strength and tensile strength than foreign softwood kraft pulps and Philippine hardwood kraft pulps. The relative rigidity and moderate length of the bamboo fibres are associated with the strength differences between bamboo pulps and the other pulps.

472. Shah, M.A; Goswami, N.C; Akhtaruzzaman, A.F.M. 1991. **Influence of active alkali on the kinetics of kraft pulping of muli bamboo (Melocanna baccifera)**. IPPTA 3(2): 62-68.

A study is made to find out to what extent the cooking is to be continued in kraft pulping of muli bamboo (Melocanna baccifera). The effect of active alkali charge is also studied. The investigation shows three distinct phases in delignification during kraft pulping of this bamboo. The rate of delignification increase with an increase in active alkali charge. The transition points between the initial and bulk, and between the bulk and residual phases shifted to a lower lignin content with an increase in alkali charge. The use of an active alkali charge of 16 per cent as NaOH seems to be insufficient to confine the cook in the bulk delignification phase. On increasing the active alkali charge to 18 per cent as NaOH, the situation has improved.

472a. Sproull, R.C. 1955. TAPPI Journal 38: 593.

473. Ujiie, M; Matsumoto, A. 1967. **Studies on semi-kraft pulps from Sasa senanensis. Part I. Selection of the cooking conditions and comparison with Birch and Larch semi-kraft pulps**. Research Bulletin of Experimental Forestry, Hokkaido University, Japan 25(1): 287-321.

Kraft semichemical pulps were prepared from culms of S. senanensis from Teshio (Hokkaido) under various conditions, and their yield and chemical and physical properties were compared with those of S. senanensis water-cooked pulps and of Betula platyphylla var. japonica and Larix leptolepis similarly prepared, or with previous data on sulphate pulps of S. senanensis and hardwoods. The

Bamboo pulps with the best physical properties were prepared with the use of 15% active alkali, which also enabled the yield to be increased by ca. 5% compared with that of conventional S. senanensis sulphate pulps, and gave a pulp with excellent chemical properties (superior to those of the Larch pulps and a little inferior to those of the Birch pulps). Fibre length (mean 1.26 mm.) slightly exceeded that of Birch. The low yield of the Bamboo pulp compared with that of hardwoods (unavoidable because of the high extractive content) can be reduced at the expense of strength by pulping with only 10% or even 5% active alkali.

474. Vivone, R.R; Gomide, J.L. 1985. **Effect of storage time of straw and moisture content of chips on the characteristics and properties of kraft pulp from bamboo**. ABCP 18th annual meeting held during paper week, 18-22 November 1985 in Sao Paulo, Brazil. ABCP, Sao Paulo, Brazil. Vol. 1: 129-137.

Pulps from recently-gathered bamboo (Bambusa vulgaris), with and without air drying, and bamboo stored for 4 months after collection were compared. Results indicate that storing bamboos for relatively long periods (4 months) should be avoided and that air drying facilitates processing without reducing pulp quality.

Rayon Grade Pulping

475. Bhat, R.V; Viramani, K.C. 1961. **Viscose rayon pulp from Ochlandra travancorica by prehydrolysis sulphate process**. Indian Pulp and Paper 16(5).

476. Chandrasekharan, C. 1968. **Indian forest resources for rayon grade pulp**. Indian Forester 94(12): 871-877.

Only bamboo is used commercially in India for dissolving pulp. Recent analyses of other Indian-grown tree species and of hardwood mixtures are tabulated.

477. Gupta, N.K; Jain, S.C. 1966. **Utilization of bamboo dust (1) Paper and rayon grade pulps**. Indian Pulp and Paper 20(7).

477a. Horio, M; Takhama, M. 1958. Bulletin of the Institute of Chemical Research, Kyoto University Japan 36(5): p157.

477b. Karnik, M.G. 1958. Indian Pulp and Paper 13(6): p283.

478. Karnik, M.G. 1961. **Viscose rayon grade pulps from bamboo (Dendrocalamus strictus) by water prehydrolysis sulphate process**. Indian Pulp and Paper 15(11).

479. Karnik, M.G. 1961. **Viscose rayon grade pulps from bamboo (Dendrocalamus strictus), Preliminary investigation**. Indian Pulp and Paper 14.

480. Karnik, M.G; Sen, D.L. 1948. **Some promising cellulose-bearing materials (other than cotton) for the manufacture of rayon**. Journal of Scientific and Industrial Research 7(8): 351-356.

Pulps from reeds, bamboo species (Bambusa arundinacea, Dendrocalamus strictus and Kamti bamboo), bagasse pulp and jute fibres compared favourably with an American alpha-pulp and a Swedish sulphite pulp. The analytical values obtained came within the limits for rayon pulp. Results are tabulated.

480a. Karnik, M.G; Sen, D.L. 1958. Journal of Scientific and Industrial Research (India) 7(8): p35.

480b. Lele, P.S. 1964. **Investigation of the Indian raw materials for the production of pulp suitable for the rayon industry.** Chemical Age India 15(2): 173-176.

481. Ramsarma, B.V. 1962. **Manufacture of rayon grade pulp from bamboo**. Sirpur Industrial Journal 1(2): 97-99.

482. Saboo, R.N. 1992. **Role of bamboo in the manufacture of rayon grade pulp**. Proceedings of the National Seminar on Bamboos, 19-20 December 1990, Bangalore. Bamboo Society of India, Bangalore: 53-59.

Need for raising plantations suitable for pulp and paper is stressed. A general picture of the process of manufacturing dissolving grade pulp is projected here. Fibre length, pentosans present and ash analysis of various raw materials used for making pulp are also presented.

482a. Simionescu, C. 1956. Celluloza Hirtie (Bucharest 5(7): p156.

482b. Simionescu, C. 1957. Papeterie 79: p589.

482c. Simionescu, C. 1958. Celluloza Hirtie (Bucharest) 5(5): p171.

483. Singh, M.M; Bhola, P.P. 1968. **Production of rayon grade pulp**. Proceedings of the Symposium on Utilization of Hardwoods for Pulp and Paper. August 1968, FRI & Colleges, Dehra Dun, India: 73-85.

