EVALUATION OF THREE NIGERIAN FIBRE SOURCES FOR PULP AND PAPER PRODUCTION

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AUGUST, 2008

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FOR PULP AND PAPER PRODUCTION

BY

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M.Sc./ENG/49297/05-06

A THESIS SUBMITTED TO THE
POST GRADUATE SCHOOL,

AHMADU ZARIA UNIVERSITY, ZARIA

NIGERIA

IN PARTIAL FULFILMENT FOR THE AWARD
OF MASTER OF SCIENCE
IN PROCESS ENGINEERING

DEPARTMENT OF CHEMICAL ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

AUGUST, 2008

DECLARATION

I declare that the work in the thesis entitled “Evaluation of Three Nigerian Fibre Sources for Pulp Paper Production” has been performed by me in the Department of Chemical Engineering under the supervision of Prof. I.M. Bugaje, Dr.O.O. Famuyide and Dr. I.A. Mohammed.

The information derived from the literature has been dully acknowledged in the text and a list of references provided. No part of this of thesis was previously presented for another degree or diploma at any university.

…….. ……....

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CERTIFICATION

This thesis titled EVALUATION OF THREE NIGERIAN FIBRE SOUCES FOR PULP AND PAPER PRODUCTION by Haruna Ibrahim meets the regulations of governing the award of Master of Science (M.Sc.) in Chemical Engineering of Ahmadu Bello University, and its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my wife and children,

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Miss Aminat H. Ibrahim

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ACKNOWLEDGEMENT

All gratitude to the Almighty Allah for His infinite mercy, protection and favour I have being enjoying throughout my life.

My profound gratitude goes to my team of supervisors; Dr. I. M. Bugaje, Dr. O. O. Famuyide and Dr. I.A. Mohammed for their patience, motivation, immerse contributions and constructive criticisms. I also wish to thank other members of staff of the Department of Chemical Engineering for their contributions to the success of this work.

Profound and profuse gratitude goes to the Provost of Federal Collage of Forestry, Ibadan for giving me the facilities of the Collage and accommodation during my study tour to the collage. I thank the Head of Department of Wood and Paper Technology, the staff of Chemistry and Biology Departments and other staff members of the Collage for their assistance I enjoyed. I thank Mr. Ekong Akpan, the Wood and Paper Technologist for his contributions.

I thank the Head of Department of Textile Science and Fashion Design, Kaduna polytechnic for allowing me the use of the laboratory facilities for the test of my sample papers. I also thank Mallam Bello, the Laboratory Assistant who guided me on how to use the Instron Table Model 1026 for tearing resistance and tensile strength tests. I also thank Mr. Adams, the Laboratory Manager of Standard Organization of Nigeria (S.O.N.). Kaduna and his members of staff for allowing me the use of Mullen Bursting Strength Tester which I used to test the burst strength of my sample papers. I thank Dr. Hadiza Nuhu of Pharmacognosy Department of the Faculty of Pharmacy Ahmadu Bello University, Zaria for allowing me the use of the Departmental Compound Microscope to measure the fibre length and fibre thickness of my pulp samples. I also thank the Laboratory Technologists who guided me on how to use the Compound Microscope.

My profound gratitude goes to Lt. Col. J. O. Obasa the Commandant, command Day Secondary School, Kaduna and the Head of Department of Science Command Day Secondary School, Miss Nnawuhe for their support and contributions to the success of this work. I also thank Mr. Benjamin Akande who taught me how to operate computer, Mr. O. D. Stephen who took the pictures of the materials I used in carrying out this work

and the rest of my friends and colleagues who contributed in one way or the other to the success of this work. My gratitude goes to my elder brother Mallam Bashar B. Ibrahim who contributed financially and morally to the success of this work. I also thank my wife and my children for their patience, perseverance and tolerance.

ABSTRACT

This investigation was carried out in an effort to search for raw materials to replace the presently imported long fibre pulp for the production of pulp and paper in Nigeria. Three fibre sources namely;silk cotton tree,bagasse and rice straw were investigated. Maceration process of pulping was used to pulp these raw materials and paper samples were produced from their pulps. The objectives of this research were to evaluate three Nigerian fibre sources and determine their suitability for pulp and papermaking. The three materials; *Ceiba pentadra*, bagasse and rice straw were all collected from Raffin Gussan environs in Kaduna State.

The tear force of the sample papers produced were found to be 956.48mN, 1226.25mN and759.25mN tear force respectively. The paper samples produced from these three materials posses greater tear force than TAPPI T414 standard 500-700mN for tear. The tear factor and breaking weight of these materials were found to be 162.50m^2 and 22.07N, 125.00m^2 and 26.00, 147.98m^2 and 6.57N respectively. These values are greater than the minimum standard for all grades of papers of The Nigeria Paper Mill Limited Jebba whose tear factor and breaking weight were 120m^2 and 5.6-7.5N respectively, showing that they would be good for the manufacture of writing and printing papers. These same sample papers however showed 9.20Nm/g, 6.50Nm/g and 3.14Nm/g respectively for tensile strength index and 42.50kPa, 57.50kPa and 7.00kPa respectively for burst strength. These figures fall below TAPPI standard of 40-70Nm/g (MD) and 20-40 Nm/g (CD) for tensile strength index (T494) and 250-300kPa for burst strength (T403). This indicates that their paper products may not be good for packaging and wrapping applications.

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LISTS OF ABBREVIATIONS

GW	Green Weight (g)
BR	Bath Ratio
K-No	Kappa Number
P-No	Permanganate Number
DW	Dry Weight (g)
TS	Tensile Strength (N/m)
BW	Breaking Weight (N)
TSi	Tensile Strength (Nm/g)
TAPPI	Technical Association of Pulp Paper Industries
NPM	Nigerian Paper Mill

LIST OF SYMBOLS

D	Fibre Thickness (mm)
d	Fibre Thickness(μm)
F	Calibration Factor
f	Correction Factor for Calculating Kappa Number
G	Basis Weight or Grammage (g/m^2)
g	Acceleration due to gravity (m/s^2)
H	Fibre Length (mm)
h	Fibre Length (μm)
T	Temperature (^0R)
To	Ambient Temperature (^0C)
Tr	Reaction Temperature (^0C)
θ	Temperature Difference (^0C)
L	Lignin Content (%)
M	Moisture Content (ml or g)
W	Width of Sample Sheet (m)
w	Weight of Chips (g)

CHAPTER ONE

1.0 INTRODUCTION

The per capita consumption of paper has been suggested as an indication of the degree of advancement, which nation attain. Certainly, world development as we know it could not have taken place without a means of communication in which speech is supplemented by written or printed records. Papers have undoubtedly been the principal media for such records.

Man has always felt the need to record his ideas and impressions of the world around him. Primitive man hunted wild animals and painted their pictures on the walls of his residential cave. The people of Sumarians, who lived in the valley of Tigris and Euphrates, in present day Iraq, were the first people who started writing on clay tablets (Dereck, 1969).

The earliest writing materials were stones, clay tiles, bones, metals, skins, leaves of certain plants, waxed wooden tablets etc. All these had their obvious limitations. Then came the ancient Egyptians of over 5,000 years ago who used a water reed known as papyrus from the bank of River Nile to make a much lighter writing material. Most of the works of great Greeks and Romans were recorded on papyrus (Julius, et-al, 1950), from which the term "paper″ is derived.

1.1 Definition of Paper

Paper can be defined as “an interwoven mat of cellulose fibres formed by their falling from suspension in water” (Dereck, 1969). A sheet of paper chiefly consists of vegetable fibres, of different lengths and sizes, twisted and interlaced with each other and finally squeezed together, to make a sheet or web with a surface suitable for writing and

printing (Robert 1952). Paper is believed to have derived its name from the water reed, papyrus (Internet, 2006b). A Chinese courtier, Tsai Lun in about 105 A.D., first invented paper. He was deified the god of papermakers (Julius, et-al, 1950). He first made paper by pulping fishing nets and rags. The raw materials were first boiled and then beaten into mash. The mash was then stirred into pulp and spread on a stationary frame or basket. When a tissue is formed, the resulting paper is pressed with heavy weights.

1.2 Fibrous Raw Materials for Paper Making

The fibrous raw materials for papermaking are derived almost exclusively from plants, of which there are thousands of different species in the vegetable kingdom, ranging from common grasses to the largest trees. The great majorities are capable of yielding valuable fibres; nevertheless, the number of species economically suitable as sources of fibres for papermaking are relatively limited (Julius, 1950). The most popular raw materials for papermaking are woods. They provide the cellulose fibre, which is the main raw material in papermaking. Although there are century long on using nonwood plant fibres in papermaking, especially in hand papermaking, the use of such fibres at present worldwide is only 5.5% of the total fibres in the world production of about 315milliontons (Manfred, 2001). Wood based pulps are preferred not because these fibres have better papermaking characteristics, but they are economically to produce. Especially the harvesting and transportation costs for wood are lower than for nonwood plant materials.

1.3 Types of Wood

Woods are classified into two: the coniferous and deciduous woods. The coniferous woods are softwood, which have needle or scale like leaves that, with a few exceptions, remain on the tree all through the year. Hence, soft wood trees are sometimes called *evergreen*s. Botanically they are known as *gymnosperms*, from the Greek word meaning "necked seed", (Internet, 2007g). Instead of bearing seeds from flowers; gymnosperms have exposed seeds in cones. Generally grown in cold climates. Softwoods grow slower than hardwoods and are the sources of the major raw materials for papermaking. The most used of these varieties are spruces and pines found growing naturally in the Northern Hemisphere, e.g. Norway, Scandinavia etc. They are trees with long fibre with average length of 3-4mm.

The deciduous trees are botanically known as *angiosperms*, usually with broad leaves. The trees grow in tropical climates. They have shorter fibre than softwoods. They shed their leaves in winter. They are called hard wood with short fibre length of 1.0 – 1.5mm (Internet, 2006c). Nigerian trees fall in this category of woods.

There are several reasons why hard woods have not been widely used for pulping to greater extent (Sven 1965).

1. Often they do not as do many types of softwood occur in pure stands, but in a mixture of several species with greatly differing properties, which do not give uniform pulping.
2. Many hard woods take up water more easily than softwoods, and are therefore almost impossible to transport by river driving which has been the economic means of wood transportation in several parts of the world.
3. The chemical composition of a hardwood e.g. its content of extractives, sometimes renders it less suitable for pulping.

4. Sometimes its structure is so dense that it is difficult to penetrate by pulping chemicals.
5. Shorter and less uniform pulp fibres are obtained, and fibre length has for a long time been considered of primary importance for the quality of paper pulp.

Even among the softwoods, there are great differences in properties, making them more or less suitable to the different pulping processes (Sven 1965).

The demand and therefore the price for the different wood species thus vary, with the properties of the wood, and these properties are determined by the structures and elements of the wood and their chemical composition. Some of the plant species used in pulp and papermaking are discussed below.

1.3.1 Spruce (*Picea excelsa*)

These are **e**vergreen trees widely distributed in the temperature regions of the northern hemisphere, occurring in European and South America (Dallimore et al, 1966). They usually have conical outline with tall, gradually tampering trunks and leaves needle – like or flattened, persisting of several years. Spruce is a usual raw material for white mechanical pulp produced by the bisulphite process. The reason for this preference for spruce is its good white colour, long of fibre, comparative softness and relatively low resin contents (Julius, et al 1950).

1.3.2 Pine (*Pinus sylvestrie*)

This is a tree of 80 to 110 feet high with reddish brown bark 0.25 to 0.75 inches thick. Its leaves are found in threes and last for two years. Its leaves are densely crowded on the branch. The tree is found in North America and North Europe (Dallimore et al 1966). It has a lower colour and is not; therefore, so suitable when a white mechanical pulp is required (Julius, et al, 1950). It also contains a larger proportion of resin, and the chemical treatment is therefore usually digestion with an alkali, such as a solution of caustic (soda process) or of a mixture of caustic soda and sodium sulphide (sulphate or Kraft process).

1.3.3 Gmelina arborea

Gmelina arborea tree locally known as Gambar is a beautiful fast growing deciduous tree occurring naturally throughout greater part of India. It is also occurring in Myamman, Thailand, Laos, Cambodia, Vietnan and South province of China, but planted extensively in Sierra Leone, Nigeria Malaysia and on experimental basis in other countries as well (Wikipedia, 2007). Gmelina arborea sp tree attains a height of 30m with a whitish greater grey corky bark, warty with lenticular tubercles.

1.3.4 Bamboo

There are thousand species of Bamboo scattered all over the tropics and subtropics and large supplies are available, particularly in the Middle belt and Eastern part of Nigeria. Their growth is very rapid and some species may grow to over 30m in height, which may reach full height in about 10years. However, the problem associated with the pulping of Bamboo is their high silica content which account for rigidity and

deposit as hard scale in the tubes of evaporators for the recovery of cooking chemicals (James 1978).

This material is used largely in India, though it has been used to a limited extent in Nigeria Papers Mill (N.P.M.) Jebba. It is commonly found in almost every part of Nigeria. It has abundant source of cellulose for, and can be cut annually. The fibres which derived from the stem are fairly long. The papers made from Bamboo possess a great strength (Sven 1965). Figure 1.1 shows a stem of bamboo.



Figure1.1; A typical Bamboo Stem (Internet, 2006a)

1.4 Sourcing Fibrous Raw Materials

Due to unavailability of softwood best known for papermaking in Nigeria, the need for sourcing local raw materials has become an imperative importance. The Nigeria

Paper Mill Jebba before its closure used to import long fibre pulp to mix with locally produced short fibre pulp (Ibrahim, 1991).

