# OIL PALM FROND (OPF) AS AN ALTERNATIVE SOURCE OF PULP & PAPER PRODUCTION MATERIAL

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# DECLARATION

I declare that this thesis entitled **"OIL PALM FROND (OPF) AS AN ALTERNATIVE SOURCE OF PULP & PAPER PRODUCTION MATERIAL"** is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

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| Date | : May 16th, 2006 |

# DEDICATION

*Special Dedication to my beloved mother (Azizah) and father (Yakari), for their love and encouragement.*

*And,*

*Special Thanks to my friends, my fellow course mate and all faculty members.*
*For all your Care, Support and Best Wishes.*

*Sincerely,*
*Mohammad Izzuddin bin Yakari*

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## ABSTRACT

The paper and paperboard industry in Malaysia grew from 1.6% to 35% from 1993 to 2000. The growth highlights the potential of using the 26.2 millions tonnes of oil palm frond (OPF) for pulp and paper production. The research has indicated that the chemical composition of OPF fibers lie between that of hardwoods and that of straws and grasses. OPF fibers can easily be pulped using the chemical process, producing pulp and paper of better properties than most hardwoods pulps. This research also highlights the beating effect in terms of the fiber morphology, paper strength and properties. A P.F.I Mill used to beat the OPF pulps. The beaten pulp was made into fiber network for morphological measurements and the stocks were tested for freeness and drainage time. Handsheets were made from pulp samples taken at different times during the beating process and standard physical test were carried out to give refining curves. The fiber length and diameter decrease with the degree of beating cause of the fragmentation. The soda pulp also gives the effect on drainage time which is increasing with the degree of beating. The content stock freeness (CSF) is decrease with the degree of beating cause of increasing the surface area to absorb water of fine fiber. The high degrees of beating give the strength paper which showed in burst and tensile indices. The study showed that beating effect of soda-AQ pulp produced pulp with different fiber morphology, strength and paper properties.

## ABSTRAK

Industri kertas dan papan kertas di Malaysia mengalami pertumbuhan mendadak dari 1.6 % kepada 35 % bermula tahun 1993 sehingga tahun 2000. Pertumbuhan ini menunjukkan potensi penggunaan pelepah kelapa sawit bagi industri pembuatan kertas adalah sebanyak 26.2 juta tan. Kajian menunjukkan komposisi kimia yang terkandung di dalam serat pelepah kelapa sawit menyamai sifat diantara kayu pejal dan spesis rumput dan lalang. Serat pelepah kelapa sawit mudah menghasilkan pulpa melalui proses kimia (alkali) dan sangat berkesan berbanding serat berasaskan kayu pejal. Kajian ini juga menekankan kesan mampatan serat terhadap struktur iaitu panjang serat, kekuatan dan sifat kertas. Alat yang digunakan untuk memampatkan serat adalah P.F.I Mill. Proses pemampatan ini dilakukan untuk ikatan fiber melalui ukuran struktur iaitu panjang serat dan diuji untuk menentukan keupayaan serat menampung air berdasarkan masa air melalui serat. Kertas yang dihasilkan adalah daripada pulpa yang berlainan masa proses pemampatan dan kajian piawai fizikal dilakukan untuk melihat lengkukan berdasarkan graf. Panjang dan ukurlilit serat menurun terhadap masa proses pemampatan disebabkan oleh pemecahan serat semasa pemampatan. Pulpa Soda juga memberi kesan terhadap masa air melalui serat dengan berkadar lansung iaitu meningkat dengan perbezaan masa proses pemampatan. Isipadu air yang ditampung oleh serat menurun terhadap perbezaan masa proses pemampatan, disebabkan oleh peningkatan luas permukaan penyerapan air oleh serat halus. Semakin lama proses pemampatan, akan memberikan kekuatan pada kertas yang dihasilkan melalui nilai ketegangan dan kepecahan yang dicatatkan. Kajian menunjukkan terdapat kesan daripada proses pemampatan pelepah kelapa sawit terhadap struktur serat, kekuatan dan sifat kertas yang dihasilkan.

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## LIST OF SYMBOLS

| | | |
|---|---|---|
| AQ | - | Anthraquinone |
| CSF | - | Canadian Standard Freeness Method |
| EFB | - | Empty Fruit Bunch |
| NaOH | - | Sodium Hydroxide |
| OPF | - | Oil Palm Frond |
| OPT | - | Oil Palm Trunk |
| TAPPI | - | Test & Analysis of Pulp and Paper Institute |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

In Malaysia, the oil palm frond (OPF) was produced 26.2 million tonnes per annum from palm oil industries. Malaysia is the one of the country that exports the palm oil in the world besides Indonesia and Ghana. Recycling is needed to produced something that can be used and avoid the pollution of environment. The production of paper and pulp from palm waste is the best way as a result of environmental issues today. The used paper also can be recycling to produce new paper for packaging, printing and manufacturing.

**Figure 1.1:** Oil Palm Frond (OPF)

Wood fibers are the main raw material used for the production of pulp and paper. This can be seen from the world wood pulp production amounted to 166.3 million tonnes in 2001 as compared to recovered fiber pulp of 19.8 million tonnes. The recovered fiber is obtained from waste and scrap paper or paperboard, while the other fibers are from vegetable materials such as straw, bamboo, bagasse, kenaf, reeds or grasses, cotton linters, flax hemp, rags, or other textile waste of the total other fiber pulp production, the main producer country in 2001 was China, followed by Australia and India.

In Malaysia, there are 20 paper establishments of these, 10 mills are operating based on recycled papers, while only one mill is using mixed tropical softwoods for its production of pulp and paper. The pulp and paper production from this mill reached 123,000 tonnes in 2001.R&D on pulp and paper has been initiated by FRIM long time ago focusing on the evaluation of the suitability of raw material for pulping and papermaking. One of the R&D findings is the suitability of oil palm frond (OPF) as raw material for pulping. The potential of this finding can be viewed from the facts that there are about 26.2 million tonnes of OPF readily available from the palm oil industry and they are treated as wastes having no value and difficult to dispose. This paper examines the technical feasibility of using OPF in the pulp and paper production and attempt to make an economic analysis on producing pulp and paper from OPF in Malaysia.

## 1.2 Objectives

1. To utilize Oil Palm Frond (OPF) as alternative source of cellulose based material to produce pulp and paper.
2. To determine the effect of beating on the properties of oil palm frond (OPF) soda-AQ pulp.

## 1.2 Scopes

The scopes of this study consist of:

1. The effect of beating on fiber morphology
2. The effect of beating on drainage time
3. The effect of beating on content stock freeness (CSF)
4. The effect of beating on paper strength.
5. The optimum condition of beating in paper production.

## 1.3 Problem statement

A lot of biomass waste not being utilize and converted to high valued product. The Oil Palm Frond (OPF) showed the potential alternatives sources of fresh pulp that replaced to substitute imported fresh pulp. The wood based paper production faced with environmental drawback where sulphur emitted contain through the acidic sulphite & prehydrolysis-kraft pulping process.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 PULP AND PAPER BACKGROUND

Malaysia is net importer of most paper product except for toilet/ tissue paper (Jahaya 1997). In 1996, Malaysia consumed about 325,000 tonnes of newsprint but produced about 5,000 tonnes (Kuusisto 1997). The imported paper and paper product have resulted in a lost in foreign exchage, which can be reduced by utilizing the local lignocellulosic materials in newsprint industry. One of the abundant lignocellulosic residues is the palm oil frond (OPF). Malaysia's 351 palm oil mills produce 26.2 million tones of OPF per annum in the year 2000. Most softwood pulp is produced the soda pulping process (Atchison 1987, Minor 1996).

