ALKALINE PEROXIDE MECHANICAL PULPING OF OIL PALM FRONDS VASCULAR BUNDLE FIBRES

by

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TAIWO

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABS	Alcohol Benzene Solubility
A.D.	Anno Domini (Before Christ)
ANOVA	Analysis of Variance
AP	Alkaline Peroxide
API	Alkaline Peroxide Impregnation
APMP	Alkaline Peroxide Mechanical Pulping
APP	Alkaline Peroxide Pulping
BBD	Box-Behnken Design
CCD	Central Composite Design
CGF	Cogenerated Fines Fibres
CMP	Chemimechanical Pulping
CMR	Chemical-Mechanical Refining
COD	Chemical Oxygen Demand
CSF	Canadian Standard Freeness Expressed in Terms of Millilitres
CWT	Cell Wall Thickness
DF	Degree Of Freedom
DPTA	Diethylenetriaminepenta Acetic Acid
EC	European Commission
EDTA	Ethylene Diamine Tetra Acetic Acid
EFB	Empty Fruit Bunches
FAO Stat	Food and Agricultural Organization Statistics
FL	Fibre Length
FT-IR	Fourier Transform Infrared
H_2O_2	Hydrogen peroxide
HWS	Hot Water Solubility
ISO	International Standards Organization
KBr	Potassium bromide
LD	Lumen diameter
L/D	Lumen Width/Fibre Diameter
LSC	Light Scattering Coefficient

MOA	Ministry of Agricultural
MPPMA	Malaysian Pulp and Paper Manufacture Association
Mt	Metric Ton
NaOH	Sodium hydroxide
OPF	Oil Palm Frond
OPF VB	Oil palm fronds vascular bundles
OPFB	Oil Palm Fruit Bunches
OPT	Oil Palm Trunk
PSI	Pounds Per Square Inch
PTI	Paper Testing Instrument
PRC-APMP	Pre conditioning with refinesr chemical in Alkaline Peroxide Mechanical Pulping
R&D	Research and Development
RR	Runkel Ratio
RSM	Response Surface Methodology
SEM	Scanning Electron Microscopy
SPSS	Statistical Package For Social Sciences
SS	1% Sodium hydroxide Solubility
TAPPI	Technical Association of the Pulp And Paper Industry
TCF	Totally Chlorine Free
TEA	Tensile Energy Absorption
USA	United States of America
VB	Vascular bundles
WRV	Water Retention Value
wt/wt	Weight by Weight

LIST OF SYMBOLS

^oC	Degree Celsius
Nm	Nanometer
Mm	Millimeter
µm	Micrometer
ml.	Millilitre
mN	Millinewton
mN/m^2	Millinewton per square metre
g/m^2	Gramme per square meter
L	Litre
Nm/g	Newton meter per gramme
$kPam^2/g$	Kilopascal square meter per gramme

PEMULPAAN MEKANIK PEROKSIDA BERALKALI BAGI BERKAS VASKULAR PELEPAH KELAPA SAWIT

ABSTRAK

Penyelidikan ini mengkaji kualiti bagi pulpa dan kertas yang diperoleh daripada rawatan peroksida beralkali (APMP) berkas vaskular pelepah kelapa sawit (OPF) dari spesis *Elaeis guineensis*. Matlamat utama kajian ini adalah untuk mengkaji potensi OPF VB sebagai sumber gentian bagi penghasilan pulpa melalui teknik APMP, yang dijana melalui proses pemulpaan mekanik peroksida beralkali (APMP). Kesan penskrinan bagi berkas vaskular OPF dirawat AP dilakukan pada kepekatan AP yang berbeza. Kepekatan-kepekatan ini termasuk kepekatan AP rendah (1.0%: 1.5%; NaOH: H_2O_2), sederhana (2.0%: 2.5%; NaOH: H_2O_2) and tinggi (4.0%: 5.0%; NaOH: H_2O_2). Kesan-kesan bagi pembolehubah heterogen pemulpaan peroksida beralkali (APMP) (masa pememasakan, kepekatan natrium hidroksida dan kepekatan hidrogen peroksida) terhadap sifat-sifat pulpa dan kertas (hasil penskrinan, nombor Kappa, indeks tegangan, indeks koyakan, indeks kepecahan, kecerahan ISO dan kelegapan), telah dikaji untuk menentukan keadaan operasi yang optimum. Kaedah permukaan sambutan (RSM) menggunakan rekabentuk Box-Behnken menunjukkan gentian-gentian berkas vaskular OPF adalah sebandigan degan gentian kayu lembut dan kayu keras yang digunakan sebagai pulpa komersil dalam pembuatan kertas. Keputusan setara menunjukkan bahawa biojisim OPF VB yang melalui proses APMP menghasilkan pulpa terskrin dalam anggaran 45% - 63%. Analisis statistik menunjukkan aras bererti bagi kesan kepekatan AP terhadap semua sifat-sifat pulpa dan kertas yang dikaji pada aras keyakinan 95%, degan sokongan imej melalui mikroskopi imbasan elektron (SEM). Model-model regresi yang dibentuk menunjukkan keadaan operasi optimum telah dicapai melalui 2.35% NaOH, 5.00% H_2O_2 dan tindakbalas antara OPF VB-AP pada 53.41 minit masa masakan. Keputusan ini adalah hasil pulpa maksimum yang diskrin (53.39%), dengan keputusan maksimum bagi sifat-sifat kertas (cth., indeks kepecahan, indeks koyakan, indeks tegangan, kecerahan ISO dan kelegapan) iaitu 6.55 $kPam^2/g$, 6.22 mNm^2/g, 9.92 Nm/g, 28.50% and 99.71%, masing-masing beserta 80.27 nombor Kappa. Berkas vaskular OPF telah menunjukkan potensinya sebagai gentian alternatif dan sumber bahan mentah bagi penjanaan pulpa dan kertas melalui pemulpaan mekanik peroksida beralkali yang mesra alam lagi ekonomik.