484. Suzuki, H. 1964. **Rayon pulp from bamboo**. Chemical Age 15(6): p582.

485. Wang, Z.W. 1991. **Status and prospects of textile shuttles made from bamboo fibre**. Chongquing Forest Science Technology (2): 56-57.

This paper gives the status and prospects of textile shuttles made from bamboo fibre.

Mixed Pulping

486. Bhargava, K.S. 1968. **Utilization of mixed hardwoods at Bengal Paper Mills**. Proceedings of the Symposium on Utilization of Hardwoods for Pulp and Paper, 1-3 August 1968.

487. Bhargava, K.S; Sharma, M.C; Maheshwari, D.K. 1969. **The effect of impregnation temperature and alkali concentration on cooking of mixture of bamboo and mixed hardwoods**. Indian Pulp and Paper 24(5): 257-258.

In a laboratory study on pulping a mixture of 60 Dendrocalamus strictus and 40 mixed hardwoods (70) Boswellia serrata in Bengal, the optimum unbleached pulp yield from chips cooked with 18.5-20 active alkali (NaOH) was obtained at an impregnation temperature of 125^{o}C. With a higher alkali concentration, a lower impregnation temperature can be used, but the total yield of unbleached pulp is reduced.

488. Bhat, R.V; Karnik, M.G. 1958. **Bamboo and blue gum pulps for grease proof paper**. Research and Industry 3(9).

489. Chiou, C.H; Tsai, L.H. 1982**. Pulping experiments on a mixture of bamboo and mixed hardwoods**. Bulletin, Taiwan Forestry Research Institute No. 366: 5p.

Trials to investigate sulphate pulping of different proportions of bamboo residue and mixed hardwoods revealed that a mixture containing 30 or 40 bamboo residue gave a satisfactory yield with good strength properties.

490. Dwivedi, R.P; Dubey, R.K; Kaul, S.S; Singh, M.M. 1983. **High yield semichemical pulping of mixture of bamboo and mixed hardwoods**. IPPTA 20(3): p43.

491. Ghosh, S.R; Saikia, C.N. 1996. **Mixed pulping of bamboo and khagra reed and evaluation of paper characteristics**. IPPTA 8(1): 19-32.

Khagra reed, Neyraudia reynaudiana is one of the important non-wood plants, that grows abundantly in the forests of the North Eastern states. Laboratory scale experiments were carried out for mixed pulping of bamboo and khagra reed chips and conditions of pulping were optimised. It was found that bamboo and reed chips mixed in the ratio 4:1, when cooked with 16 active alkali (as Na_2O), for 2 h at 170±2°C gave unbleached pulp with 44.4 yield, which was easily bleachable. Standard paper sheets from both unbleached and bleached pulps were formed and their physical strength properties were evaluated. The study carried out has indicated that mixed pulping of bamboo and reed is possible and khagra reed may be a potential source of supplementary cellulosic raw material for paper industry.

492. Goyal, P; Mishra, N.D. 1982. **Economics of bamboo and hardwood pulping by anthraquinone catalysed-kraft process**. Zonal Seminar on High Yielding Pulping and Bleaching of Pulps at F.R.I, Dehra Dun, 20-21 September 1980. IPPTA 19(1): 1-5.

With a view to study the economy of pulping bamboo and tropical mixed hardwoods using anthraquinone, laboratory studies were conducted to confirm the benefits of AQ-addition in kraft pulping liquor. A test case showed that the cost of pulp production can be reduced by Rs.80/ per M.T. for bamboo and tropical mixed hardwoods in a medium-sized pulp milk.

493. Guha, S.R.D; Singh, M.M; Bhola, P.P. 1977. **Pulping of Anogeissus spp. and Tectona grandis (lops and tops) for newsprint**. Indian Forester 103(3): 196-202.

A report on a pulping trial by semi-chemical processes (soda and kraft). Optimum conditions of chemical concn., sulphidity, temp. and time were found. The pulps of Anogeissus spp. were darker and required bleaching. Satisfactory newsprint was made by mixing Anogeissus or Tectona with 40 bamboo pulp.

493a. Jurasck, L. 1987. Proceedings of the Symposium on Bioconversion and Utilization of Wood Material, University of Maine, College of Forest Resources.

494. Khare, A; Joshi, R.C; Bhargava, G.G; Singh, M.M. 1984. **Behaviour of mill bamboo, bamboo + mixed hard woods (70: 30) percent, bamboo + mixed hardwoods (50: 50) percent and mixed-hardwoods kraft black liquor on evaporation and addition of alkali**. IPPTA 21(3): 29-36.

Mill weak black liquor, bamboo, bamboo + mixed hard woods (70:30), bamboo + mixed hardwoods (50:50) and hard woods black liquor are evaporated to different total solid contents to see the behavior of these liquor especially on black liquor viscosity and density. It is observed that mixed hardwoods black liquor has higher viscosity as compared to bamboo and with increase in hard wood percentage the viscosity of black liquor increase as go on increasing the percentage of total solids. It is reported that the black liquor viscosity of bamboo, bamboo + mixed hard woods in different proportion and mixed hard woods can be reduced with increase in initial residual alkali of the black liquor. This will help in reducing the clogging of the evaporator tubes and better performance of the recovery.

495. Maheshwari, S. 1975. **Studies on chlorination of sulfate pulps of bamboo, eucalyptus and hard woods**. Indian Pulp and Paper 30(1).

496. Mai-Aung, U; Htway, D.K; Kyaw, Z.U. 1968. **Mixed pulping of bamboo grown in Pegu Yoma. Part II.**. Union of Burma Journal of Science and Technology 1(3): 561-569.

Describes trials which showed that all 11 species of Bamboo known to grow in the Pegu Yoma could be used in mixture for the production of bleached kraft pulp, using techniques developed for the two most abundant species Cephalostachyum pergracile and Bambusa polymorpha. Resulting pulps had similar brightness and strength values, though inclusion of Dendrocalamus brandisii could slightly decrease brightness values.