(a) Silk Cotton Tree (*Ceiba petandra*)

The Silk Cotton Tree whose natural occurrence in Asia and in Africa forests remains doubtful is a large bruttressed tree of tropical America (Gunter, 1978). *Ceiba pentatra* commonly known as Silk Cotton Tree is a tree up to 200 feet height in forests and planted by villager for boundary demarcations. It has trunk with large buttressed branches indifferent forms with or without prickles or with obtuse or neatly pointed stout prickles generally prickly in the young state (Hutchinson, et al, 1958).

(b) The Bagasse (*Saccharum –officinarum*)

Large quantity of sugar canes is produced in Nigeria. After the cane juice is extracted from the stem, the latter is thrown away as waste or incinerated in power boiler. The waste stem of sugar cane called bagasse is found everywhere especially in Sugar mills. The fibres of this bagasse can be used for papermaking (Sven 1965).

(c) Rice Straw

Historically, rice straw is the oldest paper making materials and dates back to the early part of second century when the Chinese invented papermaking. It remained the major source of fibrous raw material for pulp production in Europe and North America until the wood pulp industry was firmly established in the early 1920s (James 1980).

1.5 Waste Paper Recycling

Waste paper, known as secondary fibre, is becoming increasingly important; both in an effort to save trees for other uses and to remove some of the fibre waste materials from the waste stream and reduce its deposits in sanitary landfills sites, which are becoming scarce. The fibres from waste papers are predominantly wood fibre. It is easier to repulp the waste papers and to remake it into a new sheet. The chief disadvantage is that, owing to ink and dirt, the new paper does not usually have as good colour as the original. Furthermore, the act of papermaking causes the fibres to bond together. In order to reuse the fibres from waste paper, these bonds must be broken to separate the fibres once again. It is practically impossible to break the fibres apart without damaging them somewhat (James, 1982). All these factors conspire to make paper produced from secondary fibre sources different from paper made from virgin fibre.

1.6 The Non-Fibrous Materials

A variety of substances is added to the paper stock. These may be soluble or insoluble in water. They are added at different points in the process as the case demands, some in batches, some continuously. Some of the commonest of these additives are:

(a) Starch

Starch is glue like material when prepared with water. It is used to add strength, firmness and stiffness to the sheet. It is most often added to the surface of the sheet after drying, or partly drying, but may also be used in the stock suspension.

(b) Alum

This is another common chemical additive used in the paper making process. It is used in acidic solution for various purposes, mainly the precipitation and fixing of rosin-size. The alum used is aluminium sulphate ($Al_2 (SO_4)_3.18H_2O$).

(c) Size

Because of the natural affinity of cellulose for water, paper is termed hydrophilic (water-receptive). The opposite of hydrophilic is hydrophobic (water-resistant). In order to induce hydrophobic characteristics in paper, it becomes necessary to mask the natural tendency of the fibre towards absorption of water. This is achieved by sizing.

This is added to paper to reduce its absorbency e.g. to writing ink. It may be added at the preparation stage, i.e. where the fibrils are in suspension in water and being partly treated, preparatory to forming the sheet. Sometimes it is added at a latter stage, after the stock has been partly dried on the paper machine, or latter still as a separate process after the machine. The commonest sizing material is rosin (Robert, 1980), which is dissolved or dispersed in solution and precipitated on the fibres as fine particles. Synthetic resins may be used to make a paper, which remains strong when wet, called wet strength resin.

Rosin is a yellow or brown, glassy, brittle substance obtained from pine trees. When the back is chipped, the gum or resin, which oozes out is collected and distilled with water. Turpentine is driven off and rosin is left in the still. Rosin is also obtained by heating the pine chips with steam and then dissolving out the rosin in a solvent; it is then reddish in colour (Julius et al, 1950).

(d) Mineral Fillers

These are often called loadings. They reach the paper mill in powdered forms and are used to improve the paper surface for printing, to give high finish, greater opacity and appearance. They increase the weight of paper but not strength. They may be added dry, but this tends to give uneven distribution. It is a common practice to make them up in form of a suspension and then added to the stock. The common loading is kaolin, also known as China clay, a white powder that can be obtained in various particle sizes, the finer grades being used in the finer paper (Robert, 1980).

Other white loadings include titanium oxide, an expensive material, which produces a very high opacity and whiteness, and calcium carbonate which impacts a low acidity to the paper, giving it good strength retention and aging properties.

(e) Colours

Colouring materials may be divided into those which are insoluble e.g. loadings, and those which are soluble. Obviously, they must not remain completely soluble in the water; otherwise, the dye would be lost with water, which drains through the forming mesh (Robert, 1980). Those, which are used, therefore have a good affinity for fibre or for other constituents of the paper, i.e. a usable large proportion of the dye remains with the fibre or loading rather than with the water.

1.7 Pulp and Paper Production in Nigeria

There were three paper mills in Nigeria. The Nigeria Paper Mills (N.P.M.), Jebba in Kwara State, the Nigerian Newsprint Manufacturing Company (N.N.M.C), Oku Iboku in Akwa Ibom State and the Nigerian National Paper Manufacturing Company (N.N.P.M.C.)

Iwopin, in Ogun State. The three mills had total installed pulp production capacity of 207, 000metric tonnes/year.

The Nigerian Newsprint Manufacturing Company Limited Oku Iboku, Akwa Ibom State was established to manufacture Newsprint papers with the capacity of 100, 000metric tonnes/year. Since 1990, production of newsprint declined from 31,000metric tonnes out of 100,000metric tonnes to only 3,000metric tonnes in 1993 (Internet, 2006c). The mill was shut in 1994, due to spare parts and other logistics problems.

The Nigerian Paper Mill Limited, Jebba was commissioned in 1969 with installed capacity of 12,000metric tonnes/year for the manufacturing of writing and package paper. It was expanded in 1981 to produce industrial grade papers, especially Kraft and Kraft Linerboard. The expansion added capacity to 65,000metric tonnes/annul (Ibrahim, 1991). However, since 1990, the production of Paperboard declined from 12,488metric tonnes to 2,313metric tonnes in 1992 from where a gradual up turn began. The paperboard production in 1996 was 19,744metric tonnes. The company ceased production in 1998 and has since been privatized in 2004 by the Bureau of Public Enterprises (BPE).

The Nigerian National Paper Manufacturing Company Limited in Iwopin was established in 1995 with total installed capacity of 100,000metric tonnes/year to produce printing and writing papers. Test production with imported pulp resulted in 2,500metric tonnes of printing and 1,966metirc tonnes writing paper in 1996. The production has not increased appreciably ever since (Internet, 2006c).

The major problems of these mills were identified to be:

Inadequate working capital and spare parts

Unavailability of long fibre pulp.

Relaying on imported long fibre pulp was not sustainable and is responsible for the problems faced. There is a need to look into other alternative fibre sources within Nigeria to provide substitute to the imports.

1.8 Problem Definition

This research was designed to address the following problems:

1. The three-grounded Nigeria paper mills were importing long fibre pulp for production of paper and paper products.
2. Some of the Nigerian wood species such as silk cotton tree (Ceiba *pentadra)* are under utilized.
3. Agricultural cop residues are not adequately utilized leading to environmental pollution.

1.9 Research Objectives

a. The general objective was to evaluate three Nigerian plant species / fibre sources and determine their suitability for pulp and papermaking.

b. The specific objectives are:

1. To assess fibre length and thickness, lignin content and pulp yield.
2. To produce paper samples from these materials and test their tearing, tensile and bursting strengths.

The project would help in identifying local sources of raw materials. This will go a long way to revive the declining paper mills in Nigeria, provide employment opportunities for the youths and increase revenue generation for the nation, as well as

address environmental concerns on some agricultural crop residues such as rice straw and bagasse.

1.10 Justification

1. Nigeria with her three grounded paper mills is an importer of paper and paper products.
2. One of the causes of failure of the local pulp and paper industry has been the importation of long fibre pulp, which consumes our foreign exchange.
3. Use of suitable local long fibre sources would provide import substitution.
4. Identifying local raw fibre sources will enhance the economic viability of the existing paper mills and probably lead to their revival.
5. Saving in foreign exchange will be achieved by lowering the amount of imported pulp and exportation of papers and paper products to other countries.
6. Environmental issues on agricultural crop residues would be addressed.

1.11 Scope

This investigation was as follows:

Identification of the three Nigerian fibre sources (silk cotton tree, bagasse and rice straw)

Evaluation of the following properties for the three:

Pulp fibre length and cell wall thickness,

Pulp yield and lignin content,

Tearing resistance of sample papers,

Tensile strength of samples paper, and

Bursting strength of paper produced.

.CHAPTER 2

2 LITERATURE REVIEW

2.1 The Cellulose Fibre

Cellulose fibre is a high molecular weight, steroregular and linear polymer of repeating β-D glucopyranose units. Simply speaking it is the structural element and the major constituents of the cell wall of trees and plants. The empirical formular for cellulose is $(C_6H_{10}O_5)n$ where n is degree of polymerization (DP). A simplified structure of cellulose fibre is shown in figure 2.1.

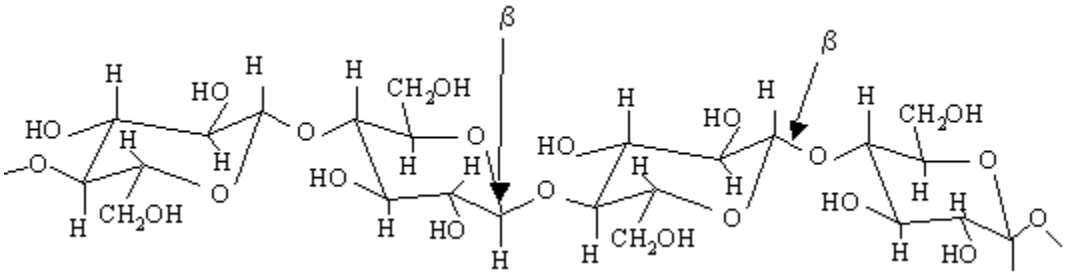


Figure 2.1;Simplified Structural Formular of Cellulose Fibre. (Internet 2006a)

Plant cells in wood are composed of cellulose, hemicellular bound together by lignin, a highly oxygenated aromatic polymer with a repeating phenylpropane skeleton. Cellulose was first isolated and recognized as a distinct chemical substance in the 1830s by the noted French Agricultural chemist, Anselme Payen, (Sven 1965). Payen concluded, more or less correctly that cellulose and starch were isomeric substances because both had the carbon and hydrogen analysis and subjected to hydrolysis, both yielded D-glucose. After about seven years, the precise empirical formular of cellulose was established as $(C_6\ H_{10}\ O_5)x$, (Sven 1965). The results from early studies on acetylation and nitration had indicated that cellulose had three free hydroxyl (-OH), groups per $(C_6\ H_{10}\ O_5)$ unit.

Plant cells have true cell walls containing polysaccharides as the major structural material. Cellulose is the major structural component of plant cell walls. It exists in the cell wall as long, thread like fibres (microfibrils). The cellulose microfibrils in mature wood cells are embedded in a matrix composed mainly of hemi-cellulose and lignin. Between the cells is a region called the compound middle lamella, which contains mainly lignin and pectic substance. The cell wall of a wood fibre is shown in figure 2.2.

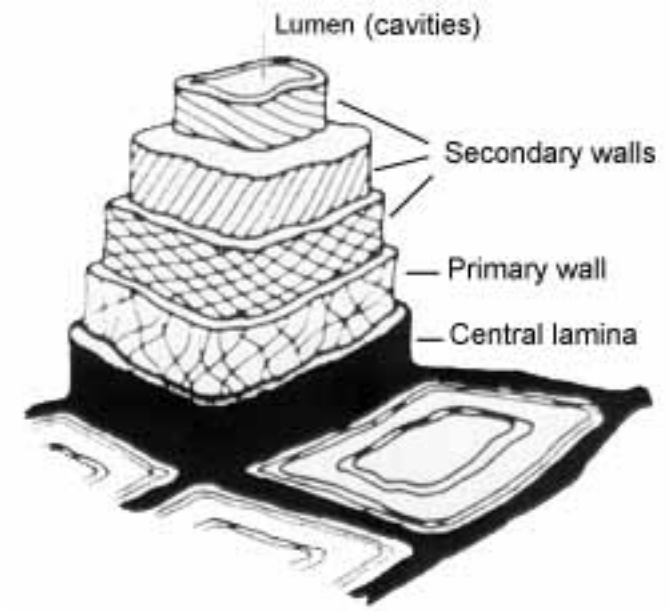


Figure 2.2; Simplified Structure of the Cell Wall of a Wood Fibre. (Internet, 2006a)

The primary wall (p) contains a randomly and loosely organized network of cellulose micro fibrils embedded in the matrix. Immediately below the primary wall does the secondary wall comprise nearly all of the cell wall. The secondary cell wall is divided into three layers called S1, S2, and S3. The outer layer of the secondary S1 has a cross-batch pattern of micro fibrils. The S2 layer of the secondary wall account for the major parts of the cell wall volume. The microfibrils in this portion of the secondary wall are oriented almost parallel to the fibre axis. In the thin S3 layer, the micro fibrils form a flat

helix in a transverse direction. The innermost portion of the wall consists of the so-called warty layer, most likely formed protoplasmic debris.

The distribution of the lignin, cellulose, hemi-cellulose and pectin over the middle lamella and the cell wall in wood fibres has been found to be heterogeneous. Early studies by Lange, (James, 1982) indicated that approximate 70% lignin in soft wood and 90% in hard wood is located in the compound middle lamella. The remaining lignin is distributed within the secondary wall with higher concentration generally being found in the S3 layer of the cell wall.