ALKALINE PEROXIDE MECHANICAL PULPING OF OIL PALM FRONDS VASCULAR BUNDLE FIBRES

ABSTRACT

This study investigates the quality of pulp and paper obtained from alkaline peroxide (AP) treatment of oil palm (*Elaeis guineensis*) fronds (OPF) vascular bundle or OPF VB. The principal aim of this study is to assess the potential of OPF VB as raw material and fibre source for pulp production via Alkaline Peroxide Mechanical Pulping (APMP). Screening effect of AP treated OPF VB fibres was carried out at different AP concentrations. These concentrations include AP prepared at low (1.0%: 1.5%; NaOH: H_2O_2), medium (2.0%: 2.5%; NaOH: H_2O_2) and high (4.0%: 5.0%; NaOH : H_2O_2) concentrations. The effects of heterogeneous APMP variables (i.e., cooking time, sodium hydroxide concentrations and hydrogen peroxide concentrations) on the pulp and paper properties (screened pulp yield, Kappa number, tensile index, tear index, burst index, ISO brightness and opacity), were studied to determine the optimum operating conditions. Response Surface Methodology (RSM) using Box-Behnken design was used to explore the effect of selected variables on the different responses. Results indicated that the vascular bundle fibres compare favourably with the softwood and hardwood fibres used as commercial pulp for paper making. The results equally revealed that the biomass was pulpable with AP liquor and subsequent refining, resulting in screened pulp yield ranging from 45% to 63%. Statistical analysis shows significant effect of AP concentrations on all of the pulp and paper properties at 95% confidence level, in line with the morphological changes acquired from Scanning Electron Microscopy (SEM). Regression models show that the optimal operating conditions of the AP were found to be 2.35 % NaOH, 5.00 % H_2O_2 and a 53.41 minutes cooking time. This results in maximum screened pulp yield 53.39% paper strenght value i.e., burst index, tear index, tensile index, ISO brightness and opacity were 6.55 $kPam^2/g$, 6.22 mNm^2/g, 9.92 Nm/g, 28.50 % and 99.71%, respectively with 80.27 Kappa number. The OPF VB fibres were shown to be a potential alternative fibrous raw material for pulp and paper application and this was made possible via the environmentally compatible and economic APMP process.

CHAPTER 1

INTRODUCTION

1.1 General Background

Pulp and paper demand and consumption are a function of the level of development and civilization of the humanity. This implies that the more developed a nation is, the more the rate of pulp and paper consumption. The demand for pulp and paper fibre resources is largely determined by the society's dependence on paper, paper boards and other related products for human welfare. The Directorate General of Manufacture Based Industry (DGMB), Ministry of Industry Indonesia reported that global demand for paper has grown by 2.1% annually (Adi et al., 2016). Pätäri et al., (2016) reported that an increase in the global population would lead to the enhancement of paper needs. According to the report, the global population and economic growth predominantly focusing on developing and emerging countries is expected to increase by 1.3 billion inhabitants by 2030. Hence, industries such as pulp and paper is expected to brace up to the sustainability of the sector. Presently, despite an increasing transition to digital media usage, the global pulp and paper industry still enjoys the benefit from an increased pulp based product consumption (Ajani, 2011; Lovins & Cohen, 2011). The Paper consumption kg/capita as of 2014 was: North America (221); EU (56); Japan (215); China (75); Korea, Taiwan, Hong Kong, Singapore & Malaysia (159); Latin America (47) and Africa (8). On average, each person consumed 57 kg of paper in 2014 (RISI, 2016). This level of per capita consumption is due to some factors, which include; the economic growth; increasing literacy rate; changing demographics with higher urbanization (Huang 2016). Other factors include increasing living standards, aspirations for changing lifestyles and growth of mass communication, which demands for high-quality paper and paper products (Goryakin et al. 2015).