497. Pasaribu, R.A; Silitonga, T. 1974. **Mixed pulping of hardwood and Bamboo**. Laporan, Lembaga Penelitian Hasil Hutan 35: 24p.

Reports pulping trials by the sulphate process on a 3-component mixture of Anthocephalus cadamba, Aleurites moluccana and a mixture of four Bamboos (Bambusa bambos, B. vulgaris, Dendrocalamus asper and Gigantochloa ater) all from Sulawesi (Celebes). Data on fibre dimensions and wall thickness are also tabulated (with English captions):all species had low Runkel ratios, showing their suitability for pulping. Cooking conditions are recommended for mixed pulping of hardwoods and Bamboo or mixed hardwoods alone. The strength properties of pulps containing different component ratios are discussed.

498. Rai, P.A; Jaspal, N.S. 1976. **Mixed pulping of bamboo and hardwoods**. IPPTA 13(4): 328-339.

Kraft pulps were made from mixtures of bamboo and Indian hardwoods (Lagerstroemia lanceolata, Adina cordifolia, Mitragyna parvifolia, Grewia tiliaefolia, Terminalia belerica, Kydia calycina, Anogeissus latifolia and Tectona grandis).

499. Romana, M.S.S; Exconde, T.A.R; Moredo, C.C. 1985. **Suitability of fast growing wood species and bamboo for the production of dissolving pulp as base of cellulose derivatives**. Terminal report. 16 leaves Forest Products Research and Development Inst., College, Laguna, Philippine Council for Agriculture and Resources Research and Development, Los Banos, Laguna.

Prehydrolysis-sulfate pulping of three-year old bolo (Gigantochloa levis (Blanco) Merr.) and bagras (Eucalyptus deglupta Blume) were conducted using varied prehydrolysis and pulping conditions. Three, four and five multi-stage bleaching sequences were used in the purification process. Pulp yields ranged from 27.98 to 32.72 and from 23.89 to 29.55 (based on the original material) for bolo and bagras, respectively. The experimental dissolving pulps from both samples have chemical and physical properties comparable to commercial dissolving rayon-grade pulp.

Bleaching and Beating

500. Bapna, S; Maheshwari, S; Jivendra; Kulkarni, A.Y. 1981. **Colour reversion of bamboo pulp bleached with CEH sequence**. IPPTA 18(1).

501. Bhat, R.K; Soundararajan, T.N; Reddy, V.G; Bhargava, R.L. 1972. **Bleaching of cold caustic soda pulps of Dendrocalamus strictus and mixed hardwoods**. IPPTA 9(2): 94-108.

The unbleached pulps of the bamboo and hardwoods obtained by cold caustic soda process possessed low initial brightness and consequently were hard to bleach. Various bleaching methods were tried to study its effects on yields and the efficacy of the methods to improve the brightness of the pulps. The results of the methods tried are presented.

502. Doat, J. 1970. **The bleaching of chemical pulps made from tropical woods**. Bois. For. Trop. 132: 47-68.

503. Eriksson, K.E; Kirk, T.K. 1985. **Bio-pulping, bio-bleaching and treatment of kraft bleaching effluents by white rot fungi**. In: Robinson, C.W. (Ed.), Comprehensive Biotechnology, Volume 4, Chapter 15. Pergamon Press Ltd., Oxford.

504. Faul, K.K. 1982. **Effect of chlorination and pH on final bleached bamboo pulp characteristics**. Indian Pulp and Paper 36(4).

505. Gopal, A.V. 1968. **Heterogeneity in bleached bamboo pulp**. Indian Pulp and Paper 22(12): 675-678.

Briefly analyses the two main causes of variation in quality of sulphate pulp made from bamboo in India, viz. the age and decay of the bamboo at the time of processing, and the process variables in pulping.

506. Grant, J. 1964. **Beating characteristics of non-woody pulps**. Paper Trade Journal 148(45).

507. Guha, S.R.D; Sharma, Y.K; Singh, S.P. 1968. **Studies on the effects of pulp blending**. Indian Pulp 23(2): 157-161.

Results (tabulated) of an investigation on the blending of pulps of bamboo with Eucalyptus grandis, Boswellia serrata and bagasse showed that the strongest pulps were obtained by blending after separately pulping and beating the constituents. By this means, the propagation of bamboo (and consequently the cost) can be reduced.

508. Guha, S.R.D; Singh, M.M; Bhola, P.P. 1976. **Beating characteristics of bamboo pulp in valley beater: Effect of temperature and consistency on power consumption and pulp sheet properties**. IPPTA 13(1): 54-56.

Results of the study made on the beating characteristics of bamboo pulp in valley beater are presented. Control of the temperature and consistency during the beating process is required to develop proper fibre to fibre bonding during the course of sheet formation. It is found that the optimum temperature for beating is 35 degree C for bamboo pulp and the optimum consistency is 1.5 degree. Power consumption is reported more at higher temperature and less at higher consistencies.

509. Guha, S.R.D; Singh, M.M; Mithal, K.C. 1966. **Production of bleached pulps from mixture of bamboo and mixed hardwoods**. Indian Pulp and Paper 20(10).

510. Guha, S.R.D; Singh, M.M; Singh, S.P. 1978. **High brightness pulps as filler for the production of urea formaldehyde and melamine formaldehyde moulding powder**. Indian Forester 104(1): 51-58.

Suitable pulps were prepared from commercially available bamboo pulps (bleached and unbleached) and from Eucalyptus hybrid pulp. Details are given of the bleaching processes used.

511. Islam, S; Bist, V; Chand, S; Pant, R. 1989. **Hypochlorite bleaching of bamboo cold-soda high yield pulping for newsprint furnishes**. Paper presented in the IPPTA Silver Jubilee International Seminar & Workshop on Appropriate Technology for Pulp and Paper Manufacture in Developing Countries, IPPTA, New Delhi: 12p.

512. Jain, D.K; Singh, S.V; Guha, S.R.D. 1976. **Bleaching of kraft pulp changes in properties throughout bleaching sequence CEH**. IPPTA Souvenir.