After the pulping operation, the pulp is often dark in colour. For newsprint production, the pulp should have a brightness of 60-65% (Biermann 1996, Wan Daud *et al*. 1998). Bleaching makes pulp whiter and brighter to the eye. Bleaching is the chemical process applied to the pulp to increase its brightness through lignin removal. Pulp brightness is one of the parameters used in monitoring bleaching progress. An unbleached pulp is colored due to the absorbance of visible light by the presence of residual lignin, highly colored substances. There are more than ten types of bleaching chemicals. Lignin removal is achieved using chlorine, hypochlorite, chlorine dioxide, oxygen or ozone (Reeve 1996). Different types of bleaching chemicals, stages and sequences are used in producing different degree of pulp brightness and will affect the pulp and paper properties.

Beating pulp is one of the most important processes in papermaking. It refers to a mechanical treatment given to pulp fibers during their preparation for papermaking. The principle objective of beating is to optimize fiber properties. The modifications of the pulp fibers are dependent on pulp quality, process conditions, and running conditions of the equipment (Levlin & Jousimaa 1988).

### 2.1.1 Pulping and pulp characterization

Pulping trials were carried out in a 4 L stationary M.K Digester (NAC Autoclave Co. Ltd., Japan) fitted with a computer-controlled thermocouple. The conditions employed were as follows: liquor-to-material ratio of 8:1, time to maximum cooking temperature of 90 min, time of cook of 120 min, with variations in the white liquor chemical composition (Table 1). After cooking, the pulps were mechanically disintegrated in a three-bladed mixer for 1 min at 2% consistency and screened on a flat-plate screen with 0.15 mm slits (a six-cut slot screen). Rejects and screened yield were determined on oven-dry weight basis. The screened pulps were characterized without being further refined. Kappa number of the screened pulps was determined using TAPPI method T 236. Handsheets were prepared and conditioned at 23 °C and 50% RH for at least 24 hours before testing in accordance with the appropriate TAPPI standard methods.

**Table 2.1:** Pulping process variables

| Pulping type | | | | |
|---|---|---|---|---|
| **Sulfite** | | | | |
| Cook no. | A1 | A2 | A3 | |
| $Na_2SO_3$ (%) | 100 | 20 | 20 | |
| NaOH (%) | 100 | 30 | 40 | |
| **Soda** | | | | |
| Cook no. | B1 | B2 | B3 | B4 |
| NaOH (%) | 20 | 30 | 40 | 50 |

### 2.1.2 Fiber properties of OPF for pulping and papermaking

**Table 2.2:** Fiber characteristic of oil palm frond (OPF)

| Description | Fiber property | Oil Palm Fronds |
|---|---|---|
| Mean fiber length (mm) | Arithmetic | 0.59 |
| | Length weighted | 1.13 |
| | Weight weighted | 1.54 |
| | Coarseness (mg/m) | 0.098 |
| Bauer–McNett fractions (%) | R14 | 0.4 |
| | R28 | 38.7 |
| | R48 | 22.9 |
| | R100 | 16.4 |
| | R200 | 6.8 |
| | P200 | 14.8 |
| Fiber dimensions (μm) | Fiber diameter (*D*) | 19.6 |
| | Lumen width (*L*) | 11.66 |
| | Cell wall thickness (*T*) | 3.97 |
| | Rigidity index $((T/D)^3 \times 10^4)$ | 83.16 |

AFL is greatly influenced by short fibers, while the WWFL by very long fibers. The effects of very short and very long components are compensated by using the LWFL. As a comparison, the data from Canadian aspen (*Populus trem*.) are also included. Although the average length is about one-third that of spruce tracheids (Smook, 2002), it is comparable to Canadian aspen (*P. trem*.) of 0.96 mm (Law and Jiang, 2001), Maple of 0.92 (Law et al., 1986), bagasse (0.5–3.75 mm) and wheat straw (0.7–3.1 mm). The bagasse and wheat straw are commercially used for pulp and paper production, as reported by Patel et al. (1987) and Atchinson (1989). Note that the frond fibers are almost twice as long as those of oil palm empty fruit bunch (EFB) fibers (Wan Rosli et al., 1998). However, the coarseness of the oil palm fibers is low (0.097 mg/m), which is slightly halved than that of spruce and significantly lower than of aspen (0.131). The fiber length distribution curve (Fig. 1) indicates a high proportion of short fibers (fines) with further evidence coming from the Bauer–McNett classification which shows a large percentage of short fibers (Table 2.2). One particular morphological attribute of these frond fibers is that they have a much thicker wall when compared with those of wood; consequently, they have a substantially higher rigidity index.

The concept of using rigidity index (or the inverse of collapsibility of fibers) is based on the assumption that fibers act like a thin-wall cylinder whose collapse pressure is proportional to ($T/D$) (Akamatsu et al., 1987), where $T$ is wall thickness and $D$ is diameter. With thick cell wall (Fig. 2.2), the fibers would not easily collapse during sheet making, hence giving a sheet of higher bulk and lower inter-fiber bonding potential in comparison with the wood counterparts.

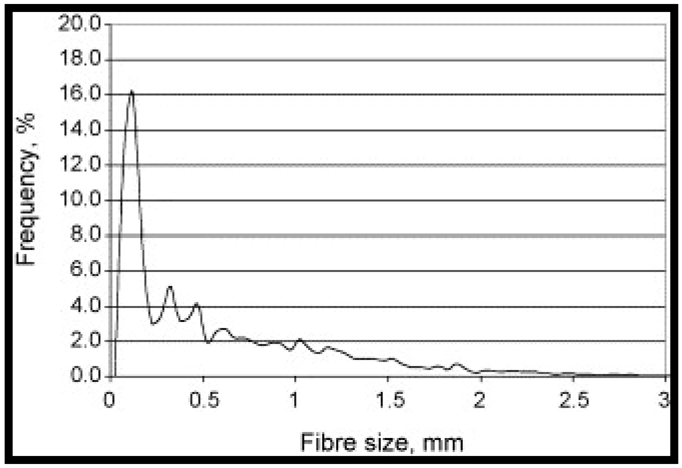



**Figure 2.1:** A fiber length distribution curve of oil palm frond fibers

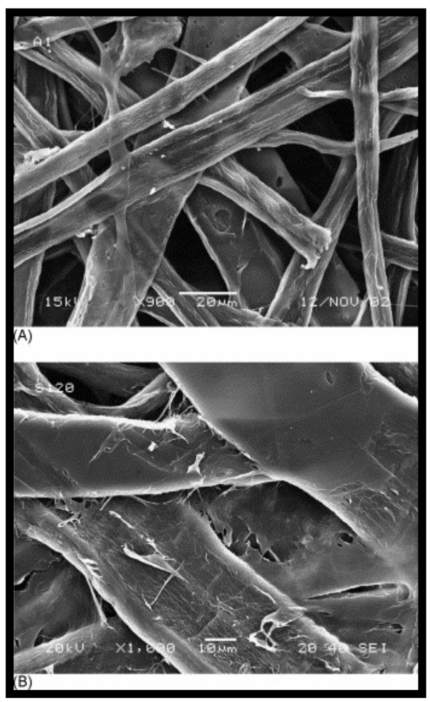



**Figure 2.2:** SEM of oil palm frond (A) and softwood spruce (B) fibers. Frond fibers have relatively thick cell walls, which do not collapse as readily as the softwood spruce fibers.