It is projected that by 2021, the global paper production would rise to 521 million tonnes per annum. Out of this projected figures, 177 million tonnes (44%) is expected to originate from Asia while the remaining 225 million tonnes (56%) would come from elsewhere (Perkins & Rawski, 2008).

1.2 Pulp and Paper Lignocellulose

Wood has been the primary paper fibre for less than a century, with paper pulp demand being predominantly used as writing-printing paper, newsprint and industrial paper (packaging and wrapping paper, and paper board) (Holik, 2012). Global paper demand has resulted in two out of every five trees cut for pulp, , which is one of the main reasons for the destruction of forests worldwide (Middleton, 2013). Wood sourced pulp and paper has been characterized by a heavy-duty industrial process to turn wood into paper (Main, et al., 2015). Wood pulping processes release large amounts of dangerous pollutants, such as chlorine, dioxin and furans into the air and water bodies (Udohitinah & Oluwadare, 2011). As forests diminish and public opinion to save forests grows, there is increasing interest in alternative fibre crops (Laftah and Wan Abdul Rahman, 2016). Fig. 1.1 shows the common sources of lignocellulose used in pulp and paper industries (Leponiemi, 2008).

Lignocellulose biomass contain cellulose, hemicellulose, lignin and extractives with the ratio of these components varying depending on the species of wood. While some of the fibres are virgin fibres, some are obtained from- recycle papers and non-wood fibres. The management of the forest biodiversity is a concept towards the preservation of some characteristic flora and fauna in the tropical region (Kozuka, 2013).

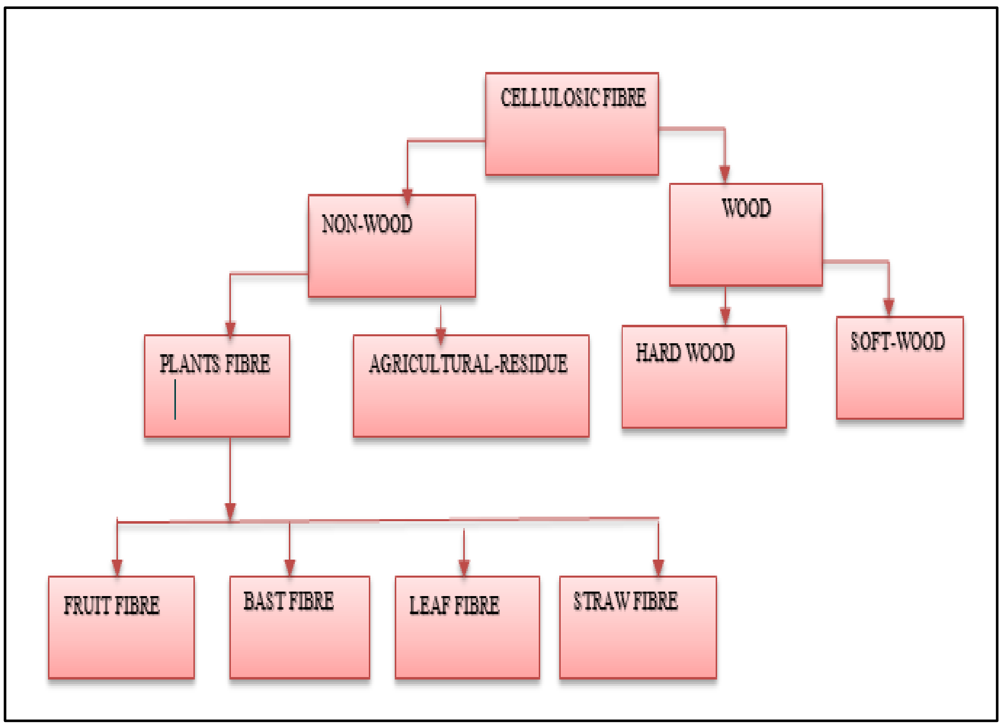

Figure 1.1 Pulp and paper lignocelluloses biomass.

Traditionally wood has been considered as the major raw biomass for paper making. Countries with limited forest size and limited plantation area like China are more prone to the used of non-wood as raw material for paper making (Carlsson et al., 2009; Ai & Tschirner, 2010; Mossello et al., 2010). There is significant growth of regional imbalances in the fibre supply globally due to shortage supply of virgin pulp.