513. Khanna,P.P; Swaleh, M. 1981. **Analysis of bamboo (Dendrocalamus strictus) black liquor**. Indian Pulp and Paper 36(1).

514. Krishnagopalan, A; Kutscha, N.P; Simar, G.L. 1975. **The effect of refining on the morphology and properties of bamboo paper**. IPPTA 12.

515. Kumar, A; Singh, S.V; Singh, M.M; Guha, S.R.D. 1974. **Kinetics of chlorination stage of bleaching bamboo kraft pulp**. IPPTA 22(4).

516. Ledoux, P; Interox, S.A; Agnihotri, V.G. 1981. **Peroxide spray bleaching of CEHH bleached pulp**. IPPTA 18(1).

517. Maheshwari, S. 1981. **Studies on colour reversion of bamboo sulfate pulp**. IPPTA 18(1).

518. Maheshwari, S. 1982. **Effect of bamboo bleached pulp viscosity on strength properties**. IPPTA 14(2).

519. Maheshwari, S; Bapna, S; Jivendra; Kulkarni, A.Y. 1980. **Studies on colour reversion of bamboo pulps bleached with CEH sequence**. Zonal Seminar on High Yielding Pulping and Bleaching of Pulps, 20-21 September 1980, Dehra Dun.

520. Mai-Aung, U. 1961. **Bleachable pulp from Burmese bamboo by chlorination process**. Pulp and Paper Magazine of Canada 62(3): 230-232.

Reports experiments showing that bleachable pulp could be made by the chlorination process from shredded Cephalostachyum pergracile.

521. Misra, D.K. 1980. **Pulping and bleaching of nonwood fibres**. In: Casey, J.P (Ed.). Pulp and Paper Chemistry and Chemical Technology 3rd Ed. Wiley - Interscience, New York: 504-568.

522. Oye, R. 1981. **The effect of beating on bamboo pulps -- characterization of bamboo dissolving pulp**. Proceedings of Bamboo Production and Utilization. XVII IUFRO World Congress, 6-17 September 1981, Kyoto, Japan. Wood Research Institute, Kyoto University, Japan: 39-44.

Comparing with wood pulps, bamboo pulp cellulose has some characteristics, one of which is a higher mercerization resistance. This could be improved by mechanical treatment or heating of the bamboo pulp, though no effect was admited on linter and wood pulps.

523. Pande, G.C. 1966. **Studies on bleaching for dissolving grade pulp from bamboo (Dendrocalamus strictus) I**. Indian Pulp and Paper: 20: 10-12.

Describes trials of improves sulphate pulping procedures for preparing dissolving-grade pulp from bamboo (in which nearly 25 of the total lignin is held in the lumen and between the primary and secondary walls of the fibres). Optimum viscosity was achieved by replacing the chlorination stage by ClO_2 treatment; after further bleaching, a most satisfactory bleached pulp was obtained.

524. Pande, G.C. 1966. **Studies on bleaching for dissolving grade pulp from bamboo (Dendrocalamus strictus) II**. Indian Pulp and Paper 20: 599, 601-605 & 703-707.

525. Pande, G.C. 1967. **Studies on bleaching for dissolving grade pulp from bamboo (Dendrocalamus strictus) III**. Indian Pulp and Paper 21(12): 735-741, 749.

526. Rao, A.R.K; Srinivasan, G; Maheshwari, H.K. 1978. **Effect of beating on bamboo fibres**. Indian Pulp and Paper 32(5): 35-46.

Chips of bamboo (Dendrocalamus strictus) were pulped by the sulphate process, and the pulp was beaten to different degrees. Effects of beating on fibre dimensions and the strength and optical properties of the pulp are shown in tables and figures. Morphological changes in the fibres are illustrated in photomicrographs. The changes are discussed in relation to the observed critical beating value, above which tensile strength and bursting strength declined.

527. Rao, M.N.R; Harikishore; Pant, R. **Bleaching of bamboo cold soda pulp**. Central Pulp and Paper Research Institute Research Report No. 8312.

528. Rao, M.N.R; Pant, R; Mathur, R.M; Rao, A.R.K; Fellegi, J. 1980. **Improves hypochlorite bleaching of bamboo pulp**. Paper presented in the Zonal Seminar on High-yield Pulping and Bleaching of Pulp. 20-21 September 1980, FRI & Colleges, Dehra Dun, India.

529. Rao, V.G; Murthy, N.V.S.R; Annam Raju, P.V; Vidyasagar, C.H.V; Sharma, G.S.R.P. 1988. **Effect of hydrogen peroxide adition in the bleaching of bamboo pulp in CEH and CED sequences**. IPPTA 25(1): 20-23.

530. Roy, T.K; Bist, V; Pant, R. **Bleaching investigations of high-yield pulp from bamboo: Influence of chromophoric groups**. Centre Pulp and Paper Research Institute. Research Report No. 8512.

531. Singh, M.M; Bhargava, K.S; Gupta, R.K. 1971. **Beating evaluation of Bengal Pulp Mill's pulps**. Proceeding of the Conference on Utilisation of Hardwoods for Pulp and Paper. April 1971, FRI & Colleges, Dehra Dun, India: 119-121.

532. Singh, M.M; Bhargava, K.S; Sharma, M.C; Oberoi, M.S. 1968. **Pulping and bleaching studies on a mixture of bamboo and mixed hardwoods**. Indian Pulp and Paper 23(3): 211-212.

Results (tabulated) oflaboratory experiments at Dehra Dun on the sulphate pulping of bamboo and mixed hardwoods (unspecified) showed that satisfactory high- and lo- brightness pulps and semi-bleached pulps could be obtained from a 50:50 mixture of bamboo and mixed hardwoods.

533. Singh, M.M; Bhola, P.P; Purkayastha, S.K; Sharma, L. 1976. **Effect of beating variables on sheet formation of bamboo pulp**. IPPTA 14(2): 178-185.