### 2.1.3 Chemical composition of OPF

Chemically, the frond strands are rich in holocellulose (83.5%) and also high in α-cellulose (49.8%) as illustrated in 2, both of which are important parameters in determining the suitability of a raw material for papermaking (Ona et al., 2000). As a comparison, the data from Canadian aspen (*P. trem*.) is also included. The lignin content (20.5%) is lower than normally found in common hardwood, for example aspen of 18.1% (Law and Jiang, 2001) and eucalyptus of 22% (Alcaide et al., 1990), which is not surprising since oil palm trees are non-woody and the requirement for structural support is lower compared to that of trees. The functional significance of lignin has long been associated with mechanical support for plant organs that enables increased growth in height (Boudet, 2000 and Douglas, 1996), its lacking will no longer allow plants to be upright (Zhong et al., 1997). This is an added advantage in that they will be much easier to be chemically pulped. The frond strands are comparatively less resinous than those of wood, as evidenced by the lower levels of extractives soluble in alcohol–benzene.

It should also be noted that the frond strands, like other non-wood fibers, contain comparatively high ash content. This characteristic might contribute to an abnormal mechanical wear of processing equipments. The potential build up of silica in the black liquor recovery system might also be a concern in pulping of this material. The monomer composition of polysaccharides shows almost only glucose and xylose, with the other monosaccharides representing less than 6%, which is in broad similarity with that of hardwoods (Timmell, 1967 and Wallis et al., 1996).

**Table 2.3:** Chemical composition of oil palm frond (OPF), Empty Fruit Bunches (EFB) and Hardwoods and Softwood.

| Component | Oil Palm Fronds | EFB | Hardwood | Softwood |
|---|---|---|---|---|
| Lignin (%) | 20.5 | 17.2 | 25.2 | 21-37 |
| Holocellulose (%) | 83.5 | 70 | 72.4 | 60-80 |
| α-Cellulose (%) | 49.8 | 42.7 | 44.7 | 31-60 |
| Alcohol–benzene extractives (%) | 1.4 | | | |
| Ash (%) | 0.7 | | < 1 | < 1 |
| Alkali solubes (%) | | 17.2 | 13.6 | |
| Pentosans (%) | | 27.3 | 12.9 | |

**Table 2.4:** Polysaccharide composition (%)

| Family Name | Composition (%) |
|---|---|
| Arabinose | 1.5 |
| Mannose | 2.2 |
| Galactose | 0.9 |
| Glucose | 66.6 |
| Xylose | 28.9 |

## 2.2 FIBER LENGTH AND DIAMETER

Oil palm frond composite possessed higher tensile strength and modulus than rubber wood composite. Fiber lengths were determined from the actual pulp produced using a Fiber Quality Analyzer (FQA, OpTest Equipment, Canada), whilst the fiber length distribution curve was obtained by plotting the fiber frequency data generated. The FQA uses optical imaging of fiber to yield length, coarseness and shape, etc. In the measure, a very dilute fiber suspension was used, about 800 mL with continuous stirring. Its concentration was not actually determined but was usually fixed at about 20 fibers passing through a small tube (where the fibers are imaged) per second. The total fiber count could range from 5000 and up. Fiber diameter, cell lumen width and cell wall thickness were measured directly from the magnified image with 100 measurements made on each property. Proximate chemical analyses of the raw material in relation to ash, extractives and lignin, were carried out following the appropriate TAPPI standards, whereas, the holocellulose and α-cellulose were determined using the method described in Wise et al. (1946) and the Japanese Standard Method JIS 8101, respectively. Polysaccharide composition of the raw material was analysed by using gas chromatography (GC) according to TAPPI standard T249 with slight modification. Acetic anhydride–pyridine mixture was employed for acetylation of polysaccharide instead of the usual standard of acetic anhydride–sulphuric acid.

## 2.3 PULPING

The pulping process separates the cellulose and hemi-cellulose from the lignin and removes other tree oils and resins. This process is important because the remaining fibers are used to produce the product we know as paper. There are two main pulping processes, chemical pulping and mechanical pulping.

### 2.3.1 Chemical or Kraft Pulping

Chemical pulping produces very pure cellulose fibers. It is the most common form of chemical pulping in North America. In Kraft pulping the OPF chips are cooked in sodium hydroxide and sodium sulfide to produce a strong dark brown pulp. It is a highly efficient process for removing lignin and resins in OPF while still producing a high-quality pulp. However, there are some problems. The release of hydrogen sulfide and the mercaptan family of sulfides can cause the characteristic paper-town smell of rotten eggs, although the use of scrubbers in mills has reduced odor emissions over the past 20 years. A second problem is that cellulose fibers that are lost during the Kraft process can be discharged with wastewater, and can build up fiber beds, causing environmental problems around wastewater pipes. In this case too, technical improvements have largely eliminated the problem. Because of the dark color of the resulting pulp, however, Kraft fibers require considerable bleaching to make them usable.

### 2.3.2 Mechanical Pulping

The second pulping process is mechanical pulping. It is a process that forces debarked logs against a grinding stone or rotating metal disks to produce pulp. This is both good and bad. The percentage of usable pulp is higher, but the resulting paper quality is lower. As much as 95 per cent of the wood resource is turned into pulp, in contrast to Kraft pulping which is only 45-50 per cent. But the paper quality is lower because mechanical pulping is an energy-intensive process that is not as efficient as Kraft because the lignin and tree resins remain in the pulp. The grinding process breaks the cellulose fibers when tearing them apart, which decreases pulp strength. As a result, the paper has a weak fiber network and the high lignin content, which causes it to darken when it is exposed to sunlight. Paper produced by this process is used mainly for newsprint, telephone books and similar applications where high quality paper is not really needed.

### 2.3.3 Steam and Chemical Treating

In a variation on the mechanical pulping process the chips are steam treated beforehand. This process also called thermo-mechanical pulping (TMP) reduces the energy consumption process by softening chips with steam prior to grinding. And then going a step further, in chemo-thermo mechanical pulping (CTMP) the wood chips are soaked with sulfur-based chemicals prior to steaming. This allows the lignin and resin to be extracted from the wood, which results in a stronger pulp. Pulp produced by CTMP can be used in the production of coated papers.