The continued rivalry in the fibre demand for pulp and paper, housing and wood for fuel has equally contributed to the reduce dependency of pulp and paper industries on virgin pulp (Carlsson et al., 2009; Ai & Tschirner, 2010; Mossello et al., 2010). Sequel to this development, agricultural residues, such as cereal straws of wheat, rice, barley and lately empty fruit bunches (introduced by EKO paper mills Malaysia) has been gaining increasing interest as fibrous source of raw materials in the pulp and paper industries (MPOB, 2012). In fact, utilisation of the agricultural residue as raw material for pulp and paper making would ameliorate the persistence waste management problems.

1.3 Problem Statement

Currently, due to the shortage of wood fibres and economic outlay the use of non-woods in pulp and paper production in several available and wood deficiency countries have been gaining increasing attention. Despite the noticeable deficiencies in the use of non-woods with respect to woods (Fazeli et al., 2016), agro wastes have been receiving increasing considerations as source of natural cellulose fibre in agro-based industries including pulp and paper industries. This development is as a result of imminent environmental instability in the area of biodiversity. Since the introduction of agro waste as alternative to wood in pulp and paper manufacture, biomass such as corn stalks (Daud et al., 2016), wheat and rice straws (Reddy and Yang, 2015), have been used for commercial pulp and paper making. Many research reported on the use of EFB for pulp and paper (Dermawan et al., 2014; Daud and Law, 2010; Ghazali et al., 2012), leaving the oil palm (*Elaeis guineensis*) fronds vascular bundle fibres yet fully investigated.

A number of methods of fibre extraction have been assessed in the literature (Daud and Law, 2010; Reddy and Yang, 2015), most of, which operate at high temperatures and pressures and a few of them releasing environmental hazardous effluents. Pulping industry has been reported as the second largest polluting industry after mining (Singh et al., 2014). Air contaminants released from pulping include particulate matter, sulphur dioxide, and total reduced sulphur (TRS) compounds. To counteract the pollution issue, adoption of an eco-friendly technique with economic criteria is needed. To this date, Alkaline Peroxide Mechanical Pulping (APMP) is the best known technique that not only fit the aforementioned criteria but is also flexible in its operational size and quality of pulp as the end-product quality. Since the introduction of alkaline peroxide mechanical pulping by Cort and Bohn in the late 80s, many Kraft mills in China had been converted to an APMP system (Ghazali, 2006) and research continue to flourish around the use of various non-wood material, except the oil palm frond, OPF. This study therefore delves into the Alkaline Peroxide Mechanical Pulping of OPF VB by accomplishing the following objectives:

1.4 Research Objectives

a) To study the chemical and morphological properties of fibre residing the OPF vascular bundle.

b) To study the thermal, morphological and chemical changes in the AP- treated OPF vascular bundle by the use of TGA, SEM and FTIR of the extracted fibres respectively.

c) To further characterize the effect of the alkaline peroxide treatment on the strength, optical and morphological properties of the handsheet from the AP-treated OPF vascular bundle fibres.

d) To develop regression model using RSM via Box Behnken design of experiment to determine the most improved and enhanced OPF pulp and paper properties.

1.5 Structure of Dissertation

The thesis consists of seven chapters that employ the use of instrumental analysis, empirical and statistical modelling approach to determine the suitability of OPF vascular bundle fibres as an alternative source of fibre for pulp and paper products. Therefore in this dissertation:

Chapter 2: reviews the literature on the use of alkaline peroxide in pulp and paper making. The suitability of non-wood and agricultural residue for pulp and paper was enumerated. Furthermore more light on the benefit of the utilization of the statistical tool in developing and optimizing the pulping condition for pulp and paper production brought to the fore.

Chapter 3: contains all the experimental approaches undertaken in this study and gives an insight to the various tools used to analyze the obtained result.

Chapter 4: reports the result of analysis and Characterisation of the OPF vascular bundle fibres.

Chapter 5: presents the outcome of the preliminary investigation of the alkaline peroxide treatment duration and level effects on the pulp and paper properties of the oil palm fronds vascular bundle fibres.

Meanwhile, Chapter 6: presents the result of the combined effects of three independent variables (hydrogen peroxide concentrations, sodium hydroxide concentration and cooking time) on the pulp and paper properties of the OPF vascular bundle fibres using Box Behnken model of the Response Surface Methodology (RSM) for experimental design. The chapter reports the analysis and process optimization modelling of the alkaline peroxide treatments on the pulp and paper properties.

The work is wrapped up in Chapter 7 by evaluation of the extent in , which the objectives had been achieved as well as recommendations for future research to overcome the identified challenges pertinent to APMP of OPF VB.

CHAPTER 2

LITERATURE REVIEW

2.1 Current Overview of Global Pulp and Paper Industries

Pulp and paper mills are big business around the world, generating $563.6 billion in revenue during 2013 (Singh et al., 2014). The global paper and paperboard demand as at 2011 stood at 402 million tonnes per annum whereas about 7,745 mills existing globally can produce only 192 million tonnes of pulp. The paper demand has almost doubled in 20 years from 242.79 million tonnes in 1990 to 402 million tons by 2011. Paper consumption and production growth in Asia is expected to double by 2030 from 2010 levels (Alexandratos & Haen, 1995; Golley & Tyers, 2006; Oh et al., 2010).