The effect of beating variables like consistency and temperature on strength development in bamboo pulp was studied. Variations in fibre morphology as well as orientation of the fibres in the hand sheets were also investigated. No significant difference was found in the strength properties of the hand sheets examined, but significant difference in fibre dimensions was observed when the temperature was varied. On beating, various cell wall layers of bamboo fibre open up leaving a gap between them. This gap not only increases the percentage of void area in the sheet but also does not allow the fibres to bind to a compact mass. This appears to be the main handicap of the bamboo fibres.

534. Singh, M.M; Sharma, Y.K; Bhola, P.P. 1976. **Beating characteristics of bamboo pulp in banning beaters: Effect of consistency on power consumption and pulp sheet properties**. IPPTA 13(1): 49-53.

Bleached bamboo pulp of Central Pulp Mills was beaten in two pilot plant banning beaters, one having phosphorbronze tackle and the other having basalt lava stone roll and bed plate. The consistency of the stock during beating was kept at 4 percent, 6 percent and 8 percent. The results indicate that at higher consistencies, less power is consumed. Stone roll beater consumes less energy for the same degree of beating. Breaking length and burst factor are higher when the pulp is beaten with phophorbronze tackle and the difference is more pronounced at lower consistency, whereas stone roll beater gives a higher tear factor and the difference is more pronounced at higher consistency.

535. Suman, S; Subhash, M. 1987. **Studies on bleaching of bamboo pulp with CHH and CEH sequences**. IPPTA 24(1): 8-11.

This paper deals with the comparative investigations of bleaching of bamboo sulfate pulp of varying kappa number with CHH and CEHH sequences. It has been observed that bleaching of pulp can be done to desired level of brightness with CHH sequence. However total chlorine requirement and post colour number are higher while the strength properties are lower of CHH bleached pulp compared to CEHH bleached pulp. For CHH bleached pulp of low kappa number these adverse effects are not much. As the alkali extraction stage is eliminated the alkali consumption will be lower and colour of combined effluent of CHH sequence will be very light compared to CEHH sequence. It has been finally concluded that CHH sequence can be followed if we maintain the pulp kappa number on lower side i.e. below 25.

536. Venkobarao, G; Murthy, N.V.S.R; Annam Raju, P.V; Vidyasagar, C.H.V; Sharma, G.S.R.P. 1988. **Effect of hydrogen peroxide addition in the bleaching of bamboo pulp in C.E.H. & C.E.D. sequence**. IPPTA 25(1): 20-23.

The results of laboratory trials on the effect of hydrogen peroxide addition in the alkaline extraction stage of C.E.H as well as C.E.D bleaching of bamboo pulp, on the final bleached pulp properties are presented. The overall advantages by the inclusion of Hydrogen peroxide in the Extraction stage (Ep) are also discussed in this paper.

537. Wang, H; Lirn, T.R. 1985. **Study on the bleaching of high yield pulp from bamboo waste**. Forest Products Industries 4(1): 2-11.

Wastes of Phyllostachys edulis, P. makinoi and Dendrocalamus latiflorus were investigated.

538. Xie, T.M; Lu, Z.J. 1987. **A preliminary study of chlorophenolics in nonwood pulp bleaching effluents [incl. reeds, Chinese alpine rush, chlorination, chlorine compounds, chlorophenols, hypochlorites]**. Nordic Pulp and Paper Research Journal 2(2): 56-60.

Storage of Bamboo and Pulp

539. Bakshi, B.K; Guha, S.R.D; Gupta, S. 1960. **Effects of fungal damage to bamboo on the yield and quality of pulp**. Research and Industries 5(2): 38-39.

Results of an investigation made to find the effect of fungal damage to the bamboo, Bambusa tulda on the yield and quality of pulp are presented. It is reported that decayed bamboo gives lower yields. Sheets made from decayed and stained bamboo pulpare found to have lower strength than from healthy bamboo pulp.

540. Bakshi, B.K; Guha, S.R.D; Singh, S; Pant, R.K; Taneja, K. 1968. **Decay in flowered bamboo and its effect on pulp**. Indian Pulp and Paper 22(9): 503-506.

A recent pulping study of dead and decayed Bambusa arundinacea that had flowered gregariously since 1958 around Dandeli, Mysore State, showed that decay, mainly attributable to white rot, resulted in loss of wood substances and pulp yield, reduced pulp strength because of holes in the fibres, and increased consumption of bleaching chemicals because of the high content of residual lignin in the pulp; cost of pulp production was therefore higher than from healthy bamboo. Bamboo attacked by brown rot was unsuitable for pulping, but the incidence of brown rot was insignificant.

541. Beeson, C.F.C. 1941. **Ecology and control of forest insects of India and neighbouring countries**. Vasant Press, Dehra Dun: 773p.

Opening with a short survey of the history of forest entomology in India and the adjoining countries, and with some general notes on the methods of feeding of insects, life cycles and connected matters, the bulk of the book is devoted to a systematic record of available information on the ecology of insects related to Indian forests. In all 4,300 species are mentioned, `including at least one representative of every type of locality-plant-insect combination found in Indian forests and every species which has been the subject of an expression of interest by a Forest Officer of the Indian Empire'. The information is arranged alphabetically by orders and then families of insects, each species being dealt with separately, again in alphabetical sequence.

542. Chandra, A; Guha, S.R.D. 1979. **Studies on the decay of bamboo (Dendrocalamus strictus) during outside storage-degradation of cellulose**. Indian Forester 105(6): 444-450.

Holocellulose and hemicellulose were analysed in untreated and preservative-treated bamboo after 4, 8 and 12 months storage. The contents of both declined with duration of storage; the effect of the preservatives was slight. After 12 months, the holocellulose content (originally 68 percent) was 59-63 percent and the hemicellulose content (originally 51 percent) was 36-39 percent. The degree of polymerization of the cellulose in untreated samples decreased over 12 months from 1074 to 948; that of the hemicellulose decreased from 1309 to 1105 (1300 to 1259 for PCP - treated samples.

543. Chandra, A; Guha, S.R.D. 1979. **Studies on the decay of bamboo (Dendrocalamus strictus) during outside storage-effect on Hemicellulose**. Journal of Timber Development Association 25(3): 10-13.