## 2.4 PAPERMAKING PROCESS

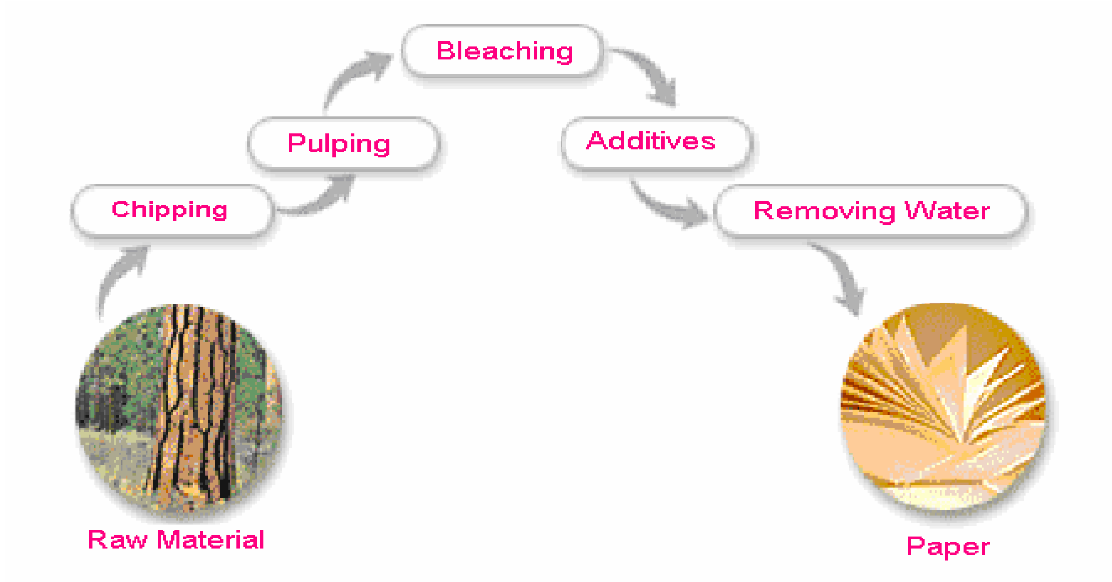



**Figure 2.4:** Process Flow of Papermaking Process

### 2.4.1 Raw Materials for Paper Industry

Paper is made of all sorts of things you can think of. One ideal raw material is Soft Wood like spruce and pine which have a long fiber for paper making. Hard Wood have short fiber and difficult in barking and chipping. Eucalyptus, Acacia, Albizzia and Wattle trees are more suitable hard wood trees for paper making and have a very high rate of growth. Several types of long grasses like bamboo, sabai grass and sarkanda are used for making paper. In India, rice, wheat straw, bagasse and corn straw are used for paper pulp making. Straw has been reported as suitable for paper making. It is a seed hair from cotton plant after extracting cotton. Only a small proportion of raw cotton in form of short fiber linters comes directly to paper mills. Cotton Rags gives more strength in paper or paper board.

### 2.4.2 Chipping

Bamboo or Wood as such cannot be used for pulping. For economical operation of pulping plant as well as for better penetration of cooking liquor, wood logs/bamboo are to be chipped into small pieces (some wood species cannot be chipped directly and needs debarking). The process is called chipping and the equipment used for chipping are called chippers. There are various designs of chippers. During chipping, chips are generated in various sizes. For better operation of the process, only chips of size 5-35 mm are taken. Chips of size less than 5 mm (dust and pin chips are taken to Boiler House for burning as fuel for generating steam). Chips of size more than 35 mm are taken into rechippers and again chipped to an acceptable size.

### 2.4.3 Pulping

Pulp is obtained by removing lignin and other impurities from the wood & other raw materials through a cooking process (Lignin is the glue that holds the fibers of the wood in their form). The cooking process requires wood, bamboo or other raw material chips. The chips are loaded into a digester and cooking liquor is added. Then by pressure cooking, the wood, bamboo or other raw material fibers are separated from unwanted ingredients. Either batch digester or continuous digesters are used in cooking. The chips and liquor are mixed as the chips are pumped to the top of the digester. The top section of the digester is pressurized to 160 psi and more. As the chip mass passes downward, the cooking liquor penetrates the chip. After about 45 minutes or more as per raw material the chips have to be passed through the impregnation zone where hot liquor (340 degree F) is circulated through the chips for heating. The actual pulping occurs at 355 degree F in about 90 minutes, a period known as the cooking period. After passing through the cooking zone, the chips (which have not become pulp) are washed with weak liquor through washing stages that follow.

### 2.4.4 Bleaching

Although cellulose fiber is white in color, due to residual lignin traces remaining on the fibers, the pulp appears creamish. Therefore, to manufacture white paper we need to remove yellowness without physically or chemically damaging the fiber, with improvement in various properties. So the main objectives of bleaching the pulp can be set out as follows that is increase brightness of the pulp by removal or modification of some of the unwanted elements in the unbleached pulp. These deleterious elements are lignin traces, resins, metal ions and non-cellulosic carbohydrates. Bleaching also give lower viscosity of the pulp for optimum flow, during subsequent operations. Bleaching for brightness improvement should also help to keep the pulp stable without turning yellow or lose strength or reduce brilliance due to aging. Bleaching also should help to reduce the fiber bundles, shaves and bark fragments. Bleaching should be done with minimum mechanical action of fibers, while dissolving lignin and other unwanted residuals. Bleaching Pulp is normally done in a step-wise sequence using different chemicals and process conditions at each stage, with washing in between stages.

### 2.4.5 Additives

Additives are added to paper pulp. Addition of fillers like talcum & calcium carbonate is very common & besides acting as fillers they add brightness to the paper. These additives must be finely ground. Additives like dyes and starch are also added. Other fillers are Titanium Dioxide, Barium Sulphate and Zinc Sulphide

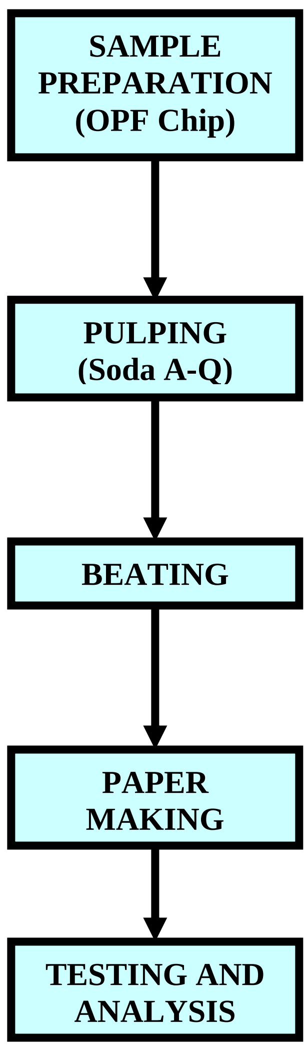
### 2.4.6 Removing Water

Removing water is the next important stage. For this the pulp is passed through a rapidly moving wire mesh called fourdriner. The objective is to remove 93% to 95% of the water in the finished paper. As the paper flows along the wire mesh and water is drained along the way, a dandy roller near the end helps to smooth out the paper. The dandy roller improves the formation of the paper web by application of pressure. When the paper reaches the end of the wire mesh it is transferred to a felt blanket which conveys it through many steam heated driers to remove the excess moisture. In the process the paper gets some glaze like coating also. Then it is made to pass through a series of calender stacks. The calenders are series of polished iron rollers stacked one on top of the other, through which the finished paper will pass to smoothen down. The next step is rewinding on a metal or fiber core. The last stages after this are sheeting, packing and testing.

# CHAPTER 3

# METHADOLOGY

## 3.1 PROCESS FLOW DIAGRAM



## 3.2 PROCESS DESCRIPTION

The raw material is Oil Palm Frond (OPF) chips that get from LKPP Corporation Sdn. Bhd. The process of preparing paper through five stages including sample preparation, pulping process, beating process, paper sheet making and testing and analysis. OPF chip have to wash and screening before soaking for 1 day. The chips undergo with the drying in oven and followed by the pulping process. In the pulping process the OPF chips pulp with caustic soda (NaOH) and soda-anthraquinone (soda-AQ) for three ad half hours to make the pulp well cooked for making paper. The pulp need to wash and screen using Somerville type to remove black liquor. After that the pulp was soaked for 1 day with the clean water. The pulp was disintegrated using Standard Disintegrator Machine at the end of digestion. After disintegration process, the pulp undergo with the beating process with the different degree of beating using P.F.I Mill. Drainage time was measured simply by draining a very dilute suspension fiber on a fine-mesh wire screen in a handsheet machine. Then the paper sheet was rolled with steel roller on fine paper sheet to remove residual water. Paper Sheet Former Machine used in paper making process before drying in semi-automatic sheet machine. At the end of drying, the paper strength analysis done with tensile, burst and tear testing machine to determine the effect of beating on paper strength.