In tropical countries like Malaysia, oil palm plantation has constituted one of the major source of gross national income (GNI). In Malaysia the oil palm export constituted $22.31 billion USD to the country's gross national income in 2014 and it is expected to rise to $55.8 billion USD by the year 2020 (Awalludin et al. 2015). Food and Agricultural Policy Research Institute FAPRI (2010) predicts that Malaysian palm oil production will increase by 26.5 percent, to 23.4 million tonnes by 2020, slightly less than the predicted Indonesian production of 28.5 million tonnes (Ivancic and Koh, 2016). Oil palm industry in Malaysia with its 6 million hectares of plantation, produced biomass as much as 100 million tons (Abdul Khalil et al., 2010). In order to maintain steady growth of oil palm plantation, large areas of primary and secondary forest have been cut or burned down to make way for oil palm plantations in Indonesia and

Malaysia, the two countries , which produce 80.5% of the world's palm oil (Ivancic and Koh, 2016).

The conducive climatic condition of Malaysian climate has contributed absolutely to the growth of oil palm plantation, making it the most important agricultural crop in Malaysia and has contributed immensely to the national economic growth (Leibo, 2015). This has made Malaysia the second world largest producer of oil palm.

The rapid growth of the palm oil industry in South-East Asian countries like Malaysia is as a result of the palm oil being the world's largest source of edible oil and hence constitutes its major economic crop. This has contributed to the expansion of the area of plantation and making Malaysia the second largest producer of oil palm after Indonesia (Ivancic and Koh, 2016). The types of waste biomass generated in oil palm industries in Malaysia as shown Fig 2.1 are generated from both the mill and the plantation site (Dungani et al., 2013). Fig. 2.1 shows that oil palm fronds, (OPF), and the oil palm trunks, (OPT), are generated from the plantation sites while the empty fruit bunches (EFB), palm oil mill effluent (POME), mesocap fibre (MF), and Kernel Shell (KS) are generated from the oil palm mill.

Increase in oil palm plantation translates to the huge generation of the oil palm biomass, globally over 190 million tonnes of solid and liquid residues are being generated from the palm oil industries. In Malaysia, about 100 million tonnes dry weight of these biomass wastes is projected by 2020, of , which the OPF constitutes 70% and is considered the highest (Wanrosli et al., 2007). These biomass are usually left on the site resulting to environmental issues while undergoing decomposition, which is aimed at fertilising the soil (Lim et al., 2000). Oil palm fronds are agricultural residues by-product biomass generated from oil palm activities and made up of the petiole, rachis and leaflets.

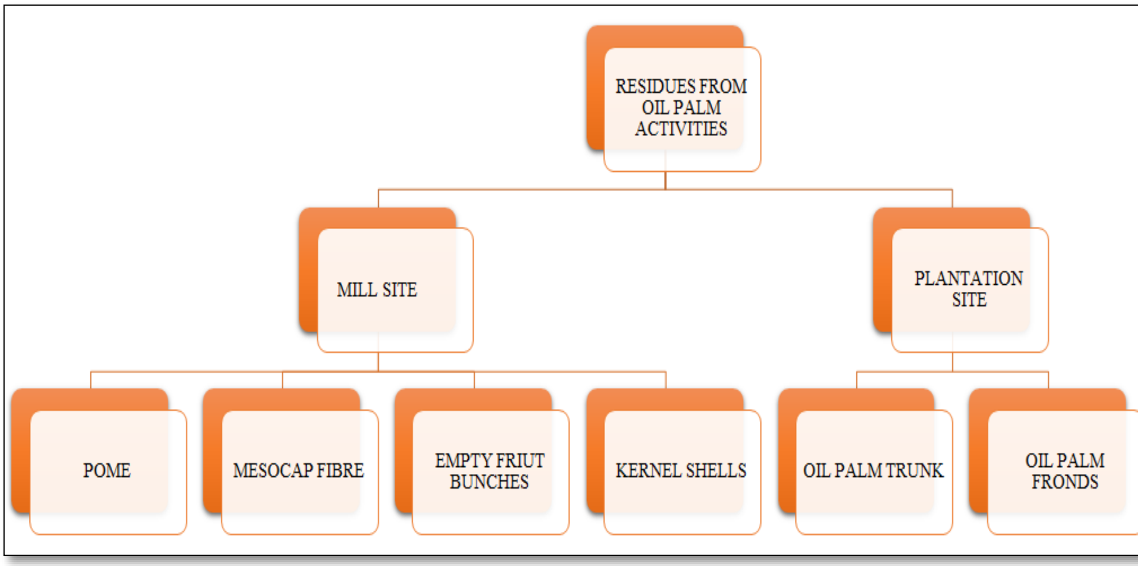

Figure 2.1 Oil palm biomass residues Source: (Dungani et al., 2013).