In this paper investigations on how the decaying organisms attacked the hemicelluloses of bamboo during outside storage and preferentially utilized the constituting monosaccharide for their metabolism and growth are reported.

544. Chandra, A; Guha, S.R.D. 1981. **Studies on the decay of bamboo (Dendrocalamus strictus) during outside storage-degradation of lignin**. Indian Forester 107(1): 54-59.

During outside storage the bamboo (Dendrocalamus strictus) was attacked by various wood destroying microorganisms. Lignin also was degraded gradually due to decay. The degradation was caused by white rot type of fungal decay. Fungal decay also chemically changed the lignin macromolecule. Chemical analysis of lignin from freshly felled bamboo and stored bamboo showed this difference. The decayed lignin was higher in oxygen, lower in hydrogen, methoxyl value and carbon contents compared to fresh lignin.

545. Chen, R.Y; Liu, M.S; Chang, T.C; Tsai, M.J. 1989. **Postharvest handling and storage of bamboo shoots (Bambusa oldhami Munro).** Acta Horticulturae: International symposium on postharvest handling of fruits and vegetables, Leuven, Belgium, 29th August and 2nd September 1988: No. 258: 309-316.

Following harvesting, bamboo shoot fibre content increased quickly from the cut end toward the tip. Crude fibre content could be reduced by keeping shoots at high humidity, low temperature or both during handling. Phenylalanine ammonia lyase (PAL) andperoxidase activities rapidly increased in harvested shoots but no trends were observed for polyphenol oxidase activity. PAL activity was closely correlated with increasing crude fibre and lignin content and was partly due to de novo enzyme synthesis.

546. Gardener, J.C.M. 1945. **A note on the insect borers of bamboo and their control**. Indian Forest Bulletin (New Series), Entomology No. 125. FRI, Dehra Dun.

Certain qualities of the bamboo itself so far as they appear to affect control of borers are mentioned. Notes on the insect borers are given with special reference to the Bostrichidae, the most important family. The amount of starch in the bamboo, which is intimately connected with liability to attack, varies with the season; also starch may under certain conditions decrease to nil in a culm in about 3 weeks after felling; in culms felled in hot dry weather starch is high to start with and shows little depletion after felling; such culms are liable to heavy attack if not treated against insect attack. Water immersion for 3 months prevents Bostrichid attack; the starch content in the immersed culms is not apparently altered, only the soluble sugars being removed. A method devised for protection of hollow culms (internodal injection) is described. This appears entirely satisfactory for large-scale work. Impregnation of hollow culms with aqueous solutions of inorganic salts or creosote by the `Basal incision method' is dealt with. Solid culms may be so impregnated if rubber tubes are used to convey the preservative (Boucherie). The leaf-suction method worked satisfactorily to draw the solutions of inorganic salts to considerable heights but is considered impracticable for large-scale work. Baking culms has no deterrent effect against Bostrichidae unless the moisture content is reduced to near 5 per cent. and sufficient moisture to support Bostrichid life is not absorbed from the air subsequently. Superficial swabbing with creosote and fuel oil (or rape oil) gives temporary protection for about one year. Methods of impregnation with preservatives by soaking, open tank and pressure processes are briefly discussed.

547. Guha, S.R.D; Bakshi, B.K; Thapar, H.S. 1958. **The effect of the fungus attack on bamboo on the preparation and properties of pulp**. Journal of the Scientific and Industrial Research 17(4): 72-74.

The decay caused by the white-rot fungi Daedales flavida, Polystictus sanguineus and Lentinus praerifdus on Dendrocalamus strictus was studied. All caused some damage, that by D. flavida being extensive. Lignin content in the cell-wall was depleted, but since the lignin percentage remained the same in damaged and undamaged bamboo it is concluded that the fungi attack other cell-wall constituents. Strength properties of pulps from decayed chips were appreciably reduced and this is explained by the parforations and corrosion marks in the cell-walls (illustrated by photomicrographs) caused by the fungi.

548. Guha, S.R.D; Chandra, A. 1979. **Studies on the decay of bamboo (Dendrocalamus strictus) during outside storage-I. Effect of preservatives II. Effect on pulping qualities**. Indian Forester 105(4): 293-300.

Experiments were conducted at Dehra Dun to study (i) the loss of wood substance in bamboo during outside storage (ii) the effect of various wood destroying microorganisms on the chemical constituents of bamboo (iii) the efficacy of three preservatives compositions in resting the fungal decay and to evaluate the effect of decay on the pulp qualities of bamboo after different storage period with and without chemical treatments and its results are presented. It is reported that the preservative treatments reduced wood substance loss by 28-30 percent and pulp yield loss by about 30 percent.

549. Kirkpatrick, T.W; Simmonds, N.W. 1958. **Bamboo borers and the moon**. Tropical Agriculture, Trinidad 35(4): 299-301.

Internodes, taken from the top, middle and bottom of mature (5- to 10-year) and immature culms of Bambusa vulgaris, felled, some during the waxing, others during the waning of the moon, were placed in a greenhouse with pieces heavily infested with Dinoderus minutus. Tables show infestation in number of holes per 100 sq.in. of surface after 63 and 97 days. Popular local rhyming statements that (a) `Bamboo cut with moon on wane will ensure financial gain', (b) `But beetles bore it very soon, if cut upon the waxing moon', and (c) `Moreover it's a well-known fact that ripe bamboo is less attacked' are disproved by the data, which show a non-significant advantage for (b) and a highly significant ($P < 0.001$) disadvantage for (c), i.e. `the lunar myth is utter tripe, and borers like their bamboo ripe'.

550. Kozukue, E; Kozukue, N; Tsuchida, H. 1999. **Changes in several enzyme activities accompanying the pulp browning of bamboo shoots during storage**. Journal of the Japanese Society for Horticultural Science 68(3): 689-693.