## 3.3 MATERIAL AND METHODS

### 3.3.1 Sample Preparation

OPF chips as a sample need to screening and wash using water before pulping. After washing, the chip was soaked for 1 day to remove trapped dirt. Then the OPF chips undergo the drying process in oven dry at the temperature between 60 ºC to 70 ºC in oven dry.

**Figure 3.3.1 (a):** Screening process

**Figure 3.3.1 (b):** Washing OPF chips


**Figure 3.3.1 (c):** Soaking OPF chips

**Figure 3.3.1 (d):** Drying process

### 3.3.2 Pulping Process

Five hundred grams (oven dry) of OPF prepared were pulped by the soda-anthraquinone (soda-AQ) process using a 4 liters M.K Digester. The pulping conditions employed were maximum cooking temperature is 170 °C, time to maximum temperature is 90 minutes, time at maximum temperature is 90 minutes, OPF to liquor ratio is 1:8, amount of anthraquinone is 0.1% of OPF dry weight and amount of NaOH is 20% of OPF dry weight. After that, the pulp washed on a screen and screened by a fractionator (Somerville type) with a screen plate of 0.20 mm slits to remove black liquor.

**Figure 3.3.2 (a):** M.K Digester

**Figure 3.3.2 (b):** Somerville type

**Figure 3.3.2 (c):** OPF pulp

Then the pulp was soaked for 24 hours before paper making process and easily to form the sheet on fine mesh wire screen. At the end of digestion, the softened OPF was disintegrated for five minutes in hydropulper using Standard Disintegrator 3000rpm.


**Figure 3.3.2 (c):** Soaking OPF pulp

**Figure 3.3.2 (d):** Standard Disintegrator

### 3.3.3 Beating with P.F.I Mill

The pulp was beaten by a P.F.I Mill according to TAPPI T 200 om-89 "Laboratory processing of pulp (beater method)" at five different degrees: 15, 30, 45, 60 and 90 minutes. Before the beating process the pulp need to filtrate with the pulp thickener after soaking process. Drainage time was measured simply by draining a very dilute suspension fiber on a fine-mesh wire screen in a handsheet machine. Pulp freeness was measured by ISO 5267/1 – 1979 (E) "Pulps – Determination of drainability – Part 2: Canadian Standard freeness method" (CSF) (ISO 1998).

**Figure 3.3.3 (a):** P.F.I Mill

**Figure 3.3.3(b):**Handsheet

**Figure 3.3.3(c):** Pulp Thickener

### 3.3.4 Papermaking Process

The paper formed using Paper Sheet Former Machine. In this process the residual water also remove before drying process. Six samples including unbeating sample and different degree of beating undergo this process. Then the paper rolled by steel roller on fine paper sheet to remove water content. At the end of this process, paper sheet need to dry with semi automatic sheet before run the tensile and burst test. The laboratory paper was made by semi-automatic sheet machine (British Handsheet Machine) according to TAPPI T 205 om-88 “Forming handsheet for physical tests of pulp”. The drying process using drying ring to remove water content in paper sheet and need for 48 hours condition applied.

**Figure 3.3.4(a):** Paper Sheet Former Machine

**Figure 3.3.4(b):** Roller

**Figure 3.3.4(c):** Drying Ring

### 3.3.5 Testing and Analysis

After prepared paper from paper making process, the testing of paper to analyze the strength of paper from Oil Palm Frond (OPF). The test analyze include tensile, burst and tear test. For every sample with different degree of beating, the testing and analysis are using Horizontal Tensile Tester, Burst Tester and Tear Tester as shown in figure below. Tensile Strength is the tensile force required to produce a rupture in a strip of paperboard, measured in MD & CD, expressed in kN/m. The procedural standards are explained in TAPPI T 404. Tearing resistance/ strengths is the ability of the paper to withstand any tearing force when it is subjected to. It is measure in both MD & CD, expressed in mN (millinewtons). Bursting Strength is the maximum hydrostatic pressure required to rupture the sample by constantly increasing the pressure applied through a rubber diaphragm on 1.20 - inch diameter sample.


**Figure 3.3.5 (a):** Horizontal Tensile Tester


**Figure 3.3.5 (b):** Burst Tester

The properties of these papers were measured according to TAPPI T 220 om-88 “Physical testing of pulp handsheets” (TAPPI 1994) in a controlled temperature and humidity environment as stipulated in TAPPI 402 om-93 “Standard conditioning and testing atmosphere for paper, board, pulp handsheets and related products” (TAPPI 1994).


**Figure 3.3.5 (c):** Tear Tester

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 INTRODUCTION

Production paper must consider the quality and strength of the paper. The raw material selection is important as a result of quality, strength and friendly environment. The chemical composition in oil palm frond has higher cellulose contain that give the advantages to OPF compared the empty fruit bunches (EFB), hardwoods and softwood. The silica content must be considered in the raw material selection caused by chemical reaction on the metal equipment in producing paper. The hardwoods and softwood have higher silica content as a result of higher maintenance of equipment. This alternatives way to overcome the problem by changes the hardwood to oil palm frond (OPF).

## 4.2 RESULT AND DISCUSSION

The sample of OPF chips was beating with P.F.I Mill with the degree of beating (15, 30, 45, 60 and 90 minutes). Drainage time was measured simply by draining a very dilute suspension fiber on a fine-mesh wire screen in a handsheet machine. Pulp freeness was measured by ISO 5267/1 – 1979 (E) “Pulps – Determination of drainability – Part 2: Canadian Standard freeness method” (CSF) (ISO 1998).The strength properties of the pulps were analyzed in terms of tensile, burst and tear indices.

### 4.2.1 Drainage Time and Stock Freeness

The drainage time of pulp increase in degree of beating as shown in Figure 4.2.1 (a). The degree of beating strongly influenced drainage time. Drainage is influenced mainly by the resistance of the forming mat to the flow of water. There are eight factors in determining how much resistance a forming fiber mat will present to drainage: the temperature of the stock, the presence of surfactants, the amount of air entrained in the stock, ash or filler content, the freeness of the stock on the wire, the fiber surface chemistry, the presence and degree of flocculation by chemical and the fines content (Unbehend 1992). Since the temperature was constant and no chemicals were added into the stocks, only three factors determined how much resistance a forming fiber will present to drainage: the freeness, the surface chemistry and the fines content. The CSF, a pulp freeness measurement, decreased with the increase in beating shown in Figure 4.2.1 (c). The freeness of the stock is a function of the amount of free water and imbibed water in the sheet and associated with the fibers. The shortening of fibers has increased the surface area to absorb water.