2.2 Pulping processes

Pulping can be described as treatment of raw material to liberate the fibres from the lignin binding it. Pulp is the product of the separations of the fibres in wood or other plant fibre material and is an intermediate product in the manufacture of paper. There are two major classes of pulping processes, namely mechanical and chemical processes.

2.2.1 Chemical pulping

There are many chemical pulping processes that include: the acid or sulphite process, Kraft or sulphate process, alkaline process, neutral sulphate process and maceration. All these processes separate the fibre in the wood by dissolving the lignin that holds them together. Maceration is called Cold digestion. It separates the fibre and bleaches the pulp and takes longer time than the other pulping processes.

(a) Sulphite pulping process

This method uses sulphur dioxide (SO_2) dissolves in water to produce an acid condition to break down the lignin.

$$SO_{2\,(g)} + H_2O_{\,(1)} \longrightarrow H_2SO_{3\,(aq)} \qquad (2.1)$$

The sulphur (IV) oxide is prepared by burning sulphur in a controlled atmosphere.

$$S_{(s)} + O_{2\,(g)} \longrightarrow SO_{2\,(g).} \qquad (2.2)$$

The acid solution, H_2SO_3 (aq) reacts with the lignin to form acids by the lignin and sulphur combining to form molecules called lignosulphonic acids. These acids can be dissolved from the wood if there is a base present. Calcium was originally used but because of the formation of calcium carbonate in the evaporator during the recovery of the pulping liquor, it is now substituted with sodium, magnesium and ammonium as the base. Other problem associate with sulphite operation is the presence of sulphur (II) oxide, which must be handled very carefully because it is a toxic gas (James 1982).

The fibres produced from sulphite process are white, which produce brighter paper than Kraft process. It also produces fibres of non-pure cellulose, which is good for writing papers. However, because of the potential pollution and recovery problems, sulphite pulping is less favoured and is currently on the decline.

(b) Kraft pulping process

The Kraft pulping process has become the common process for the production of full chemical pulp. The reasons are:

(I) The strength of the pulp that produces stronger papers than the other methods.

(ii) The versatility of the process in its ability to handle a wide range of raw materials, and

The readily availability of a chemical recovery system.

Kraft process can handle woods with high resin content, and in some cases modified to allow the removal and conversion of these and other organic materials into useful by products e.g tall oil and turpentine. The main cooking chemical is sodium hydroxide, (NaOH) of a pH 12. The wood, when cooked, will release acids into the cooking solution to reduce the pH during cooking process. The sodium hydroxide can enter into several different reactions with the wood, some of which will also contribute to the consumption of the NaOH and the subsequent lowering of pH. If the pH is allowed to decrease during the cooking, the result will be degradation of the cellulose and loss of pulp quality. The loss of quality in pulp may show up either in strength loss or colour development. In addition, if the concentration of NaOH is too high, it causes harm to the chips. The balance is maintained by the use of sodium sulphite, (Na_2S) which function as a buffer or caustic donor as shown in the equilibrium reaction below.

$$Na_2S + H_2O \rightleftharpoons NaOH + NaHS \qquad (2.3)$$

The controlling factor in this equation is the relative concentration of the compounds on either side of the equation. If the caustic soda concentration is reduced, the reaction will proceed to the right to replenish the NaOH concentration. The inclusion of the Na_2S in the cooking liquor helps control the pH throughout the cook and thereby prevents, or at least reduces the degradation or quality loss, of the resultant pulp. The equilibrium reaction in equation (2.3) shows that the caustic concentration remains suppressed as long as the pH is high, but the potential for regeneration or maintaining its concentration as the pH is lowered is available until the Na_2S is also expended.

The chemical nature of the lignin is such that it is a very large molecule that is made up of a large number of phenolic sub molecules, or building blocks, which makes it

hard to characterize lignin molecule by representing it with a chemical formula. The lignin in the tree is found in many different forms. The combining of the building blocks takes place along with the formation of the secondary cell walls. The fibre growth cycle causes the random or varying structure of the lignin, but also causes lignin to be situated throughout the fibre wall structure. The caustic reaction with the lignin is primarily to break the bond between the basic building blocks. The sulphur attaches to the lignin fragments that have been broken loose in such a way as to create acid groups or charged points that aid in holding the fragments in solution, thereby contributing to their removal from the wood or fibre structure. The sulphur lignin molecule is more soluble in water than pure lignin with the aid of sodium ion which furnishes the counterion (or base) to stabilize the solution or dispersion of the liquid acids (James, 1982).

Maceration

One method, which reveals cells in their cellular structure, is the dissociation method. Maceration process is a small scale pulping which is referred to as test tube pulping. The target plant is treated with chemicals, which dissolve the middle lamella and allow the cells / fibres to become separated from one another. It combines pulping and bleaching. Works on maceration were carried out by the following Scientists, (James et at, 2001):

Schulze' (1857) **method consists of the application of a combination of various concentrations of nitric acid with a small quantity of potassium chlorate. The mixture is allowed to stand at room temperature or heated slightly to initiate the reaction.**

Jeffrey (1917) **proposed an alternative method for milder treatment by using a mixture of equal portions of freshly combined 8 to 10% nitric acid and chromic acid. Although maceration at a cold temperature often gives best results, the mixture may be warmed slightly to hasten the reaction.**

Franklin's (1945) **method uses acetic acid and hydrogen peroxide mixture at a cold temperature or heated to a temperature of 100 to 110^{0}C to hasten the reaction.**

Spearin and Isenberg 's (19 47) **method uses sodium chlorite and acetic acid.**
Burkart's (1966) method consists of treatment with triethylene glycol containing an organic catalyst, such as phenolsulphonic acid or p-toluenesulphonic acid at 130^{0}C

Maceration can be achieved by treatment of plant with a mixture of hydrogen peroxide (or peroxide releasing agent), metal carbonate and oxalate (James et al, 2001). The hydrogen peroxide serves to function as lignin removing agent. In the absence of hydrogen peroxide, or a peroxide-releasing agent such as sodium peroxide, potassium peroxide, sodium peroborate and potassium peroborate can serve. The peroxide concentration of 0.02 – 0.8mol/L more preferably 0.05 – 0.4mol/L is used (James et at, 2001).

Metal carbonate such as sodium carbonate and potassium carbonate also serve as lignin removing agent. Hydrogen peroxide is unstable and is readily decomposed under an acid or alkaline condition, and an alkali metal carbonate is added to the cooking liquor so that the cooking mixture after completion of the cooking has a pH of 5 - 9, preferably 6 – 8. Preferable concentration of metal carbonate is between 0.02 – 0.2mol/L or more preferably 0.04 – 0.12mol/L.

Oxalic acid may also be used as long as the pH of the resulting cooking liquor at the endpoint of the cooking falls within the above-specified range. The cooking liquor preferably has an oxalate concentration of 0.01 – 0.1mol/L, more preferably 0.02 – 0.08mol/L and the bath ratio of 2 – 15L/Kg or preferably 4 – 10L/Kg. It may vary with the concentration of the cooking liquor.

2.2.2 Mechanical pulping

The mechanical or ground wood pulp process is deceptively simple. Logs are held against an abrasive stone, which tears the fibres from the log, and water is used to wash the fibres from the stone. Modern stones are not solid, but rather covered with blocks of synthetically produced abrasive materials of controlled grit size. Such synthetic stone can be made more than 1.5m in diameter and up to 2m across their face and can be motor driven at speed up to 50m/s. The stones have burr pattern which help to control the removal of the fibres and their quality. The stone is patterned with a series of groove that cause the surface of the log next to the stone to be alternately compressed and relaxed. It is also theorized that the groove pattern pumps water in and out of the wood fibres, aiding in their removal and also helping to control the temperature of the wood. The alternate compression and contraction generates heat in the wood, which softens the lignin and fibres and aids in their removal. However if too much heat is generated, the wood will char and the fibres will be destroyed.

The ground wood pulp from the grinders needs to be screened to remove large fibre bundles known as shives and other large materials such as silvers or under ground pieces of wood and knots. After screening, the ground wood pulp is ready for subsequent treatment or

may be sent directly to the paper machine. If unbleached pulp is desired (e.g. for newsprint), the pulp needs no further treatment. Ground wood pulp makes weaker and less permanent paper.

2.2.3 Other Pulping Processes

Chemical and mechanical pulps differ not only in the properties of the pulp produced, but also in the yield or efficiency of the operation. The mechanical pulps produce a high yield of fibre based on the original weight of the wood, and the full chemical pulps removes more chemicals (lignin and hemicelluloses) and produce a much lower yield.

High yield processes are found in almost as many varieties as there are mills, and there is considerable confusion in the names applied to these processes. In between full mechanical wood pulp and chemical wood pulp are:

1. Refiner Mechanical Pulp (RMP). The chips are simply squeeze to remove water and fed to a disc refiner. The chips are partially crushed in water and completely broken into fibres in the refiners. The process can produce almost as fibre damage as the ground wood process with little savings in power,

2.Thermo Mechanical Pulp (TMP). The chips are softened with steam prior to refining or during refining. Both damage to fibres and energy cost can be reduced. The first approach is called thermo refiner mechanical pulp (TRMP) while the second is called thermo mechanical (TMP). The quality of pulp produced by these operations is similar, but not identical to that of stone ground wood,

3. Chemical Mechanical Pulp (CMP). This is produced from chips using a chemical Pretreatment at a temperature below 100^0C, followed by atmospheric refining.

4. **Chemical Thermo Mechanical Pulp (CTMP**). This is Produced from chips pretreated with chemicals prior to or during pre-steaming and first refining stage at temperature of more than 100^0C and other refining stages at atmospheric pressure,

5. **Semi Chemical Mechanical Pulp (SCMP**). This is produced from chips pretreated with chemicals at more than 100^0C and then refined at atmospheric pressure.

2.2.4 Pulping Processes Used on Straw

Rice **s**traw stems are elastic and tubular and connected at intervals with nodes. The top portion of the stem where the seeds are attached is called rachis. Leaves originating from the nodes formed a sheath enclosing part of the stem. The head of the plant contains chaff, leaf sheath, blade, glumes, bristles and rachis.

Straw has low cellulose content, but the total holocelulose content is approximately equal to that of wood. Straw contains a high percentage of pentosans and a low percentage of lignin compared to wood and its ash content is higher than that of wood (James, 1980).

Straw is pulped by chemical process and by the mechano – chemical process. Soda, sulphate, and neutral sulphite processes are used for high – yield semi chemical as well as for bleachable grades of pulp (James 1980). In terms of strength, properties, and the soda process do the sulphate and the neutral sulphite process follow the best and yield values are in the reverse order. The acid sulphite process is unsuitable for straw pulping: the pulp produces a brittle and poor in strength. The celdecor – pomilio process (soda-chlorine) is mostly used for bleached pulp production but the process can be interrupted after alkali indigestion stage to produce a high yield pulp for corrugating medium and

board manufacture. Lime or soda lime process is used for the production of coarse for the manufacture of boards, packing and wrapping paper and corrugating medium.

2.3 Pulp Washing

It is necessary to remove the waste liquor from the stock to reclaim the liquor and also to produce high quality pulp. The washer consists of rotary drums designed to wash the stock into tank below the washing drums. The water in the stock passes through the wire screen on the surface of the washing drum causing a pad of fibres to builds up on the drum surface. The pad of fibres is raised up out of the tank by the rotation of the drum and washed further by showers located above the drum. The washed stock can be removed from the drum and mixed with water and pumped to the next operation.

2.4 Bleaching

Both full chemical pulping operations and the high-yield processes leave the pulp too highly coloured to be used in making white paper. Unbleached ground wood and sulphite have been and are being used in newsprint, but the brightness of these papers is not really too high. Further more, due to the presence of lignin, these papers do not have any degree of permanence and become yellow easily (James, 1982). Bleaching improved the whiteness, the brightness and the permanence of the whiteness by the removal of the lignin from the fibre. Therefore, bleaching can be seen as a continuation of the purification that begins in the pulping operations. This accounts for the loss of weight experienced by the pulp during bleaching. Depending on the purity of the pulp before bleaching, the lost may be great or small. If the pulp is to be bleached to a high brightness, then the pulp is required to be well cooked to deliver a purer pulp to the bleaching operation. The removal

of impurities also indicates the need for washing as an integral part of the total bleaching sequence. The pulp is subjected to washing immediately after bleaching to remove both the spent bleach liquor and the impurities.

Equipment used for bleaching operations consists primarily of closed tanks into which the pulp is pumped in water suspension after being mixed with bleaching chemicals. The pulp is carried by water throughout most of the bleaching operations. The chlorination stage is usually carried out at fairly low consistencies (of about 30%) (James 1982). The washing is carried out in rotary drum washers. The pulp coming off the drum washes will usually be about 6% consistency, which is high enough that it will not flow readily and looks as if it would need to be shoveled to make it move. There are pumps that can deliver 6% consistency pump. The extraction stage can be performed at consistencies form 6% to 12% by raising the consistency and then diluting it again by the addition of sodium hydroxide solution.

2.5 Beating

Beating or refining is a process of modifying the fibres under controlled conditions to produce stuff, which has the characteristics necessary to produce paper with the required properties (Robert, 1980).

When the beating operation commences, it would seem that the primary wall or skin of the fibres is first partially rubbed loose; exposing part for the underlying surface, or secondary wall. Then the water enters the fibre, causing it to swell up to the size it formerly was in the original living plant by entering between the micelles and, at the same time, probably breaking some of the bonds between the hemicelluloses and the amorphous and crystalline

cellulose (Noris 1952). The intensive rubbing action that follows in the beaters in conjuction with the solvent action of water, this appear to cause the formation of a colloidal suspension of cellulose and water or a hydrous envelope forming the so-called water of hydration around the secondary wall of the fibre. The insoluble primary wall of the unbeaten fibre serves as a protective skin around the fibres, so that in a wet web of paper, they do not adhere to one anther on drying.