The changes in glucose-6-phosphate dehydrogenase (G6PDH), shikimic acid dehydrogenase (SADH), phenylalanine ammonia-lyase (PAL), tyrosine ammonia-lyase (TAL) and polyphenol oxidase (PPO) activities of bamboo shoots during storage at 20°C were examinedin relation to their browning. Determination of G6PDH, SADH and PPO activities in the three sections of bamboo shoots revealed that G6PDH and SADH activities were highest in the apical section and least in the basal section, and also that G6PDH activity was the highest among the three enzymes. PPO maintained nearly the same activity in the three sections. After 2 days in storage, G6PDH and SADH activities of bamboo shoots increased to about 1.3 and 1.7 times those on the initial day, respectively, then decreased over 9 days as browning increased. Meanwhile PPO activity increased slightly after 2 days, then decreased. PAL activity in bamboo shoots was highest in the basal and least in the apical sections. TAL activity in all sections was quite low, compared to PAL activity but they exhibited the same trends. Both PAL and TAL activities in the basal section of bamboo shoots decreased after 2 days, then stayed at the same level; after 9 days they increased rapidly.

551. Kumar, S; Dobriyal, P.B; Tandon, R.C; Tipre, D.S. 1990. **Longterm protection of flowered bamboo during storage**. Third Forest Product Conference, FRI, Dehra Dun.

552. Kumar, S; Dobriyal, P.B. 1990. **Management of biodeterioration of timber loss and bamboos during storage: A review for Indian conditions**. Journal fo Timber Development Association of India 36(3): 5-14.

553. Kumar, S; Kalra, K.K; Dobriyal, P.B. 1985. **Protection of pulp bamboo in outside storage**. Journal of Timber Development Association of India 31(4): 5-11.

Field trials were carried out at 3 paper mills (2 in Andhra Pradesh and 1 in West Bengal) investigating the protection of stacks of flowered, semi-dry, dried and green bamboo with PCP-Na, boric acid/borax or PCP-Na/boric acid/borax. Results are presented showing pulp yield and density losses of the stored bamboo. Higher pulp yield losses were in unprotected green bamboo (12.3 after 12 months). Best protection was with the PCP-Na/boric acid/borax mixture which reduced pulp yield loss to 4.5 in this material; the protective effect decreased with time because of preservative leaching. An assessment of the cost of preservative treatment shows that it is economically viable. It is recommended that treatment is repeated after 4-6 months, immediately after the monsoons.

554. Kumar, S; Shukla, K.S; Dev, I; Dobriyal, P.B. 1994. **Bamboo preservation techniques: A review**. INBAR New Delhi and ICFRE, Dehra Dun (INBAR Technical Report No.3.): 59p.

555. Kumar, S; Singh, M.M; Guha, S.R.D. 1980. **Protection of pulpwood in outside storage - A case for using chemicals for prophylactic treatments**. Journal of the Timber Development Association of India 26(2): 30-42.

A review of the laboratory work done on storage losses with different wood species including bamboo and the adverse effect of inadequate protection on strength of paper sheets, bleach consumption and brightness and loss in digester capacity utilisation. Possible saving by using effective chemicals on some of these counts have also been qualitatively and quantitatively enumerated.

556. Maheshwari, S; Maheswari, O.N; Bajaj, V.D. 1988. **Efficient management of bamboo storage to reduce cost of paper production**. IPPTA 25(2): 1-7.

The paper deals with a few aspects of efficient management of storage of bamboo. The emphasis has been made to have optimum inventory of bamboo at different places of storage. Proper selection of site for storage, layout of stacks in the yard in compliance to the insurance rules and easy approach for transport system, stacks design, etc are to be given due consideration to reduce cost of loading and unloading, prevention from fire hazards, preservation of raw material and overall reduction in cost of raw material. The paper also discusses in detail the biological infestations due to prolonged storage. Details regarding types of infestations and remedial measures to check the same are also described. A brief account of the experiments conducted to evaluate the efficacy of prophylactic treatment to check degradation of bamboo and its effect on papermaking characterestic given along with the mill experience. It is concluded that adoption of scientific forest management practices, systematic storage, optimum inventory and preservative treatment would be helpful in checking loss of woody substance at various stages of operation, which would ultimately give better pulp and paper quality with improved productivity.

557. Mai-Aung, U; Htway, D.K; Kyaw, Z.U. 1969. **Pulps from stored bamboo**. Union of Burma Journal of Science and Technology 2(2): 345-354.

When Bambusa polymorpha and Cephalostachyum pergracile were stored in Burma for 12 months in piles in the open or submerged in a natural pond, deterioration through stain and rot fungi and beetle attack were severe in the open but negligible in water. Losses of specific gravity were respectively 16.7 and 6.13% B. polymorpha and 6.52 and 1.61% in C. pergracile. Neither duration nor method of storage had a great effect on chemical composition and sulphate pulp yields, but some strength properties of the pulp decreased about equally in both methods during storage. Brightness and response to bleaching was better in pulp from water-stored Bamboo; this was also confirmed in a limited bleaching trial on mechanical pulp from B. polymorpha.

558. Mathew, G; Nair, K.S.S. 1990. **Storage pests of bamboo in Kerala**. In: Rao, I.V.R, Gnanaharan, R and Sastry, C.B (Eds.). Bamboos Current Research: Proceedings of the International Workshop, Cochin 1989. KFRI, Peechi and IDRC, Canada: 212-214.

About 12 spp. of insects, mostly beetles, were recorded causing damage to stored reeds and bamboos in Kerala, including an unidentified subterranean termite and 2 spp. of beetles, Dinoderus minutus and D. ocellaris (Bostrichidae), which were the most serious borers. Observations on the seasonal incidence, general characteristics as well as the nature of attack caused by these beetles are given.

559. Murphy, R.J; Alvin, K.L; Tan, Y.F. 1991. **Development of soft rot decay in the bamboo Sinobambusa tootsik**. IAWA Bulletin 12(1): 85-94.

The development of decay cavities caused by growth of the soft rot fungus Chaetomium globosum in the fibre cell walls of Sinobambusa tootsik was studied in 1- and 3-year-old culms. Soft rot attack was found only in the cell walls of fibres; parenchya and vessel elements remained unattacked. The extent of soft rot and cavity morphology were influenced by the position of the fibre bundles in the culm wall, culm age and the degree of lignification of individual fibres. Decay was greatest in the walls of those fibres which matured late in the course of culm development and in which the wall contained zones of low lignin content. It was least in the early maturing, uniformly lignified fibres and in very immature, thin-walled fibres. The results are discussed in relation to developmental anatomy and the reported ultrastructure of bamboo fibre walls.