Owing to its abundance, biodegradability and problem of disposal, has contributed to the present currently increases farming costs. In addition it has lead to environmental deterioration through pollution, fires, and pests. According to Abdul Khalil and co-workers (2008), oil palm frond contains various sizes of vascular bundle fibres imbedded in thin-walled parenchymatous ground tissue. While the parenchyma cells act as a storage medium, the vascular bundle fibres act as mechanical support for the oil palm frond. This growth of the palm oil industry has caused a corresponding increasing in the biomass wastes derived from the pruning management practices and replanting operations (Daud and Law, 2010; Paltseva et al., 2016).

Malaysian and Indonesian based researchers have been saddled with research and development into economic viability of oil palm wastes in order to minimise if not totally eradicates the environmental issues associated with the poor management of the biomass. Biomasses such as agricultural crops and residues, forest resources and residues, and municipal wastes are the largest source of cellulose in the world (Awalludin et al. 2015). Among the merits of non-wood plants include short growth cycles, moderate irrigation and fertilization requirements and low lignin content resulting to reduced energy and chemicals use while pulping (Wang & Chen, 2013). Agricultural by-products are annually renewable, available in abundance and of limited value at present. The use of non-wood fibres and agricultural wastes in papermaking has been proposed by some environment advocates as a way to preserve natural forests and prevention of global warming. EFB have proven to be useful raw material for the pulp and paper industries (Rushdan, 2002).

In countries where the supply of wood resources is inadequate, the rate of paper consumption continue to be on the increase despite the challenges of commercial papermaking with respect to limited wood resources. Many ecological problems occasioned by deforestation such as global warming, hurricanes, flooding, droughts are among some of the detrimental global environmental problem facing humanity (Middleton, 2013). While global campaign towards improvement in reforestation has been on the increase, the utilisation of agricultural residues have attracted the interest of environmentalist and scientist. The suitability of these agricultural biomass through various analytical investigation has been the first step in their utilization. For paper making, the morphology and chemical properties of fibres of the lignocelluloses for pulp and paper are of great importance to the suitability of pulping and papermaking processes, as well as for final paper products.

In India, the pulp and paper industry is divided into three sectors based on the raw materials usage (Reddy & Ray, 2011). These include:-

a) The wood based mills , which comprise of 26 large integrated paper mills using both wood and bamboo, contributes to 31% production of the mill production and this translates to 3.19 million tonnes of pulp per annum.
b) The 150 agro-based mills constitute about 25% of the total output and
c) The 538 recycle fibre mills contribute to 4.72 million tonnes, or 47% total paper product.

In Malaysia, the total capacity of the paper mills is about 50 T/day that translates to about 1,300,000 T/year. Of all these, integrated pulp and paper mill in Sipitang, Sabah (Sabah Forest) uses wood fibres (Grafton & Jago, 2013). Table 2.1 shows the total annual production capacity of the paper mills in Malaysia and the actual production per annum.

It is apparent that the production capacity per annum is short 10.52% of the total annual capacity of the of the mills. This shortfall is attributable to the lack of raw material and the maintenance culture of the machinery, , which often breakdown. There are significant regional differences in pulp and paper consumption and production patterns. Asia is the biggest region in term of paper consumption and production, about twice as big as the North America (Fontagné & Fouré, 2013; Taylor et al., 2013). Perhaps the most striking fact is that Africa's paper consumption and production are so extremely low compared to the other region. The paper making process thus far has mainly used wood materials from the cut, debarked, chipped, and pulped tree stems. The continual growth in pulp and paper production entails massive deforestation.

The pulp and paper industry is currently facing broad structural changes because of global shifts in demand and supply (Hujala, (2013), as a result of the short supply of wood materials. This challenge has led to the reductions in the number of pulp and paper mills, lower rates of capacity growth, employment downturns, and a loss of market share to foreign competitors (Brown and Wang 2015). These structural shifts portray an industry that has encountered difficulty in adapting to a more competitive environment and earning sufficient profits to generate a return on investment that covers opportunity cost. These changes have significant impacts on most national economies worldwide. Increasing competition for wood supplies for construction purposes coupled with gradually rising costs of wood have generated renewed interest in the use of nonwood plant fibres for papermaking in the highly industrialized countries (Smith, 1997). It is interesting to note that some environment advocates have proposed the use of non-wood fibres in papermaking as a way to preserve natural forests and prevention of global warming.

Both wood and non-wood resources are currently being exploited for the manufacturing of pulp, paper and paper boards. In countries where the supply of wood resources is inadequate, the rate of paper consumption has been on the increase despite the challenges of commercial papermaking with respect to limited wood resources.