Therefore, while the fibres soften and swell as the beating progresses, it is reasonable to assumed that they tend to weaken at the points where the amorphous cellulose occur in the fibre structure and that some of the hemicelluloses begins to break away in particles. With continued beating the wearing away of the primary fibre walls, the fibres now begin to split longitudinally or fibrillate at the ends which increases the surface tension between the fibres and the area of bonding between them (Noris 1952). This results in the compacting of the ultimate sheet of paper and also makes it very much stronger. The effect of bonding and strengthening the mat of fibres forming the sheet is further increased by the cementing action of the cellulosic matter which rubbed off the fibres, which in addition to the particles of hemicelluloses; act as the adhesive fillers between the interstices of the large fibres. If, however, the beating is continued still further, the point is soon reached where their bonding and cementing action is increasingly negatived by decreasing length of the fibres until the resultant paper becomes weaker and weaker in strength, tear and folding resistance. Over beating should therefore be avoided.

2.8 Screening and Cleaning

For the operation of the screening processes, the pulp is diluted to about 0.5% or less consistency (Julius et al, 1950), which flows over screen plates, which are perforated with round holes or slots of 0.008 to 0.010 inches wide. The screen is made to vibrate and sorts the material on the basis of their particle sizes. The smaller ones pass through and the larger ones are held on the screen. Therefore, the flow rate though the screen is very important. By balancing the flow rate to the screen surface against the reject flow rate, it is possible for the holes to reject fibre bundles smaller than the width of the opening (James 1982). Figure 2.3 shows a section of flat screen.

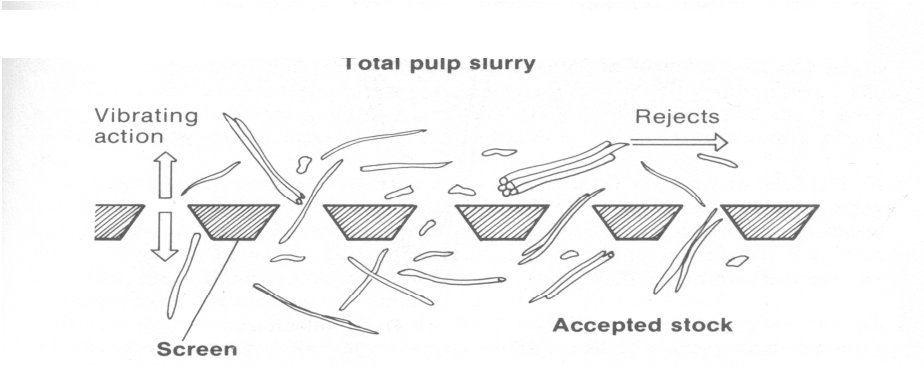


Figure 2.3: Section of Flat Screen (James, 1982)

These screens remove oversize particles but will not remove heavy particles. The particles heavier than pulp are removed with a centrifugal cleaner. The total stock flow enters the cleaner at the top and is pumped into the cleaner tangentially to the outside wall.

2.9 Sheet Formation

Paper is formed when fibres, usually cellulose are made into dilute suspension with water and the water is then removed on the paper machine by drainage through a screen that is commonly referred to as the paper-machine wire. The resulting wet mat of fibre is then pressed and dried. For some very light paper grades, some wet mat of fibre is

simply dried to produce the finished sheet of paper. The Fourdrinier paper machine is mostly employed for this purpose.

In Fourdrinier paper machine the screened, cleaned and diluted stock enters in the upper left corner behind the head box. The function of the head box and slice are to deliver a ribbon of stock to the wire at uniform dilution, thickness and speed. The head box is a tank of necessary size to deliver the volume of stock required and is positioned above as shown in figure 2.4 or beside the wire so it delivers the stock to the wire through the slice. The slice is a narrow opening in the head box through which the stock flows. The slice is adjusted so that the thickness of the ribbon of stock can be controlled. The head box and the slice work together to control the volume or weight of fibres as well as the flow rate. Figure 2.4 shows Fourdrinier paper machine.

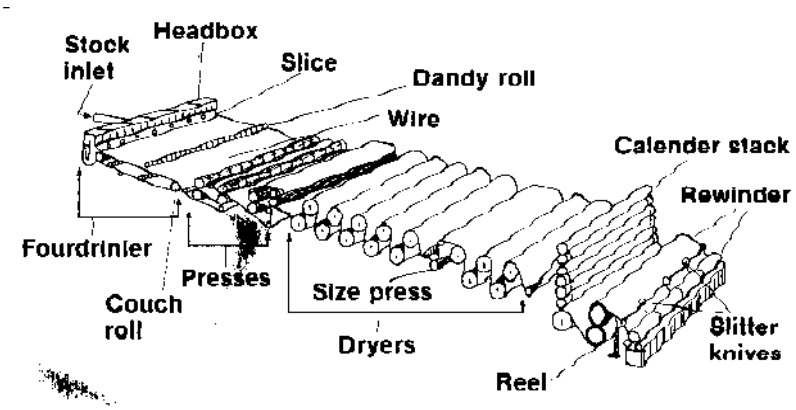


Figure 2.4: Fourdrinier paper machine (James 1982)

2.8 Properties of Paper

The properties of papers, which are of interests to papermakers include: mechanical strength, optical properties and water sensitivity.

2.8.1 Basis Weight or Grammage

The basis weight, substance or grammage is obviously most fundamental property of paperboard. The basis weight of paper is the weight per unit area expressed as the weight in grams per square metre (GSM or g/m^2). The basis weight is what determines, how much area the buyer gets for a given weight.

For papermaker basis weight is important from the point of view of production rate.

All paper machines are designed to manufacture paper in a given basis weight range. The tighter the range the more efficient will be the machine. The values of basis weight of some grades of papers are given in appendix H

2.8.2 **Tearing Resistance (**TAPPI T414)

Tearing resistance indicates the behaviour of paper in various end use situations; such as evaluating web runnability, controlling the quality of newsprint and characterizing the toughness of packaging papers. Where the absorb shock is essential fibre length and fibre bonding are both important factors in tearing strength. The fact that long fibres improve tear strength is well recognized. The long fibres tend to distribute the stress over a greater area, over more fibres and more bonds, while short fibres allow the stress to be concentrated in a small area. The tearing resistances of papers are best measured with Elmendof tester shown in figure2.5. The tearing resistance of some grades of papers are giving in appendix H.

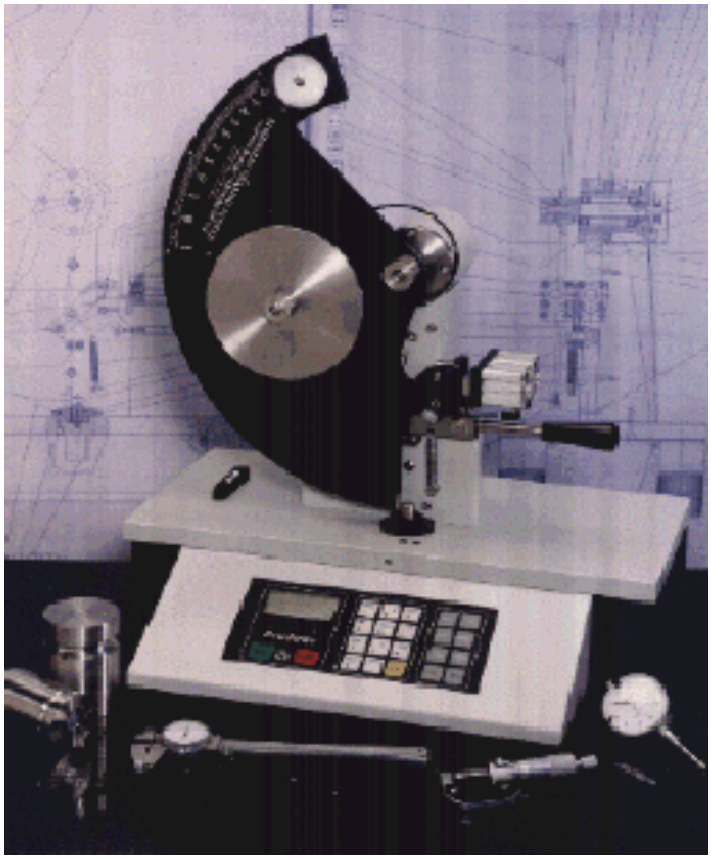


Figure 2.5:Elmendorf Tearing Tester (Internet, 2006d) for tearing resistance testing.

2.8.3 Tensile Strength

The tensile strength is the force required to produce a rupture in a strip of paperboard, measured in machine direction (MD) and cross direction (CD), expressed in kN/m. Tensile strength is indicative of fiber strength, fiber bonding and fiber length. Tensile strength can be used as a potential indicator of resistance to web breaking during printing or converting. The stress can be expressed as the force per unit width of test specimen, the recommended units being kilogram per centimetre, (Kenneth 1970). Testometer in figure 2.6 is a modern apparatus for testing tensile strength of papers. The procedural standards are explained in

TAPPI T 494. The values of tensile strength indices of some grades of papers are in appendixH.

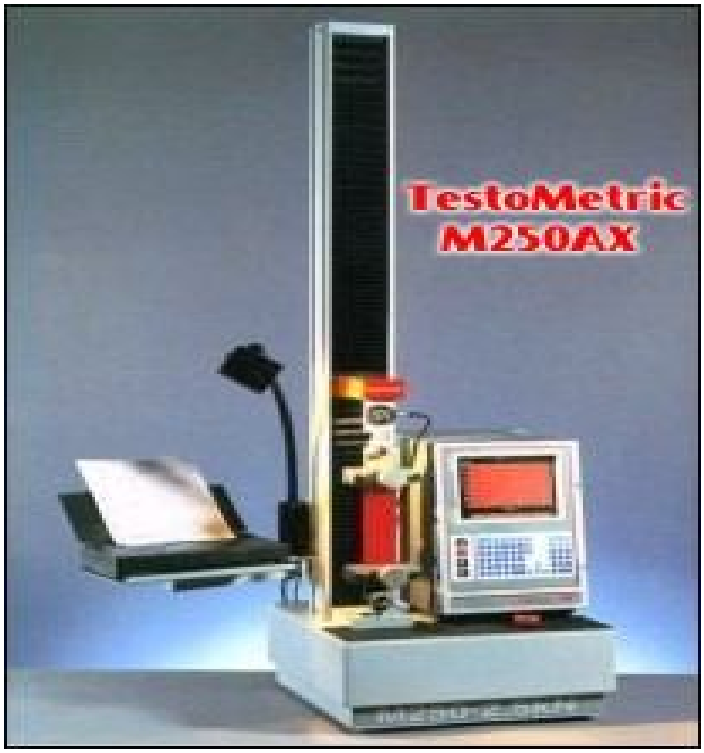


Figure 2.6: Testometer for Tensile Strength tester (Internet, 2006d).

2.8.4 Burst Strength

Bursting strength tells how much pressure paper can tolerate before rapture. It is important for bag paper. Bursting strength is measured as the maximum hydrostatic pressure required to rapture the sample by constantly increasing the pressure applied through a rubber diaphragm on 1.20 – inch diameter (30.5mm) sample. The standards procedure is described in TAPPI T403. Mullen burst strength tester is shown in figure 2.7.

Bursting strength depends on basis weight of paper. To normalized the bursting strength for various paper, bursting strength is reported as

(a) Burst index = Burst strength (kPa)/ Basis weight (g/m^2) (2.4)

(b) Burst factor = Burst strength (g/cm^2)/ Basis weight (g/m^2) (2.5)

Burst ratio = Burst strength ($Ib/inch^2$) (2.6)



Figure2.7: Burst Strength Tester (Internet, 2006i) for bursting strength testing.

2.8.5 Fold

The fold test measures the number of 270^0 folds required to weaken the strip so that it will break less than 1kg load. It gives an indication of the paper's toughness (James 1982). All strength tests are sensitive to the moisture content of the paper at the time of the test, but the fold strength is the most sensitive. For this reason, most paper mills maintain a standard testing room that is held at 50% relative humidity and 32^0C.

The moisture content of the paper will also affect the performance of paper in actual printing or other converting operations. Too low a moisture content makes paper brittle and less extensible to static problems. Raising the moisture content improves these performance properties, but too much moisture can make the paper limp, perhaps too extensible and could lead to curl.

2.8.6 Optical Properties

(i) Whiteness and Brightness

When making paper for communication, the interest is placed on how well the paper will be able to carry the message and display it to the reader. The basic qualities are whiteness and brightness. Whiteness is related to the colour of the paper and actually is the equal presence of all colours. If a sheet is truly white, it will have a high degree of reflectance and will not absorb one wavelength of light more than another.

Brightness is defined as the amount of blue-white reflectance compared with magnesium oxide (MgO), which is considered 100% bright (James 1982). The significant difference between brightness and whiteness is that brightness is measured in the blue region. The blue region was selected because the human eye and psychological system prefer yellow to brown in colour and bleaching increases the blueness of the paper.

(ii) Opacity

Opacity is referred to how well the paper can hide the printing on the back side of the sheet. The paper term opacity is an indicator of the degree of opaqueness. It is expressed

as a % with the highest opacity being 100%. An average printing paper will be around 90% opacity. Figure 2.8 shows opacimeter for measuring opacity of papers.



Figure2.8 Opacimeter TAPPI T425 *(Internet, 2006d*) for analysis of opacity.