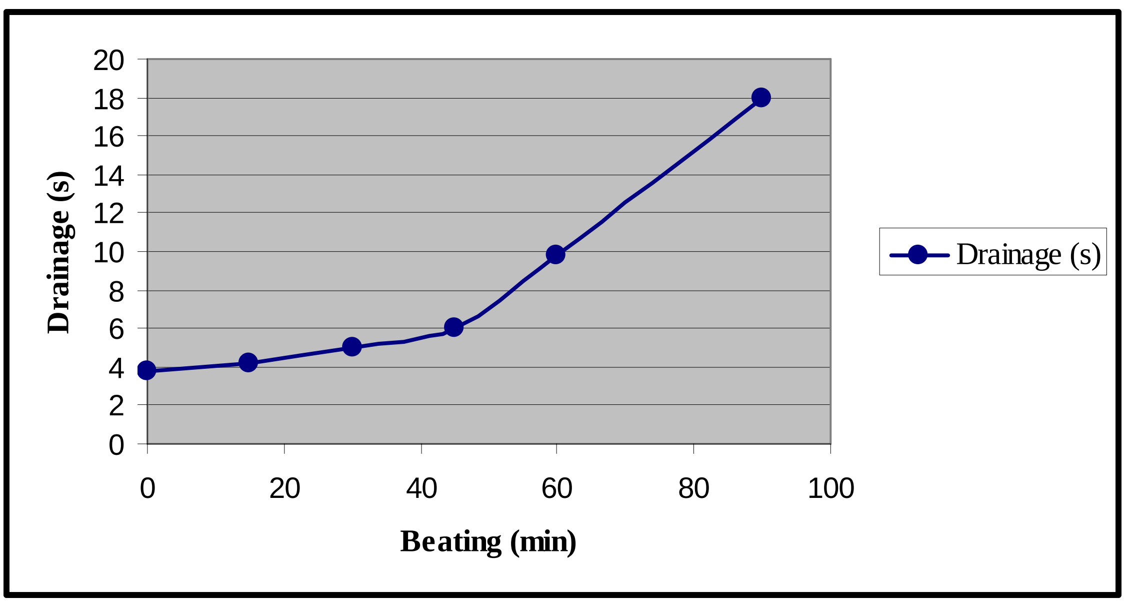



**Figure 4.2.1 (a):** The effect of beating on stock drainage

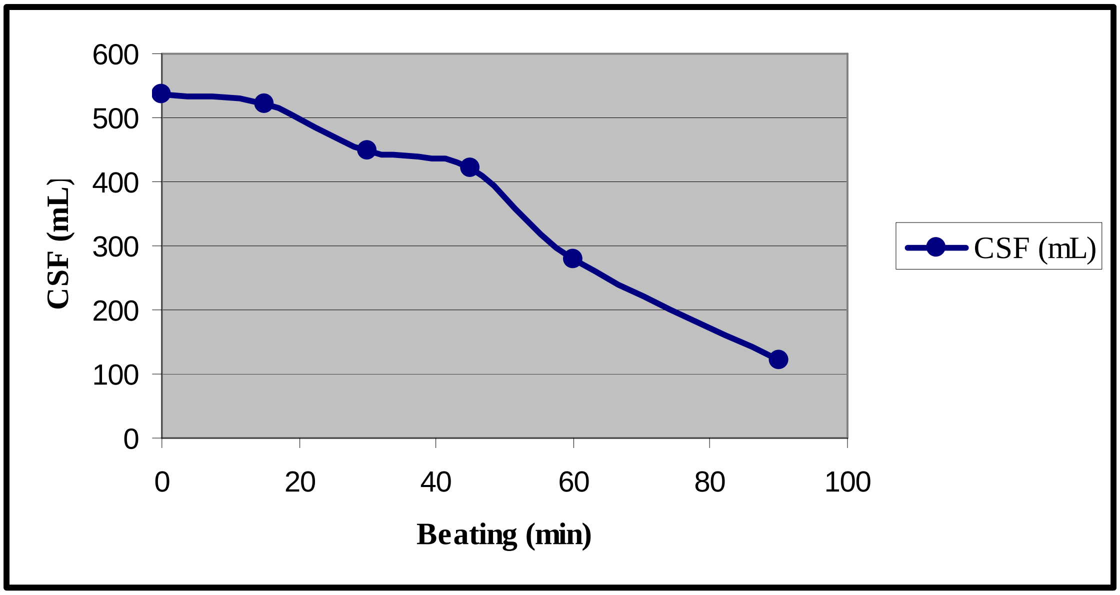



**Figure 4.2.1 (b):** The effect of beating on the stock freeness

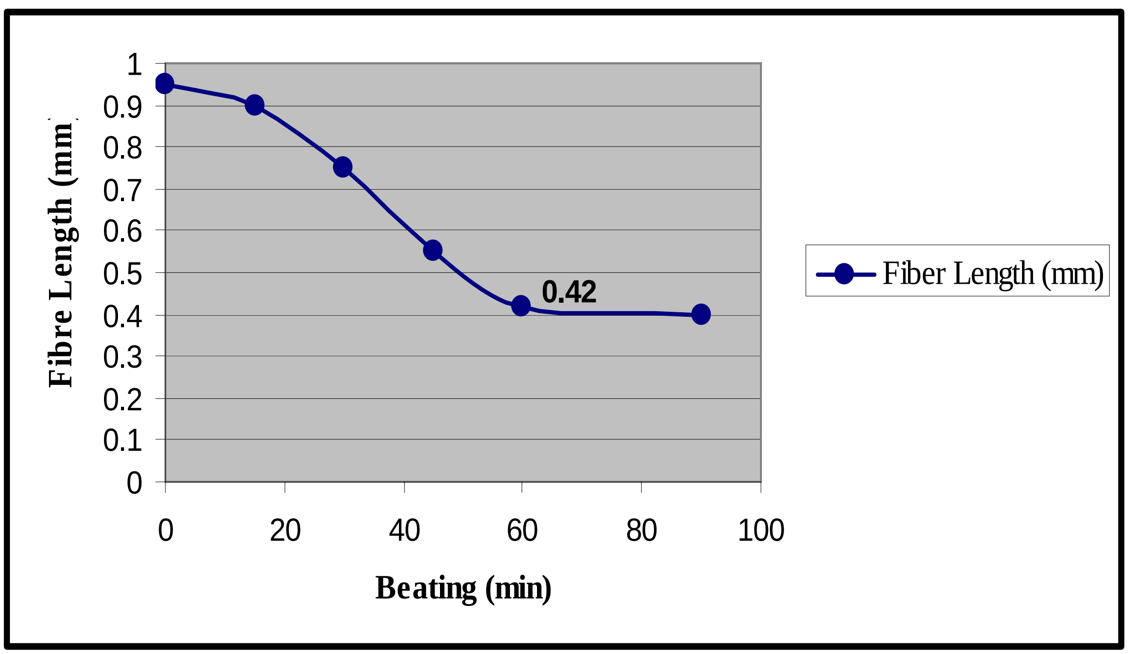



**Figure 4.2.1 (c):** The effect of beating on fiber length

Fibers were shortened and fines were produced during beating shown in Figure 4.2.1 (c), and they had a large surface area per unit weight. In general, the specific surface area of fines is 5-8 times that of fibers (Unbehend 1992). Fines major influenced on drainage performance. This is mainly due to the fact that fines swell considerably in water. Fines retain two to three times more water than fibers and behave much like a gel to cause pulp freeness to decrease. This gelatinous nature retards the flow of water through the fiber interstices of the mat as it forms (Unbehend 1992).

### 4.2.2 Paper Strength

The strength properties of the pulps were analyzed in terms of tensile and burst indices, evaluated and presented in Figure 4.2.2 (a). According to the graphs, the pulps strength improved tremendously with beating. The comparison was made by observing the decrease in freeness associated with beating in the P.F.I Mill. Different between the freeness of the two were small, with the bleached pulp giving pulp giving the lower freeness.