The use of agricultural residues in pulping and papermaking is gradually gaining attention because of the problem of disposal, , which currently increases farming costs and causes environmental deterioration through pollution, fires, and pests (Bajpai, 2015). In 2003, Malaysia's Eko Pulp & Paper Sdn Bhd (Company No. 590644-K).

(EPP) was established in joint collaboration with Forest Research Institute of Malaysia (FRIM) and Malaysian Palm Oil Board (MPOB) to undertake research and development and commercialization of pulp production using the oil palm Empty Fruit Bunches (EFB) (MPOB 2012).

Many ecological problems occasioned by deforestation such as global warming, hurricanes, flooding, droughts are among some of the detrimental global environmental problem facing humanity(Middleton, 2013). Many attempts have been made to simplify the design of the mill to achieve the reduction in the effect of the economies of scale (Karltorp & Sandén, 2012).

The global pulp production is expected to increase simultaneously with the consumption of paper, and this is especially through for fines paper with 6.5% increase in global non-woods consumption (Laftah and Wan Abdul Rahman, 2016). In China and India over 70% of raw material used by the pulp industries come from non-woody plants and agricultural residues such as reeds, bamboo, bagasse and cereal straw (Al-Mefarrej et al., 2013). Biomasses such as agricultural crops and residues, forest resources and residues, and municipal wastes are the largest source of cellulose in the world. Non-wood plants offer several advantages including short growth cycles, moderate irrigation and fertilization requirements and low lignin content resulting in a reduced energy and chemicals consumption during pulping (Wang & Chen, 2013).

Table 2.1 Annual Paper Production from Malaysian paper mills

No.	Company	Total Capacity per Annum (mt)	Production per Annum (mt)
1	Cita Peuchoon	30,000	24,000
2	Johmewah	35,000	8,000
3	Genting Sanyen	300,000	250,000
4	MudaPaper (Kajang)	170,000	140,000
5	Muda Paper (S. Prai)	130,000	140,000
6	Malaysia Newsprint	250,000	250,000
7	Nibong Paper	60,000	60,000
8	Pascorp Paper	140,000	135,000
9	Pembuatan Kertas (Perak)	3,000	3,000
10	Sabah Forest	165,000	165,000
11	Kimberly-Clark	45,000	35,000
12	See Hua Paper	12,000	10,000
13	Talping Paper	2,400	2,400
14	Then Seng Paper	15,000	11,500
15	Trio Paper	30,000	23,000
16	Union Paper	12,400	6,000
17	United Paper Board	80,000	60,000
18	Yeong Chaur S	3,600	3,600
	TOTAL	1,483,400	1,327,300

(Source:- MPPMA- 2003)

Agricultural by-products are annually renewable, available in abundance and of limited value at present.

2.2 Pulp and Paper Production

Modern pulp and paper manufacturing evolved from the ancient art first developed in China, ca. 105 A.D (Singh et al., 2014). Papers are manufactured from cellulosic fibres, generally wood (composed cellulose, lignin, hemicellulose, and extractives (e.g., resins, fats, pectins, etc.)), recycled paper, nonwood raw materials such as bagasse, cereal straw, bamboo, reeds, esparto grass, jute, flax, and sisal and agricultural residues (Main et al., 2015). In principle, papers are made by raw material preparation (wood chipping and size reduction) and handling, Pulp manufacturing (to separate and clean the fibres), Pulp Washing and Screening, Chemical recovery, Bleaching, Stock Preparation, and Papermaking (Samariha and Khakifirooz 2011). The main goal of pulping process is to remove as much lignin as possible without sacrificing fibre strength, thereby separating the fibres and removing impurities that can cause discoloration and paper instability. Hemicellulose, which is similar to cellulose in structural composition and function plays an important role in fibre-to-fibre bonding in papermaking. Other components of wood that are removed during pulping process are extractives (e.g., oleoresins and waxes).

2.3 Pulping Technique

Two basic processing steps are involved in pulp and paper production this include the conversion of fibrous raw material into pulp followed by the conversion of the pulp into paper. This processes could be achieved mechanically or chemically. The pulp is then bleached and further dispersed in water and reformed into a web, depending on the type and grade of paper that is needed to be produced (Bajpai 2015). Table 2.2 gives the common pulping method for lignocelluloses materials. The first step in pulping is the cost efficient and environmental sound pulping technique even at small scale. This is what forms the interest of researchers exploring the avenue of using non-wood and agricultural residue as alternative raw material to wood. Globally, several factors have contributed to increasing the level of industry interest in the use of nonwood and agricultural residue as fibre sources. Some of these factors include :-

(a) environmental pressure to stop using trees due to deforestation

(b) projections of world fibre shortage by 2010 (Jepma, 2014), and the need to find alternative fibre sources

(c) abundance of agricultural residues (such as corn stover, sugar cane bagasse, banana pseudostem and wheat straw) that are otherwise burned off fields and

(d) opportunities of integrated mill to produce multiple products (oils, textile fibres, papermaking fibres, board fibres, plastics, food) from a simple fibre source, , which provides unique opportunities for sustainable agriculture.