(iii) Gloss

Gloss is the measure of the reflectance of light from the surface of the web. The measurement is made using a focused beam of light directed towards the paper surface at an angle of 15^0 from the surface, 75^0 from the normal. The test takes this last angle as its name and is called the 75^0 gloss (James 1982). There is also a 20^0 gloss, which is used for some waxed grades. The 75^0 gloss is used commonly for the measurement of glossy coated paper. Uncoated paper is normally below 20% and coated paper is between 20% and 80%.

2.8.7 Water Sensitivity

Dimensional Stability and Curl

As water absorbs the web, it causes the fibres to swell and forces them apart. The caliper of the sheet will increase slightly, and the dimensions of the sheet will increase. The ability of the sheet to resist this growth is called dimensional stability.

If the water penetrates one side of the web only, the web will coil away from the moistened side since that side will expand and the other will not. If the pore structure of the webs is not the same on both sides, then uniform absorption of water throughout the web can still lead to curling. A non-uniform web structure is susceptible to curling from either an increase or decrease in moisture content.

2.9 Grades of Papers

Having understood the main properties of paper imposed on it by its fibrous structures, next is how the paper maker alters the structure of the paper in order to produce a desire combination of qualities.

2.9.1 Filter and Blotting Papers

The main objective is to produce an open, absorbent sheet and to avoid blocking the channels. The fibres should be cleaned and of good qualities and the beating process restricted to a cutting action, without fibrillation (Julius et al, 1950). Mineral matters, woody impurities and the fibre debris are excluded so far as possible since they tend to block up the channels and make the sheet less absorbent.

For filter papers, the sheet should be chemically pure and as inert as possible, so that it will not give rise to any reaction, which might interfere with chemical analysis. The fibre is washed with acids to remove the last traces of mineral matter.

2.9.2 Drawing Paper

A good quality drawing paper is strong, permanent, white and opaque, take India and writing ink well, accept colour wash without mottle and withstand the action of India rubber or an erasing knife. The best quality drawing papers are still hand made rag paper, but these are costly, and machine-made papers from rag or rag–chemical wood mixture are satisfactory for many purposes and cheaper.

2.9.3 Writing Paper

This is uncoated paper that is suitable for writing with ink on both sides. The writing must neither bleed nor strike through. Writing paper is always fully sized and also suitable for printing. It can be wood free or mechanical, depending on the intended purpose. The mixture of fillers makes it less translucent (Internet, 2006a).

2.9.4 Printing Papers

They are intended mainly for printing with oil-base inks. They are almost invariably machine-made papers of wood pulp. Sizing is not necessary for paper intended only for printing with oil-base inks, but if there is any likelihood that the paper will be written on with pen and ink (for instance, forms) it is better to engine size (Julius et al, 1950).

2.9.5 Wrapping Papers

Wrapping papers required to be made strong, provide protection to wrapped goods especially in rain. These qualities are obtained by engine sizing. The fibre should be strong, long and beaten so as to give a sheet the maximum strength. Brown Kraft-Pulp is widely used for making wrapping papers (Julius et al, 1950).

2.9.6 Wet Strength Paper

This is one of the special papers that are made for specific uses. This paper retains its mechanical strength after soaking in water. They are made by the addition of a urea-formaldehyde or melamine formaldehyde resin to the pulp during the manufacturing of the papers (Julius et al 1950). The resin cements the fibres together and the bond tends to improve with age. They are used for maps printing and wrapping (especially military parcels).

2.9.7 Bitumen Laminated Paper

These are other special papers impervious to liquid water, and have been used extensively as the inner liners of packing cases for goods to withstand unfavourable conditions of climate and transport.

2.9.8 Security Papers

These are used either for cheques, forms, money order, postal order and other similar documents, the writing on which is liable to be tampered with by erasive, or by the application of a chemical ink removal.

2.9.9 Cigarette Papers

Cigarette paper is specially made smell and taste free on burning and in addition, it must be opaque. Opacity is usually secured by the addition of a filter from chemicals such as calcium carbonate, which gives good white appearance and helps to promote uniform burning of the paper (Julius et al, 1950).

2.9.10 Miscellaneous Papers

These include insulating papers for the electric industry materials ranging from thin condenser papers to coverings for telephone and power transmission cables, paperboard for cartons and tissue papers for wadding and surgical dressing. Handkerchiefs, towels and reinforcement in laminated sheet for plastic industries are also in this group.

Specialty papers such as currency, cigarette papers, teabags, dielectric papers etc, may be made from furnish of 100% nonwood specialty pulps (Robert, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Some of the equipment required for this work are discussed below.

3.1.1 Oven

Oven was used to determine the moisture content of chips and pulps. This is shown in figure 3.1.

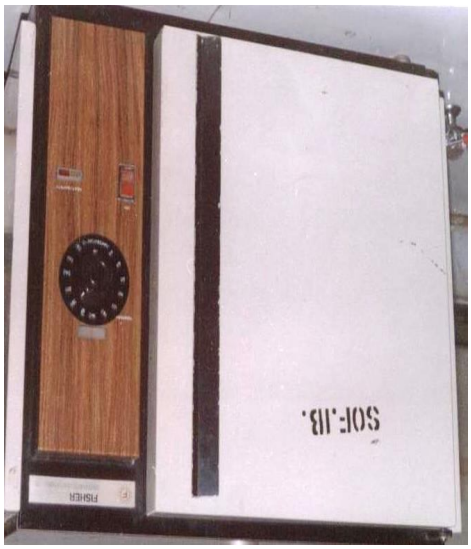


Figure 3.1: Oven (For moisture content analysis)

3.1.2 Mortars and Pestles

Mortars and pestles were used for Kappa number analysis and pulp refining. These are shown in figure 3.2.





3.2(a) Wooden Mortar and Pestle (For beating pulp)

3.2(b): Ceramic Mortar and Pestle (For grinding pulp and chips)

3.1.3 Compound Microscope

The fibre length and cell wall thickness were measured with compound microscope. This is shown in figure 3.3



Figure 3.3: Compound Microscope (For fibre morphology analysis)

3.1.4 Mould (Sheet former)

An improvised mould was made of fine net with wood in a cylindrical shape and a wire gauge to strengthen the net used for forming sheets. This is shown in figure 3.1.4

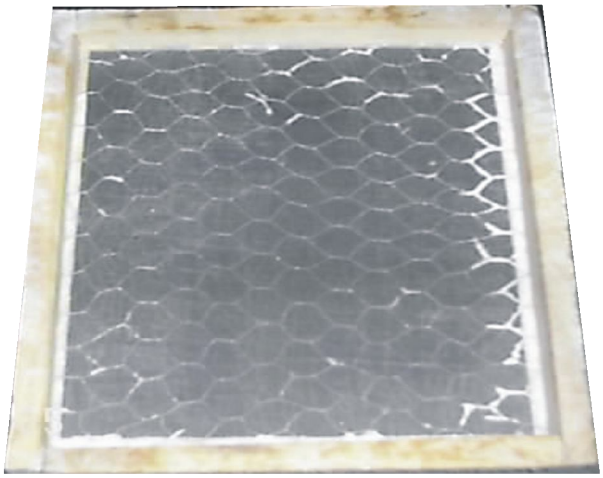


Figure 3. 4: Mould (Developed for the research)

3.1.6 Mullen Burst Strength Tester

This machine was used for testing the burst strength of the sample sheets formed. This is shown in figure 3.5

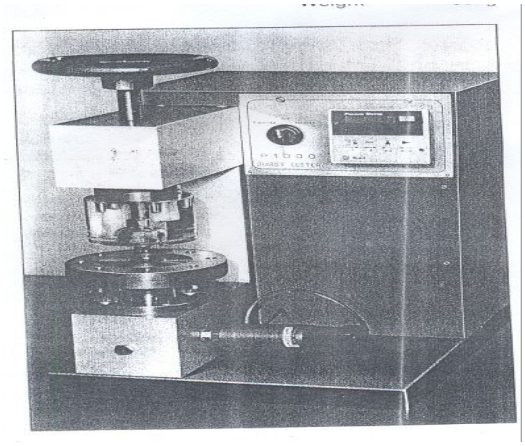


Figure3.5: Bursting Strength Tester (For testing bust strength sample papers)

3.1.6 Instron Table Model 1026

This machine was used for testing tearing resistance and tensile strength of paper samples. This is shown in figure 3.1.6

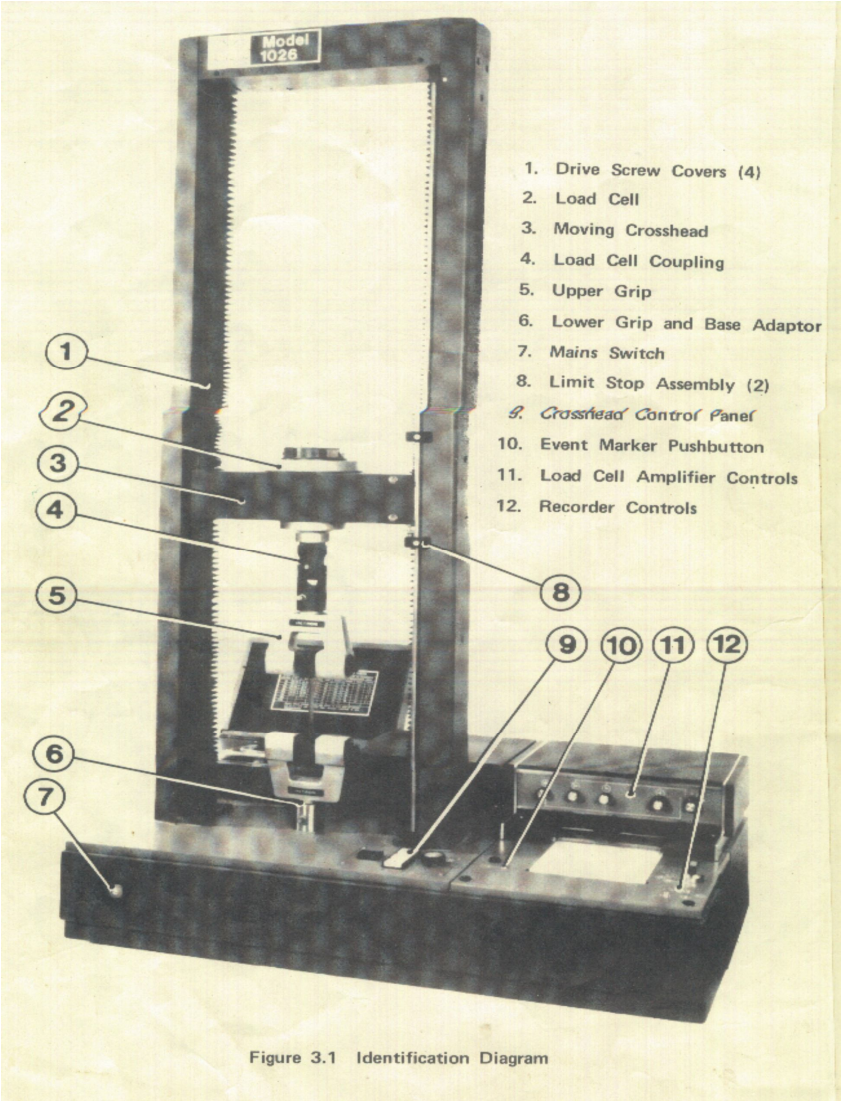


Figure 3.6 :Instron Table Model 1026 (For testing tearing and tensile strength)

Consumables

The macerating liquor consisted of glacial ethanoic acid and hydrogen peroxide.

3 .2 METHODOLOGY.

3.2.1 Preparation of Chip

A stem of silk cotton tree was cut from Raffin Gussan along the bank of River Kaduna. It was debarked and cut into chips of average size of 25mm long. Sugarcane with dark green stems were obtained in a farm at Raffin Gussan village near Kaduna .The stems were washed and crushed into bagasse. The bagasses were cut into chips. A swamp rice straw of china specie were obtained in a farm along the bank of River Kaduna near Raffin Gussan village. The straw was prepared and cut into chips.

3.2.2 Raw plant Kappa Number and Lignin Content

0.50g oven dry weight of raw silk cotton tree, bagasse and rice straw were separately soaked in 30ml of distilled water and grounded to paste in a ceramic mortar. 570ml of distilled water was added to the paste in a 1000ml beaker and stirred. A mixture of 75ml 4N sulphuric acid and 75ml 0.1N $KMnO_4$ was added to the paste, stirred and the temperature was maintained at 25^0C for 10 minutes. After 10 minutes 15ml, 1N KI was added to the mixture and stirred. 25ml of this mixture was titrated against 0.1N $Na_2S_2O_3$ to pale colour, two drops of starch solution was added and the titration continued to colourless. The Kappa number and lignin comtent were evaluated using Hussain (et al 2002) method.

$$\text{P-No} = 7.5 - v \tag{3.1}$$

$$\text{K-No} = \frac{P - No \times f}{w} \tag{3.2}$$

Where

P-No = permanganate number,

K-No = Kappa number,

v = titre value (ml),

f = correction factor and

w = the weight of raw sample mixed with distilled water.

3.2.3 Digestion by Maceration (cold cooking)

The chips of silk cotton tree, bagasse and rice straw were weighed and soaked separately in a mixture of 50:50 glacial ethanoic acid and hydrogen peroxide in the laboratory of Wood and Paper Technology of Federal College of Forestry, Ibadan in the month of November 2006. It took silk cotton tree and bagasse six days to digest and rice straw ten days. Digestion is achieved when the pulp is formed. The average room temperature was 34^0C. During this period of digestion, the mixtures were thoroughly stirred each day. At the end of digestion, the pulps were washed and screened. The pulps were weighed.