560. Nair, K.S.S; Mathew, G; Varma, R.V; Gnanaharan, R. 1983. **Preliminary investigations on the biology and control of beetles damaging stored reed**. KFRI Research Report No. 19. Kerala Forest Research Institute, Kerala, India: 35p.

The damage potential of Dinoderus beetles stored bamboo, reed Ochlandra travancorica, one of the fibrous raw materials for paper pulps and possible methods of their control were investigated. The study included a general survey of insect damage of stored reed in Kerala, development of methods for rearing dinoderus in the laboratory, experimental investigations on factors influencing succeptibility of reed to Dinoderus and evaluation of several chemicals under laboratory as well as field conditions for control of the borers.

561. Purushotham, A. 1970. **Protection of pulpwood (timber, bamboo) from deterioration due to biological agencies (fungi and insects, etc.) during transit and storage**. Journal of the Timber Development Association 16(2): 50-53.

Author suggests measures for protection of bamboo against insects and fungus attack at felling and stacking site. Methods of prophylactic treatments are described.

562. Sadawarte, N.S; Prasad, A.K. 1978. **Indian experience in collecting, handling, storing, preservation, and preparing bamboo for pulping**. USA, Technical Association of the Pulp and Paper Industry, Nonwood Plant Fiber Committee. Nonwood plant fiber pulping. Progress report No. 9: 3-9 TAPPI, Atlanta, Georgia, USA.

Bamboo accounts for over 60 of the raw material used in the Indian pulp and paper industry. Research done at Central Pulp Mills in India is briefly described on removing silica from bamboo prior to pulping and on utilizing bamboo dust as fuel and in pulping.

563. Sai Ram, M; Seenayya, G. 1991. **Production of ethanol from straw and bamboo pulp by primary isolates of Clostridium thermocellum**. World Journal of Microbiology and Biotechnology 7(3): 372-378.

Two strains of Clostridium thermocellum have been isolated and these strains are found displaying higher ethanol tolerance and can grow and degrade cellulose in the presence of 1.5 percent ethanol. The abilities of these isolates to degrade native and pretreated agricultural material such as rice straw, bamboo pulp (Bambusa sp.) and stems of Lantana and Parthenium weeds are reported. The effect of reducing sugars and ethanol on the cellulose fermentations is also reported.

564. Satish Kumar; Kalra, K.K; Dobriyal, P.B. 1985. **Protection of pulp-bamboo in outside storage**. Journal of the Timber Development Association 31(4): 5-12.

Field trials on protection of flowered, semi dry, dried and green bamboos were carried out at Sirpur Paper Mills, Kagazagar, Andhra Pradesh Paper Mills, Rajahmundhary and Bengal Paper Mills, Raniganj. At the three mill sites, variable losses in raw material were noticed. Real losses were, however, more than the apparent losses as the former were camouflaged due to loss in wood content. Prophylactic treatment with mixture of sodium-pentachlorophenate-boric acid-borax affected a saving of nearly 60 percent, in terms of pulp yield, in green material over a storage period of one year. Single treatment at the time of making a stack has a limited scope as the chemicals are leachable. However, the savings affected make the treatment economically viable.

565. Satish Kumar; Dobriyal, P.B. 1990. **Management of biodegradation of timber logs and bamboos during storage: A review for Indian conditions**. Journal of the Timber Development Association of India 36(3): 5-14.

Studies on the effect of storage of pulp wood revealed that untreated material attacked by borer and fungi while the treated material degraded less. The degree and type of attack depend on the climatic conditions and the moisture content of the wood. Borer and fungus attack influence the pulp yield and cause appreciable decrease in strength properties of paper. It is reported that prophylactic treatment of bamboos with effective chemicals can affect considerable savings in wood raw materials. The best treatment was found to be with 2.5 per cent solution of Boric acid, Borax and Sodium pentachlorophenate (1:1:05). Laboratory screening tests on fungicides/insecticides revealed several formulations to be tried for field application.

566. Singh, M.M. 1977. **Summary of FRI investigation on affects of storage on paper making raw materials**. IPPTA Zonal Seminar on Afforestation, Exploitation and Preservation of Forest Raw Materials, 1977, Dehra Dun.

567. Sulaiman, O; Murphy, R.J. 1992. **The development of soft rot decay in bamboo fibres**. Twentythird Annual Meeting - International Research Group on Wood Preservation, Harrogate, United Kingdom, 10-15 May 1992: 17p.

568. Sulaiman, O; Murphy, R.J. 1995. **Ultrastructure of soft rot decay in bamboo cell walls**. Material und Organismen 29(4): 241-253.

The penetration of soft rot (Chaetomium globosum) hyphae and cavity formation was greatly influenced by the microfibrillar orientation of bamboo (Phyllostachys viridi-glaucescens) cell walls. Penetration hyphae normally changed direction when they encountered a different microfibrillar orientation of the cell wall, particularly associated with a narrow lamella. The microfibrillar structure of the bamboo cell walls led to the development of 3 types of soft rot branching:typical 'T' branching, 'tangentially' orientated branching and 'radially' orientated branching. Penetrating hyphae that grew tangentially followed the microfibrillar angle of the narrow lamellae and the cavity was confined to just outside the transitional region between the broad and narrow lamellae. Radially orientated hyphae normally traversed across the cell wall either via pits or by direct penetration. Soft rot hyphae were able to exert a strong mechanical force to penetrate through the cell wall. Considerable distortion of the microfibrillar structure of fibre and parenchyma cell walls was commonly observed resulting from penetration hypha and during hyphal enlargement accompanying penetration. Lignin played an important part in decay produced by soft rot fungi. High lignin content was demonstrated to act as a barrier for the development of soft rot as shown in the decay resistance of the compound middle lamella.

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