Among the qualities governing good pulp and paper material in paper production is, increasing the amount of cellulose and decreasing the value of lignin, the extractive content, and the percentage ash content. All these result in increased yield, a decrease of chemical material consumption, and cooking time (Panshin & Zeeuw, 1980).

Table 2.2 Common Pulping Method for Lignocellulosic Materials

	Pulping method	Chemical used	Properties of isolated pulp	Application of pulp	Refences
1	Kraft/ sulphate	Sodium hydroxide + sodium sulphide	Strong, low brightness (dark brown)	Making boxes, paper bags and wrapping paper. Can also be used for writing paper and paperboard when bleached.	(Kim et al., 2016)
2	Sulphite	Sulphurous acid / sodium sulphite	High flexibility and requires little bleaching	Used in making paper and special purposes.	(Moradbak et al., 2015)
3	Soda	Sodium hydroxide + anthraquinone	Have properties similar to sulphite	Ideal for all paper uses.	(Wutisatwongkul et al., 2016)
4	organosolv	Organic solvents and organic acids	Properties still under review	Preliminary results suggest multi-purpose uses.	(Moral et al., 2016)
5	Biopulping	Involve the use of white fungus	Increase tear index, low Kappa number and other properties are still under investigations.	Results suggest possible uses in all aspects of the paper.	(Singhal et al., 2015)
6	APMP/PRC-APMP	Hydrogen Peroxide+ Sodium hydroxide	High yielding pulp, high iso-brightness, right paper properties	Ideal for all paper uses	(Cort and Bohn, 1991)
7	APP	Hydrogen peroxide + Sodium Hydroxide	Same as obtained for APMP	Preliminary laboratory result suggest multi-purpose use	(Ghazali et al., 2009)

The second step is the choice of pulping technique. Among the array of the environmentally friendly pulping is alkaline pulping, organosolv pulping, and Chemi-mechanical pulping (Sridach, 2010; Bajpai, 2013a).

There are three principal groups of pulping processes namely mechanical pulping, chemical pulping and bio-pulping. Mechanical pulpingis a pulping method that uses disc refinesr on raw wood (mainly softwood) against the abrasive surface with the aim to de-fibre the raw material without the dissolution of lignin (Harinath et al., 2013). Khakifirooz et al., (2012b) reported that this method is characterized by high yield and usually more than 95% of the dryweight of the wood. High temperature and pressure are used by some methods to increase the efficiency of the process. Although mechanical pulping generates very low polluting effects but is an energy intensive process, as the non-cellulosic wood components are not available conversely to what obtain in chemical pulping (He et al., 2013). Chemical pulping involves the dissolution of all the non-cellulosic components of the lignocelluloses biomass in cooking liquor at high temperature and pressure thereby separating the fibres. Generally chemical pulping gives better paper quality (Biermann, 1996; Bajpai, 2013a). However it is characterized with greater environmental pollution (through its pulping and bleaching process), capital intensive and operating costs are higher than those of mechanical pulping. The yield of chemical pulping is about 50% of the dryweight of raw material. An example of the method is: sulphate or kraft, sulphite, and soda pulping.

2.4 Hybrid Form of Pulping: Chemi-Mechanical Pulping

Hybrid pulping is another form of pulping, which involves a chemical pre-treatment of the raw material, before a mechanical treatment to liberate the fibres. The yields of these processes are situated between those for mechanical and chemical pulping (Hosseinpour et al., 2014).

Chemi-Mechanical Pulping (CMP) has gained global attention as an environmental benign pulping method (Khakifirooz et al., 2012b). It is a type of hybrid pulping process involving impregnation of raw material with small amounts of chemicals to soften the lignin, while it then employs mechanically treatment to liberate the fibres. Masrol and co-workers (2015) reported that the pulp yields of these processes are situated between those for mechanical and chemical pulping, due to the synergistic operations of the two pulping protocol in CMP. Cort and Bohn (1991) observed that heat is typically applied to improve pulping. The report further revealed that this method is characterized by good fibre properties, low chemical application, lower capital and operating costs compare to pure mechanical pulping. Chemi-mechanical pulps can be used for low- to medium-quality papers, and with additional processing they may be used for some high-end purposes. However,the most popular and widely accepted process is the invention of a new CMP technology called alkaline peroxide mechanical pulping (APMP) (Cort and Bohn, 1991). However, the dissolved lignin and the other trace elements in the biomass are treated and discharged into the environment.