Another set of maceration was carried out in the chemistry laboratory of Command Day Secondary School Kaduna in the month of December 2006 using the same procedure. The chips were digested up for 17days. Average laboratory temperature was 21^0C. The chips of silk cotton tree were heated to a temperature of 90^0C for 15minutes, while that of bagasse and rice straw were heated to 110^0C for 35minutes.

To determine the optimum maceration time four samples of equal weights 19.95g dry weight of silk cotton tree chips were soaked in 150ml of maceration liquor of 50:50 glacial ethanoic acid and hydrogen peroxide for 5,10,15 and 20 days. Similarly, four samples of 11.68g of bagasse and 6.77g of rice straw were soaked in 150ml in the mixture of glacial ethanoic acid and hydrogen peroxide for the periods as silk cotton tree.

Silk cotton tree and bagasse could not pulp until 7 days and rice straw 10 days. At the end of 7, 10, 15, 20 and 25 days the pulps were washed, screened and dried.

3.2.4 Pulp Moisture Content Analysis

Sample of each pulp was weighed and kept in an oven for two hours after which it was removed cooled and reweighed. It was put back in the oven for about thirty minutes and reweighed. The process was repeated until a constant weight was obtained. The moisture content was evaluated as thus;

$$M = GW - DW \quad (3.3)$$

$$\%M = \frac{GW-DW}{GW}100 \quad (3.4)$$

Where

M = moisture content,

GW = green weight (fresh weight) (g),

DW = dry weight all in (g).

The calculation is shown in appendix C.

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3.2.5 Fibre Morphology Analysis

Compound microscope was used to determine the fibre length and fibre thickness of the pulp samples. These analyses were carried out in the laboratory of Pharmacognosy, Faculty of Pharmaceutical sciences of the Ahmadu Bello University, Zaria.

The pulp suspension was prepared with distilled water, and the pulp slide of each sample was picked with needle dropper onto the slide (7.5 x 2.5cm). Two drops of glycerol (mounting reagent) were added to the pulp slide and then covered with cover

glass (20 x 30cm). The slide was mounted on the compound microscope under the magnification of 10 objective (total magnification 100). The fibre lengths and fibre thickness were measured with the calibration factor, f of 9.7.

The readings obtained were multiplied by 9.7 in micrometre and converted into millimetre. The fibre length and cell wall thickness were evaluated as thus;

$$H = h \times 9.7 \quad (3.5)$$

$$D = d \times 9.7 \quad (3.6)$$

Where

H = fibre length in mm,

h = reading of fibre length measured from the microscope,

D = fibre thickness in mm and

d = reading of fibre thicknesses from the microscope.

The detailed calculations are shown in appendix E

3.2.6 Pulp Refining (Beating)

The accept pulp of the three species were beaten separately using a mortar and pestle for about twenty minutes. The inner part of the mortar was covered with a nylon sack, the pestle was wrapped with cellophane bag to avoid direct contact with the wall of the mortar and pestle, which may contaminate the pulp. At the end of the pulp beating, each of the refined pulp was treated with plenty of water to reduce the consistency to about 0.1% pulp suspension ready for sheet forming.

3.2.7 Sheet Formation

After thorough mixing, a mould was dipped into the pulp suspension for a few seconds and then raised out of the suspension. The woven mat of pulp formed on the mould was sun dried for about four hours. After drying, the paper formed was carefully removed from the mould and then left on the sun for further drying

3.2.8 Pulp Kappa Number and Lignin Content

1.0g dry weight pulp was soaked in 30ml distilled water in a ceramic mortar and was grounded to paste with pestle. It was transferred into 2000ml beaker and the volume was made up to 1200ml with distilled water and stirred thoroughly. 40ml 4N H_2SO_4 solution was added to it and stirred. After five minutes, 40ml 0.1N $KMnO_4$ solution was added to the mixture and stirred. After another five minutes 5ml, 10% KI solution was added and stirred. The reaction temperature was taken and 25ml of the solution was titrated against 0.1N $Na_2S_2O_3$ solution to pale colour. A drop of starch was added and the titration continued until colourless solution was obtained. The titre value was read and recorded from which the Kappa number and the lignin content were calculated using Nigeria Paper Mill method (N.PM. Lab. Manual, 1991) as thus.

$$\text{P-No} = 40 - v \tag{3.7}$$

$$\theta = Tr - To \tag{3.8}$$

$$T = \theta \times (1.8) \tag{3.9}$$

$$\text{K-No} = P_No - T \tag{3.10}$$

The Kappa number is corrected to 50%

$$\%L = K_No \times 0.147 \tag{3.11}$$

Where

P – No = permanganate number,

v = titre value (ml),

θ = temperature difference (^{0}C),

Tr = reaction temperature (^{0}C),

To = ambient temperature (^{0}C),

T = temperature (^{0}R)

K – No = Kappa number and

L = lignin content.

See appendix (VI) for detail calculations.

3.2.9 Tearing Resistance Test

The samples were prepared by cutting sheets of the sample-produced papers of silk cotton tree, bagasse and rice straw 10cm by 4cm. An initial tear was done up to half of the length. The torn side was held by the upper grip and lower grip of the Instron Table Model 1026. The Load cell amplifier controls were adjusted to 5 and then the control switches were pressed to start the test until the tearing was completed. The force required to tear the samples were read from the graph sheet in grams and converted to milinewtons, according to the TAPPI standard.

$$T = m \times g \qquad (3.12)$$

$$Tf = \frac{100 \times m}{G} \qquad (3.13)$$

Where

T = tear resistance (mN),

m = mass (g) of load that tears the paper sample,

Tf = tear factor (m^2) and

G = basis weight (g/m^2).

3.2.10 Tensile strength test

The samples were prepared by cutting the sheets of the sample papers of silk cotton tree, bagasse and rice straw 15cm by 4cm. A load of 500g was placed on the load cell and the sample paper was held by upper Grip and Lower Grip of Instron Table model 1026, (used in the laboratory of Textile Science and Fashion Design of Kaduna Polytechnic). Load cell amplifier controls were set to 50, the cross load control panel and recorder control were pressed to start the test until the paper cut. The force that is required to cut the paper was read from the graph sheet in grams and tensile strength was calculated.

$$TS = \frac{BW}{w} \qquad (3.14)$$

$$TSi = \frac{TS}{G} \qquad (3.15)$$

Where

TS = tensile strength (N/m),

BW = breaking weight (N) ,

w = with of the sample sheet (m),

TSi = the tensile strength index (Nm/g) and

G = basis weight (g/m^2).

3.2.11 Burst Strength Test

For conditionings, the sample papers were left in the laboratory of the Standard Organisation of Nigeria (SON) for two days before the test. The sample papers were clamped separately in position on the Digital Bursting Strength Tester using the screw clamps over the diaphragm. The motor drive was switched to the forward position, the paper was observed until it bursted, and the motor drive was switched off while the reading was read and recorded. The paper position was changed, the procedure was repeated, and more readings were obtained and recorded.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

The results of this investigation are presented and discussed in this chapter. The parameters investigated were Kappa number and lignin content, chips moisture content for the raw materials and pulp, optimum maceration time and pulp yield, fibre morphology and strength properties of paper samples.

4.1: Kappa Number and Lignin Content

The Kappa number and the lignin content of raw materials are presented in Table 4.1. The Kappa number of silk cotton tree wood was found to be 96.864 and its lignin content was found to be 15. 00%. There is no literature value to compare with but this value is less than that of *Populus tremuloides* 18.10% (Sven, 1965), a hard wood specie. The Kappa number of bagasse and rice straw were found to be 89.600 and 90.205 respectively. The lignin content of bagasse was found to be 13.89% which is less than the range of 18.10 -22.20% (James, 1980). The lignin content of rice straw was found to be 13.98%. This value falls within the range obtained in the literature 12 – 16% (Hurter, 2006).

Table 4.1: Kappa Number and Lignin Content

Sample	**Wood Kappa Number**	**Wood %Lignin**	**%Lignin From Lit.**
Silk cotton tree	96.864	15.00	18.1
Bagasse	89.600	13.67	18.1 – 22.2
Rice straw	90.205	13.98	12 -16

4.2 Fibre morphology

The fibre length and fibre thickness of the three species were measured with compound microscope. The results are shown in Table 4.2. The average fibre length of silk cotton tree was found to be 1.674 mm, which is longer than average fibre length of hardwood 1.25 mm (Hurter. 2006). Its fibre thickness was found to be 0.0170 mm, which is less than the average fibre thickness for hard wood 0.025mm (Hurter, 2006). The average fibre length of bagasse used for this research was found to be 2.071 mm, which is longer than the value obtained in the literature 1.7 mm (Horn et al, 1997). Its average fibre thickness was found to be 0.02425mm, which is slightly greater than literature value 0.018mm (Horn, 1997). These values might be due to high maturity of the cane sugar used, soil condition and the geographical location. The average fibre length of rice straw was found to be 0.8148mm which is shorter than literature value 1.5mm (Horn, 1990) and its thickness was found to be 0.097mm which is greater than literature value 0.09mm (Sven, 1965), this may depends on the specie of rice. Their values determine the strength of paper sheets produced from the source. The bursting and tensile strengths of paper are highly dependent upon fibre-to-fibre bonding which increases with increase in ratio of fibre length–to-cell wall thickness, L/T. L/T of silk cotton tree was 98:1 which is higher than the average value for hardwood 50:1 (Horn et al,1997). The L/T of bagasse was 85.4:1 which is slightly equal to of the literature value of 85.1 and that of rice straw 84.4 is lower than the literature value of 175.1 (Horn et al, 1990).

Table 4.2: Fibre Morphology

Sample	Fibre Length (mm)			Fibre Thickness (mm)			L/T	L/T
	First	second	Average	First	Second	Average		Lit.
Silk cotton tree	1.698	1.649	1.674	0.0146	0.0194	0.0170	98.50	94.40*
Bagasse	2.134	2.008	2.071	0.0243	0.0243	0.0243	85.40	85.10
Rice straw	0.8245	0.8051	0.8148	0.0097	0.0097	0.0097	84.00	175.10

*Range of values for Hardwood (Horn et al, 1997)

4.3: Chip Moisture Content

The results of the chips moisture content are presented in Table 4.1.The moisture content of the silk cotton tree was found to be on the average11.63%, bagasse 14.14% and rice straw 10.08% as shown in Table 4.1.

Table 4.3: Chips Moisture Content Prepared for Digestion

Sample	GW (g)	DW (g)	M (ml)	Average %moisture
Silk cotton tree	53.3O	47.10	6.20	11.63
Bagasse	9.90	8.50	1.40	14.14
Rice straw	11.90	10.70	1.20	10.08

Key; GW = green weight, DW = dry weight, M = moisture content

4.4: Digestion Analysis

The maceration analyses for the chips are presented in Table 4.4. From the 265.11g, dry weight of silk cotton tree was soaked in 1400ml of macerated liquor. This yielded a bath ratio, BR (ratio of volume of liquor in ml to mass of chip in grams) of 5.3:1. 150.86g of bagasse was soaked in 1700ml of liquor with BR 11.3:1 and 63.22g of rice straw was soaked in 1000ml of liquor with BR 18.8:1.

Table 4.4: Digestion Analysis

Sample	DW (g)	M (ml)	%M	Liquor vol.(ml)	BR
Silk cotton tree	265.11	34.85	11.65	1400	5.3:1
Bagasse	150.86	24.84	14.14	1700	11.3:1
Rice straw	63.22	6.08	10.08	1000	18.8:1

4.5: Digestion Analysis for Optimum Maceration Time

The parameters used for macerating the materials at different maceration periods are presented in Table 4.5. The moisture content of the chips of silk cotton tree, bagasse and rice straw were determined and the results are tabulated in Table 4.5.

Table 4.5: Chips Moisture Content for Optimum Maceration Periods

Sample	GW(g)	DW (g)	M (g)	%M	BR (ml:g)
Silk cotton tree	20.00	19.95	0.05	5.25	7.5
Bagasse	13.70	11.85	1.85	13.51	12.7
Rice straw	7.90	6.77	1.13	14.29	22.2

4.6: Pulp Moisture Content

The moisture content of the produced pulp was determined and the results are shown in Table 4.6.

Table 4.6: Pulp Moisture Content

Sample	GW (g)	DW (g)	M (ml)	%M
Silk cotton tree	6.20	1.10	5.10	82.26
Bagasse	3.80	0.70	3.10	81.38
Rice straw	6.30	1.30	5.00	79.37

4.7 Pulp Yield

Table 4.7 shows the results the two macerations earlier carried out. The yields of silk cotton tree were found to be 37.40% and 29.00%, bagasses were found to be 36.1% and 28.60% and rice straws were found to be 42.40% and 23.24%. The low yield could be as the result of incomplete maceration in the first maceration at Ibadan and degradation of pulp by maceration chemicals due to long time of maceration followed by heating at Kaduna.

Table 4.7: Pulp Yield

Sample	GW (g)	DW (g)	%Yield I	% Yield II
Silk cotton tree	558.4	99.06	37.4	29.90
Bagasse	194.2	35.77	36.1	28.60
Rice straw	109.4	22.57	42.4	23.24

4.8 Optimum Maceration Time for Pulp yield

The results in Table 4.7 prompted further work to determine the optimum maceration time for pulp yield. Table 4.7 contains the results of four samples each of the three fibre sources macerated for 7, 10, 15 and 20 days. After 7 days the average pulp yield of silk cotton tree and Bagasse were found to be 43.92% and 45.57% respectively. Their Kappa numbers were found to be 13.65, 12.83, and their lignin contents were found to be 2.01% and 1.89% respectively. The rice straw showed no indication of being pulped up to 10 days. This is due to its chemical composition.