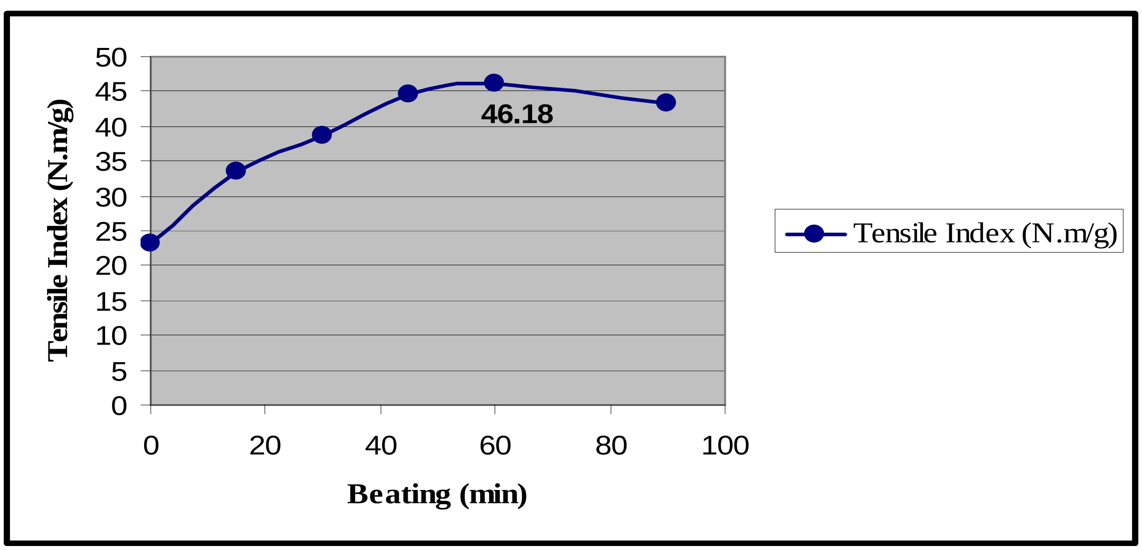



**Figure 4.2.2 (a):** The effect of beating on tensile indices

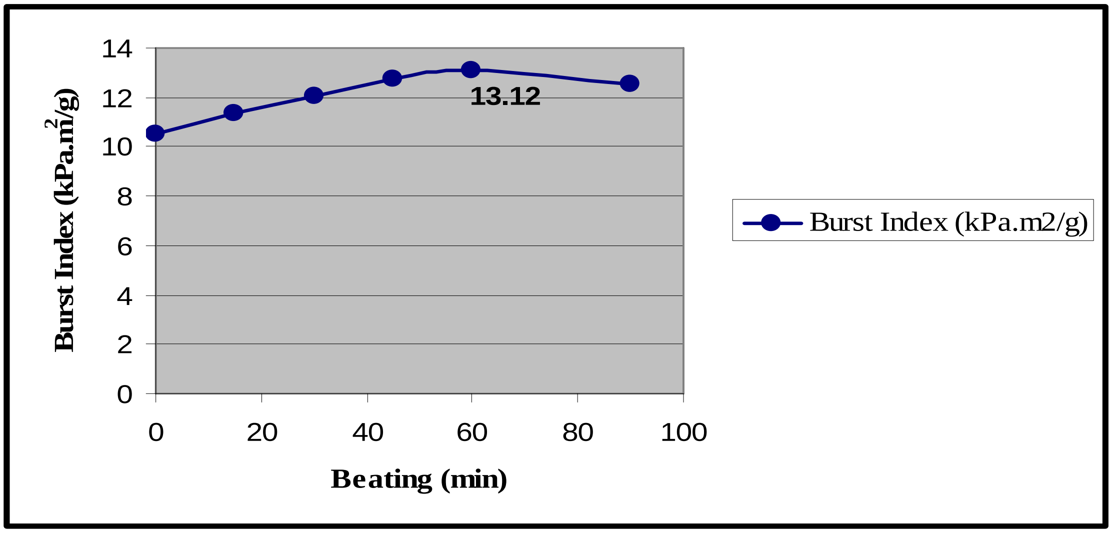



**Figure 4.2.2 (b):** The effect of beating on burst indices

The paper strength, with randomly oriented fiber is dependent on the strength of individual strength and number of bonds between them. The number of bonds is influenced by fibered flexibility. A flexibility fiber will have more surface area for bonding. Fiber flexibility and bonding potential can be determined from the paper apparent density (Law & Jiang 2001).

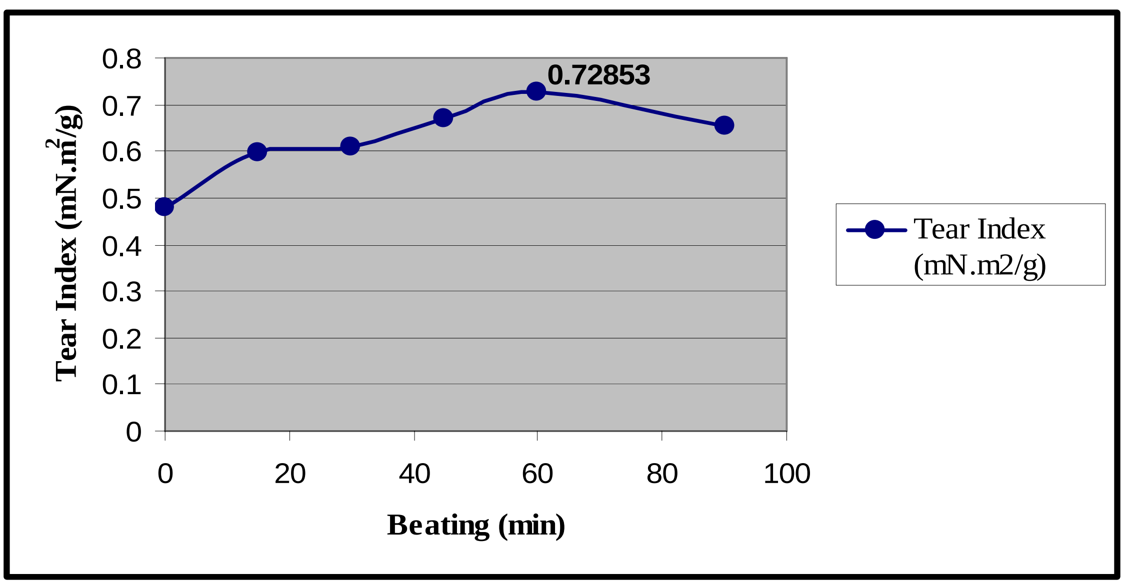



**Figure 4.2.2 (c):** The effect of beating on tear indices

Figure 4.2.2 (d) shows that as the apparent density were increased, the burst and tensile indices were also increased. It can be seen that the burst and tensile indices for bleached pulp were higher than those for unbleached pulp. These differences were consistent over most of the apparent density. The apparent density affected the burst and tensile indices in bleached pulp.