From these results 7 to 10 days lies the optimum period for complete maceration of silk cotton tree and bagasse. Beyond 10 days, there is loss of yield without significant

decrease in Kappa number. For rice, straw 10 to 15 days could be regarded as the optimum maceration period for similar reasons.

Table 4.8: Optimum Maceration Time for Pulp yield

Time	Pulp yield %			Kappa Number			% Lignin		
	CP	**B**	**R/S**	**CP**	**B**	**R/S**	**CP**	**B**	**R/S**
7 DAYS	43.91	45.57	-	13.65	12.83	-	2.01	1.89	-
10 DAYS	41.77	28.10	46.97	13.55	12.75	13.70	1.99	1.87	2.01
15 DAYS	37.37	25.82	27.08	13.55	12.65	12.58	1.99	1.86	1.85
20 DAYS	36.10	25.53	26.48	13.50	12.60	12.35	1.98	1.85	1.82
25 DAYS	-	-	25.26	-	-	12.25	-	-	1.80

CP = *ceiba pentadra* (silk cotton tree), B = bagasse and RS = rice straw

4.9 Mechanical strengths of the sample sheets

The results of the strength properties of the sample sheets are presented in Table 4.9. The average tear force for silk cotton tree, bagasse *and* rice straw were found to be 956.48mN, 1226.25mN and 759.25mN respectively. They all have tear force greater than TAPPI T414, which ranges 500 -700mN as shown in Figure 4.1 for all grades of papers except test liner, which is 1800 mN (Internet, 2007g). The tear factor of ilk cotton tree, bagasse and rice straw were found to be 162.50m^2, 125.00m^2 and 147.98m^2 respectively.

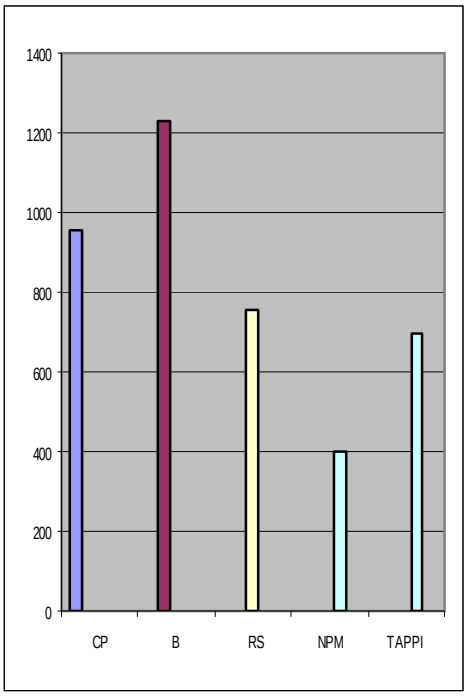
Table 4.9: **Mechanical Strength of the Sample Sheets**

Properties	Silk cotton tree	Bagasse	Rice straw	NPM Jebba	TAPPI
Basis weight (g/m^2)	60.00	100.00	52.30	80-100	50-100

Tear (mN)	956.48	1226.25	759.25	N/A	500-700
Tear factor (m^2)	162.50	125.00	147.98	120	30 MD,40 CD
Breaking weight(N)	22.07	26.00	6.57	5.6 – 7.5	30
Tensile strength index (Nm/g)	9.20	6.50	3.14	N/A	40-70 (MD) 20-40 (CD)
Burst strength (kPa)	42.50	57.50	7.00	N/A	250 – 300

Key: NPM = Nigeria Paper Mill. TAPPI = Technical Association of Pulp and Paper

The values of tear factor shown in Figure 4.2 are all greater than the standard required by Nigerian Paper Mill, Jebba which has a minimum tear factor of 120m^2 for all grades of paper products of the mill (NPM Lab. Manual, 1991). Hence, their products can be good for writing and printing applications.



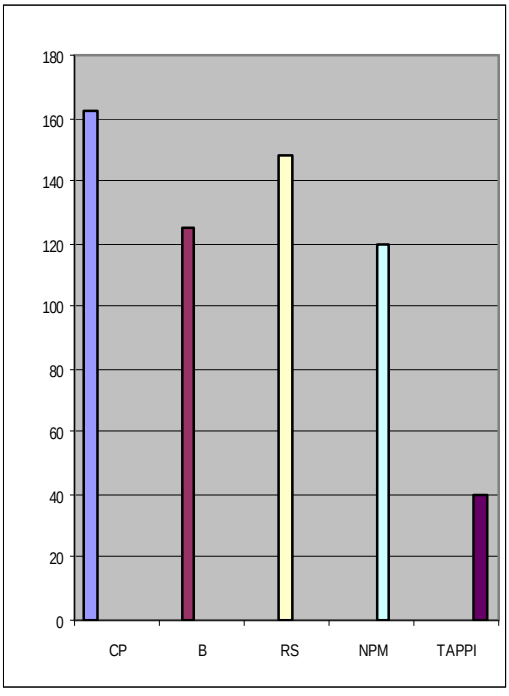
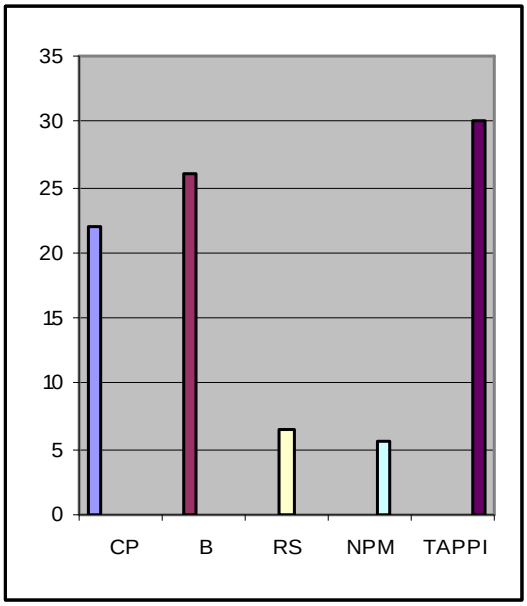


Figure 4.1: Average Tear Force (mN/g) Figure 4.2: Average Tear Factor (m^2)

The breaking weight of silk cotton tree, bagasse and rice straw are all higher than the range of Nigerian Paper Mill Jebba, 5.6 – 7.5N (NPM Lab. Manual, 1991) as shown in figure 4.3. However, their tensile strengths are too low. The tensile strength indices of silk cotton tree, bagasse and rice straw were found to be lower than TAPPI T494, as shown in figure 4.4 which is 40 – 70Nm/g for machine direction, (MD) and 20 – 40Nm/g for cross direction, (CD) respectively (Internet, 2007g).



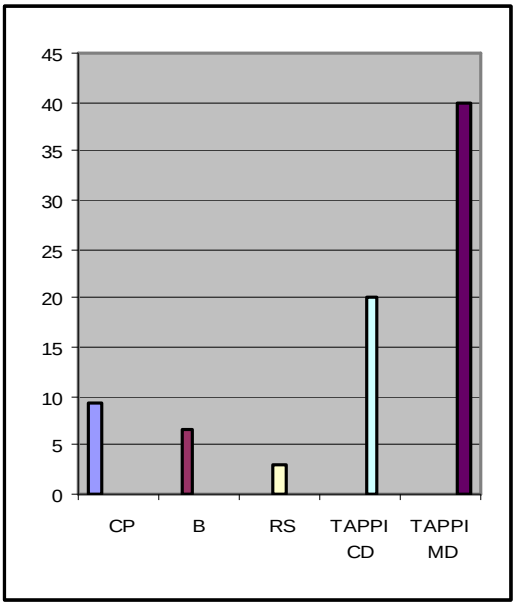


Figure 4.3 Breaking Weight of Sample Papers (N) Figure 4.4 Tensile Strength Index (Nm/g)

The average burst strength of silk cotton tree and bagasse were found to be lower than TAPPI T403, ranges from 250 - 300kPa (Internet, 2007g). The burst strength of rice straw was found to be lower than TAPPI T403, which ranges 250 – 300kPa as shown in

figure 4.5. This indicates that these paper products may not be suitable for wrapping and packaging applications.

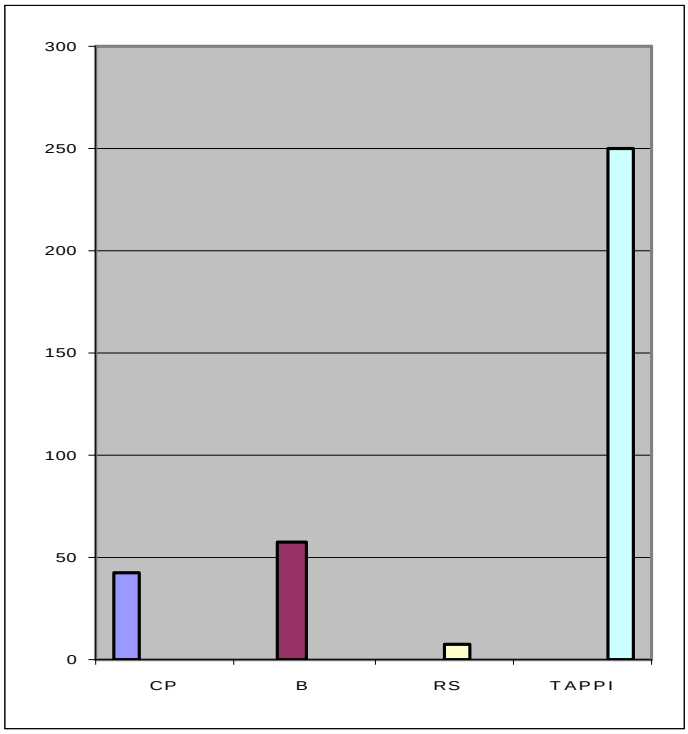


Figure 4.5 Average Burst Strength of the Sample Papers (kPa)

The sample sheets of silk cotton tree, bagasse and rice straw are presented in figure 4.6. The silk cotton tree and bagasse papers were found to be smooter than that of rice straw. This may be due to the nature of their pulps. The fibres of rice straw pulp were coarser than that of silk cotton tree and bagasse pulps; hence, its fibres may not be as closely bonded as in silk cotton tree and bagasse.



Silk cotton tree Bagasse Rice straw

Figure 4.6: Samples of paper produced

The tensile strength index of bagasse paper was 6.5Nm/g, which is lower than the literature value of 85- 103.3Nm/g (James, 1980) for Kraft paper. The burst strength of bagasse and rice straw were 57.50 kP and 7.00kPa respectively which are lower than the

literature values of 387kPa for bagasse and 407kPa for rice straw (James, 1980) from Kraft method. Maceration pulping process was used in this investigation, which usually does not produce strong paper as Kraft process. Kraft pulps produce high physical strength papers for high strength requirements such as linerboard, wrapping papers and bags (James 1980). There are no literature values with which to compare those obtained for silk cotton tree.

However, the tear resistance of bagasse and rice of this research were 1226.25mN and 759.25mN respectively, which are higher than the literature values of 393mN and 405mN respectively pulped by Kraft method (James, 1980). This indicates that tear resistance may not be affected by maceration method.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The major findings of this investigation are summarized below.

i The average fibre length of silk cotton tree, bagasse and rice were 1.674mm, 2.071mm and 0.8148mm respectively. Their average fibre thickness were 0.017mm, 0.02425mm and 0.0097mm respectively..

ii The Kappa number of silk cotton tree, bagasse and rice straw were 96.86,89.60 and 90.21 respectively and their corresponding lignin content were 15.00%, 13.89% and 13.98%.

iii . The maceration period of silk cotton tree, and bagasse were 7 to 10days, and rice straw was 10 to 15 days with the corresponding pulp yield of 43.91 – 41.77%, 45.57 – 28.10% and 46.97 – 27.08%respectively

iv The average tear resistance of papers produced from silk cotton tree, bagasse and rice straw were 956.48mN, 1226.25mN and 759.25mN respectively. The average tear factors were 162.50m^2, 125.00m^2 and 147.98m^2 respectively.

v The average breaking weight of papers produced from silk cotton tree, bagasse and rice straw were 22.70N, 26.00N and 6.57N respectively.

vi. The average tensile strengths silk cotton tree, bagasse and rice straw were 551.81N/m, 644.91N/m and 164.32N/m respectively.

Vii The average tensile strength indices of silk cotton tree, bagasse and rice straw were 9.20Nm/g, 6.50Nm/g and 3.14Nm/g respectively.

viii The average burst strengths of papers produced from silk cotton tree, bagasse and rice straw were 42.50kPa, 57.50kPa and 7.00kPa respectively.

Based on these, the following conclusion and recommendations are drawn.

5.1 CONCLUSION

Three Nigerian fibre sources were evaluated for production of pulp and paper. These were *Ceiba pentadra*, bagasse and China brand of swamp rice straw. Sample papers were produced and tested for mechanical properties. They all exhibited standard qualities for tearing resistance above TAPPI T414, for all grades of papers except test liner, hence their paper products can be used for writing and printing applications. They also exhibited standard qualities for tear factor and breaking weight above Nigeria Paper Mill Jebba for all grades of paper so the bagasse papers can be used for corrugating medium and insulating board.

The values of the tensile and bursting strength of the paper samples of silk cotton tree, bagasse and rice straw fell below TAPPI T494 and T403 for tensile and bursting strength respectively, thus indicating that, they are not suitable for packaging and wrapping papers.

5.2 RECOMMENDATIONS

It is recommended that further work on the three fibre sources be carried out in the following areas.

1. Kraft method should be employed to pulp these three materials for pulp and paper production.
2. Nigerian paper mills should replace the foreign long fibre pulp with these three for the production of printing and writing.
3. Silk cotton tree plantations should be established to produce it in large quantity to meet the local demand for the production of papers.
4. For packaging and wrapping paper, other local plant species should be investigated.