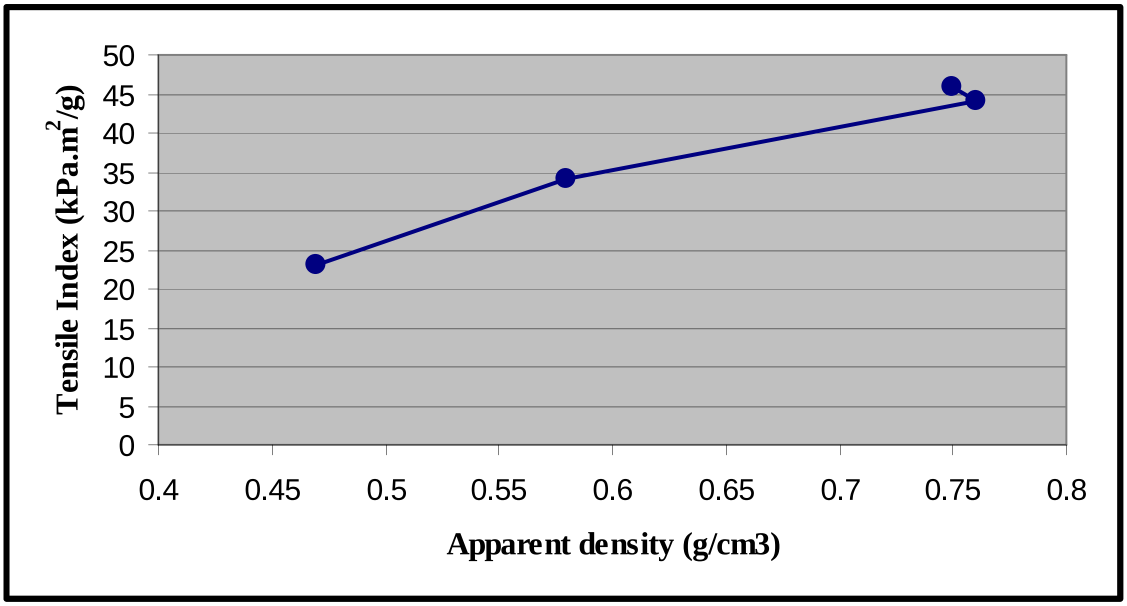



**Figure 4.2.2 (d):** Relationship between apparent density and tensile indices for OPF soda-AQ pulps.

Since the bleached pulp has a higher strength, its bonding strength is higher at the same apparent density of unbleached pulp. The removal of lignin during bleaching has increased the bonding strength due to the exposure of cellulose and hemicelluloses. Cellulose and hemicelluloses contain hydroxyl and carboxylic acid group that contribute to the interfiber bonding (Retulainen *et al*. 1998). According to the strength analysis the optimum condition is at 60 minutes cause of the high value of tensile, tear and burst index.

# CHAPTER 5

# CONCLUSION & RECOMMENDATION

## 5.1 CONCLUSION

This study showed that the beating of Oil Palm Frond (OPF) produced pulp with different drainage, strength and paper properties. The following conclusion may be drawn from the present study. During beating, the pulp's fiber length reduces in percentage as a result of fine and shortened fiber produced. The drainage is proportionally to degree of beating cause of the reducing in the fiber length. The freeness also gives the effect which is decrease the freeness of the fiber by degree of beating. Fine and shortened fiber has increased the surface area to absorb water. The strength of paper was analyzed in term of tensile, burst and tear indices. The optimum condition of the beating process for paper production of OPF pulp is at 60 minutes where the value of tensile index is 46.18 N.m/g, burst index is 13.12 kPa.m$^2$/g and tear index is 0.72853 mN.m$^2$/g.

## 5.2 RECOMMENDATION

As a recommendation for further study on paper production, continue with right bleaching stage and analyzed the effect of paper strength and properties. Other sources of raw material such as Oil Palm Trunk (OPT) can be used for the next research study. The effect of temperature and chemical concentration of sodium hydroxide (NaOH) also can be the scopes of the further study in paper production. The paper from OPF can be commercialized as a new source to change the wood base production. The wood base of paper production give the environmental drawback of sulphur contain emitted by the acidic sulphite and prehyrolysis-kraft pulping process. Economically, the productions of paper are profitable and have the potential market value.

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# APPENDICES A

**Appendix A.1:** Table for the fiber morphology analysis based on fiber length

| Beating (min) | Fiber Length (mm) |
|---|---|
| 0 | 0.95 |
| 15 | 0.9 |
| 30 | 0.75 |
| 45 | 0.55 |
| 60 | 0.42 |
| 90 | 0.4 |

**Appendix A.2:** Table for the drainage time analysis of OPF pulp fiber

| Beating (min) | Drainage (s) |
|---|---|
| 0 | 3.8 |
| 15 | 4.2 |
| 30 | 5 |
| 45 | 6 |
| 60 | 9.8 |
| 90 | 18 |

**Appendix A.3:** Table for the freeness measurement analysis of OPF pulp fiber

| Beating (min) | CSF (mL) |
|---|---|
| 0 | 535 |
| 15 | 520 |
| 30 | 450 |
| 45 | 420 |
| 60 | 280 |
| 90 | 120 |

**Appendix A.4:** Table for the paper strength based on tensile index

| Beating (min) | Tensile Index (N.m/g) |
|---|---|
| 0 | 23.14 |
| 15 | 33.44 |
| 30 | 38.74 |
| 45 | 44.68 |
| 60 | 46.18 |
| 90 | 43.31 |

**Appendix A.5:** Table for the paper strength based on burst index

| Beating (min) | Burst Index (kPa.m$^2$/g) |
|---|---|
| 0 | 10.51 |
| 15 | 11.32 |
| 30 | 12.02 |
| 45 | 12.74 |
| 60 | 13.12 |
| 90 | 12.53 |

**Appendix A.6:** Table for the paper strength based on tear index

| Beating (min) | Tear Index (mN.m$^2$/g) |
|---|---|
| 0 | 0.47955 |
| 15 | 0.59603 |
| 30 | 0.60874 |
| 45 | 0.67171 |
| 60 | 0.72853 |
| 90 | 0.65496 |

**Appendix A.7:** Table for reduction of fiber length based on beating effect

| Beating (min) | Beating Difference (%) |
|---|---|
| 15 | 10 |
| 30 | 20 |
| 45 | 43 |
| 60 | 55 |
| 90 | 62 |

**Appendix A.8:** Table for apparent density of paper based on tensile index

| Apparent density ($g/cm^3$) | Tensile Index (N.m/g) |
|---|---|
| 0.47 | 23 |
| 0.58 | 34 |
| 0.76 | 44 |
| 0.75 | 46 |

**APPENDICES B**

**Appendix B1:** Oven for drying OPF chips


**Appendix B2:** Scanning Electron Microscope (SEM) for fiber morphology

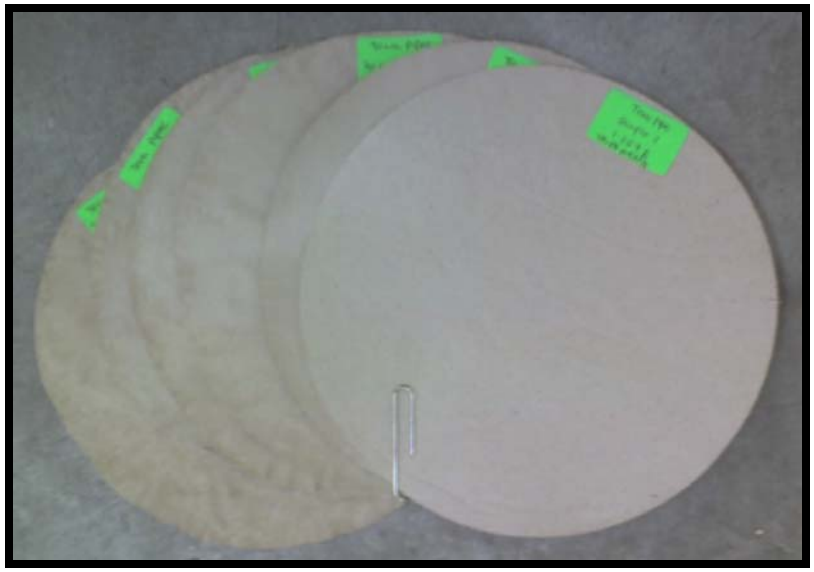
**Appendix B3:** Sodium Hydroxide (NaOH) pellets


**Appendix B4:** Anthraquinone (AQ) powder

**APPENDICES C**

**Appendix C1:** Oil Palm Frond (OPF) chips

**Appendix C2:** OPF Soda-AQ pulp



**Appendix C3:** Paper from OPF

**Appendix C4:** Beating Equipment (P.F.I Mill)