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APPENDICES

APPENDIX A:

CHIP MOISTURE CONTENT ANALYSIS

Ceiba pentadra

GW =53.30g, DW =47.10g,

M = GW – DW $\Rightarrow$ 53.3 – 47.10

= 5.20g

% M = $\frac{moisture \times 100}{BD} = \frac{5.2}{53.3} \times 100 = 11.63\%$

Bagasse

GW = 9.90g, DW = 8.50g

M = GW – DW $\Rightarrow$ = 9.90 – 8.5g = 1.4g (ml)

% M = $\frac{1.4}{9.9} = \times 100 = 14.14\%$

Rice straw

GW = 11.90g, DW = 10.70g

M = 11.90g -10.70g = 1.20g (ml)

% M = $\frac{1.20}{11.90} = \times 100 = 10.08\%$

Chips Moisture Content for Optimum Maceration Time

Ceiba pentadra

GW =0 .95g, DW = 0.90g

M = GW – DW = 0.95 – 0.90

= 0.05g

$$\%M = \frac{M}{GW} \times 100$$

$$= \frac{0.05}{0.96} \times 100 = 0.25\%$$

Bagasse

GW = 3.70g, DW = 3.20g

M = 3.70 – 3.20 =0.50g

$$\%M = \frac{0.5}{3.7} \times 100 = 13.51\%$$

Rice straw

GW = 1.75g DW =1.50g

M = $7.90 - 6.87 = 1.13\,g$

$$\%M = \frac{1.13}{7.90} \times 100 = 14.29\,\%$$

Appendix B

Digestion Analysis

Ceiba pentadra

GW = 300g, % moisture = 11.63%

$$M = \frac{BD \times \%moisture}{100}$$

= 300 x 0.1163 = 34.89g (ml)

DW = GW – M

= 300 – 34.89 = 265.11g

Bagasse

GW =175.70g, %moisture = 14.14%

M = 175.70×0.1414 = 24.84g (ml)

DW = $175.70 - 24.89 = 150.86g$

Rice straw

GW = 60 3g, % moisture = 10.08%

M = 60.3 x 0.1008 = 6.08g

DW = 60.3-6.08 =53.22g

Appendix C

Pulp Moisture Content Analysis

Ceiba pentadra

GW = 6.20g, DW =1.10g

Mt =GW - DW = 6.2 – 1.10 = 5.10g

$$\% M \quad \frac{moistent}{BD} = \times 100$$

$$= \frac{5.1}{6.2} \times 100 = 82.26\%$$

Bagasse

GW = 3.8g, DW = 0.7g

M = 3.30 – 0.7 = 3.10g

$$\% M = \frac{3.10}{3.80} \times 100 = 81.38\%$$

Rice straw

GW = 6.30g, DW = 1.3g

M = 6.30 – 1.30 = 5.00g

$$\% M = \frac{5.00}{6.00} \times 100 = 79.37\%$$

Pulp Moisture Content Analysis for Optimum Maceration Time

(*Ceiba pentadra*)

GW = 2.55g, DW = 0.65g

M = 2.55 – 0.65 = 1.90g

$$\%M = \frac{1.90}{2.55} \times 100 = 74.51\%$$

Bagasse

GW = 1.40g, DW =0 .35g

M = 1.40 – 0.35 = 1.05g

$$\%M = \frac{1.05}{1.40} \times 100 = 75.00\%$$

Rice srtaw

GW = 0.70g, DW = 0.40g

M = 0.70 – 0.40 = 0.30g

$$\%M = \frac{0.30}{0.70} \times 100 = 42.86\%$$

Appendix D

Pulp yield sample I

Ceiba pentadra

GW = 558.4g , %moisture = 82.26%

M = $GW \times$ %moisture

= $558.4 \times 0.8226 = 457.34$g (ml)

DW = DW – moisture content

= 558.4 - 457.34 = 99.06g

Yield = $\frac{DWpulp}{DWchips} \times 100$

= $\frac{99.06}{265.11} \times 100 = 37.4\%$

Bagasse

GW = 194.2g , % moisture = 81.34%

M = $194.2 \times 0.7149 = 139.81$

DW pulp = GW pulp - moisture

=194.2 – 139.81 = 54.36

Yield = $\frac{54.36}{150.86} \times 100 = 36.10\%$

Rice straw

GW pulp = 109.4g, %moisture = 79.37%

$M = 109.4 \times 0.7937 = 86.83g$

DW pulp $= 109. - 86.83 = 22.57g$

Sample II

Ceiba pentadra

DW Pulp = 46.73g

DW Chips = 162.24

$$\text{Yield} = \frac{46.73}{162.34} \times 100 = 29.90\%$$

Bagasse

DW pulp = 50.13g

DW Chips = 175.25g

$$\text{Yield} = \frac{50.13}{175.25} \times 100 = 28.60\%$$

Rice straw

OD Pulp = 14.15g

OD Chips = 67.7g

$$\text{Yield} = \frac{14.15}{67.70} \times 100 = 23.24\%$$

Appendix E

Fibre Morphology

Ceiba pentadra

Readings obtained for fibre length;

h1 =175 µm, h2 = 170µm,

Calibrate factor, F =9.7

H = h × F

h1 =175 × 9.7 =1697.5µm, h2 = 170 × 9.7 = 1649µm

$$H = \frac{L1 + L2}{2}$$

$$= \frac{1697.5 + 1649}{2} \times 9.7 = 1.674mm$$

Fibre thickness;

d1 =1.5µm, d2 = 2.0µm

$$\text{Average value} = \frac{1.5 + 2.0}{2} = 1.75\,\mu m.$$

D =1.75 × 9.7 = 0.0170mm

Bagasse

Readings obtained for fibre length;

H1 = 2007.9µm, h2 = 2134µm

$$H = \frac{2007.9 + 2134}{2} \times 9.7 = 2.071mm$$

Fibre thickness;

d1 =2.5µm, d2 = 2.5µm.

D= 2.5 × 9.7 = 0.02425mm.

Rice straw

Readings obtained for fibre length; h1 = 0.85µm, h2 = 0.83µm,

$$H = \frac{0.85 + 0.83}{2} \times 9.7 = 0.8148\,\text{mm}$$

Fibre thickness;

d1 = 1.0µm d2 = 1.0µm

D = 1.0 × 9.7 = 0.0097mm.

Appendix F

Kappa Number and Lignin Content

Raw Ceiba petandra

v = 27ml.

P-No = 75.00 - v

75 – 27 = 48

Applying Hussain (et al) method correct to 50%,

K-No = $\frac{P_No \times 1.009}{m}$ (m = mass of chips used in grams, 1.009 = 50% correction factor)

= $\frac{48 \times 1.009}{0.5} = 96.86$

%L = K-No * 0.155 = 96.86 * 0.155 = 15%

Raw Bagasse

v = 30.6ml, P-No = 75 -30.6 = 44.4

K-No = $\frac{44.4 \times 1.009}{0.5} = 89.6$

%L = 89.6×0.155 = 13.895

Raw rice straw

v = 30.3ml,

P N = 75 – 30.3 = 44.7

K N = $\frac{44.7 \times 1.009}{0.5}$ = 90.205

%L = 90.205×0.155 = 13.98%

Pulp Kappa Number and Lignin Content

Seven Days Maceration

Silk Cotton Tree (*Ceiba pentadra*)

v = 9.10ml, To = 30^0C, Tr = 28^0C

Θ = To –Tr, θ = 30 – 28 = 2 T = $\theta \times 1.8 = 2 \times 1.8 = 3.6$

P-No = 40 – 9.10 = 30.90

K-No = 30.90 – 3.6 = 27.30 Correct 50% = 13.65

% L = K-No × 0.147 =13.65 × 0.147 = 2.01

Bagasse

v = 8.95ml, P=No = 40.0 – 8.95 = 31.05

To = 31^0C Tr = 28^0C, θ = 31 – 28 = 3 T = 3 × 1.8 = 5.4

K-No = 31.05 – 5.4 = 25.65, Correct to 50% = 12.825

%L = 12.825 × 0.147 = 1.89

Ten Days Maceration

Silk Contton Tree (*Ceiba pentadra*)

v = 9.30ml, To = 29^0C Tr = 27^0C Θ = 29 – 27 = 2, T = 2 × 1.8 = 3.6

P-No = 40 – 9.30 = 30.7

K-No = 30.7 – 3.6 = 27.1 Correct to 50% = 13.55

% L = 13.55 × 0.147 =1.99

Bagasse

v = 9.10ml, To = 31^0C Tr = 28^0C Θ = 31 – 28 = 3, T = 3 × 1.8 = 5.4

P-No = 40 – 9.10 = 30.9

K-No = 30.9 – 5.40 = 25.50 Correct to 50% = 12.75

%L = 12.75 × 0.147 = 1.87

Rice straw

v = 9.00ml, To = 31^0C, Tr = 29^0C Θ = 31 – 29 = 2, T = 2 × 1.8 = 3.6

P-No = 40 – 9.00 = 31.00

K-No = 31.0 – 3.6 = 27.4, Correct to 50% = 13.7

%L = 13.7 × 0.147 = 2.01

Fifteen Days Maceration

Silk Cotton Tree (*Ceiba pentadra*)

v = 9.30ml, To = 30^0C, Tr = 28^0C θ = 2, T = 2 * 1.8 = 3.6

P-No = 40.0 – 9.3 = 30.70

K-No = 30.7 – 3.6 = 27.10, Correct to 50% = 13.55

%L = 13.55 * 0.147 = 1.99

Bagasse

v = 9.30ml, To = 31^0C, Tr = 28^0C θ = 3, T = 3 × 1.8 = 5.4

P-No = 40.0 – 9.3 = 30.7

K-No = 30.7 – 5.4 = 25.3, Correct to 50% = 12.65

%L = 12.65 × 0.147 = 1.86

Rice straw

v = 9.45ml, To = 31^0C, Tr = 28^0C θ = 3, T = 3 × 1.8 = 5.4

P-No = 40.0 – 9.45 = 30.55

K-No = 30.55 – 5.4 = 25.15, Correct to 50% = 12.575

%L = 12.575 × 0.147 = 1.85

Twenty Days Maceration

Silk Cotton Tree (*Ceiba pentadra*)

v = 9.50ml, To = 29^0C, Tr = 27^0C θ = 2, T = 2 × 1.8

P-No = 40.00 – 9.5 = 30.5

K-No = 30.5 – 3.6 = 26.9, Correct to 50% = 13.45

%L = 13.45 × 0.147 = 1.98

Bagasse

v = 9.40ml, To = 31^0C, Tr = 28^0C θ = 3, T = 3 × 1.8 =5.4

P-No = 40.0 – 9.4 = 30.6

K-No = 30.6 – 5.4 = 25.2, Correct to 50% = 12.60

%L = 12.60 × 0.147 = 1.85

Rice straw

v = 9.90ml, To = 30^0C, Tr = 27^0C Θ = 3, T = 3 × 1.8 = 5.4

P-No = 40.0 – 9.9 = 30.1

K-No = 30.1 – 5.4 = 24.7, Correct to 50% = 12.35

%L = 12.35 × 0.147 = 1.82

Twenty-Five Days Maceration

Rice straw

V = 9.20ml, To = 32^0C, Tr = 28.5^0C Θ = 3.5, T = 3.5 * 1.8 = 6.3

P-No = 40.00 – 9.20 = 30.8

K-No = 30.8 – 6.3 = 24.50, Correct to 50% = 12.25

%L = 12.25 × 0.147 = 1.80

Appendix G: Physical Properties of the Sample Sheets

G I: Tear Force, T

Ceiba pentadra

$T = m \times g$ (3.12) $97.5 \times 9.81 = 958.48mN$

Bagasse $125 \times 9.81 = 1226.25mN$

Rice straw $77.4 \times 9.81 = 759.25mN$

G II: Tear Factor, Tf

Ceiba pentadra

$Tf = \frac{100 \times m}{G}$ (3.13) $\frac{100 \times 97.5}{60} = 162.5m^2$

Bagasse $\frac{100 \times 125}{100} = 125.00m^2$

Rice straw $\frac{100 \times 77.4}{52.3} = 147.99m^2$

GIII : Breaking Wight

Ceiba pentadra

$BW = m \times g$ $2.25kg \times 9.81 = 22.07N$

Bagasse $2.65 \times 9.81 = 25.99N$

Rice straw $0.67 \times 9.81 = 6.57N$

G IV : Tensile Strength

Ceiba pentadra

TS = $\frac{BW}{w}$ **(3.14)** $\frac{22.0725}{0.04} = 551.81N$

Bagasse $\frac{25.99}{0.04} = 644.91N$

Rice straw $\frac{6.5}{0.04}$ = 164.52N

G V: Tensile Strength Index

Ceiba pentadra

TSi = $\frac{TS}{G}$ **(3.15)** $\frac{551.8125}{60}$ = 9.20Nm/g

Bagasse $\frac{644.9125}{100}$ = 6.45Nm/g

Rice straw $\frac{164.517}{52.3}$ = 3.14Nm/g

Appendix H

Table of TAPPI Standard Paper Physical Properties

Grades of paper	Basis weight (g/m^2)	Tear resistance (mN) T414	Tensile strength index(Nm/g)	Burst strength (kPa) T403
Newsprint	40-50	_	MD CD 45-60 _	_
Bond/Office paper	100	500-700	_ _	250-300
Stationary	50-100	_	40 70	_
Coated paper	130	_	_ _	200-300
Coating paper	80	500-700	_ _	_
Tracing paper	60-110	_	70 40	_
Carbonless paper	50-60	_	_ _	150-200
Bleached Kraft	60	_	_ _	210-260
Test liner	186	1800	175 80	250-476