CHAPTER 1

INTRODUCTION

1.1 The Oil Palm

The oil palm, *Elaeis guineensis* Jacquin, was first introduced into Malaysia in 1870, through the Botanic Gardens in Singapore (Ministry of Agriculture and Co-operatives, 1966). The oil palm industry was introduced to Malaysia in 1917 and since the late 1960's, Malaysia has ranked as the world's largest producer and exporter of palm oil. At present there are about 1.46 million hectares of plantation capable of supplying 4.1 million tonnes of crude palm oil annually. By the year 2000, it is predicted that the area under oil palm plantation would be doubled and the production of six million tonnes of palm oil per year is forecasted (Husin *et al.*, 1985).

As 1960 was the start of an accelerated cultivation of oil palm, 1985 was viewed as the start of a major replanting era of the oil palm industry, since the average life-span of the oil palm is about 25 years. The end of this decade would see the peak of the replanting era of the oil palm industry. Table 1 shows that in 1985, the estimated area replanted was only 3,043 hectares but by 1998 this will reach a maximum total area of 89,000 hectares (Husin *et al.*, 1985).

Table 1: Expected replanting area of oil palm plantation from year 1985 to 2000 (in hectares)

YEAR	W. MALAYSIA	E. MALAYSIA	TOTAL
1985	3,035	8	3,043
1986	4,321	130	4,451
1987	5,500	368	5,868
1988	7,700	824	8,524
1989	9,650	1,938	11,588
1990	11,500	4,204	15,704
1991	21,150	7,342	28,492
1992	30,250	9,932	40,180
1993	35,500	12,822	48,322
1994	39,400	15,356	54,756
1995	37,150	14,872	52,022
1996	38,550	13,220	51,770
1997	62,100	11,138	73,238
1998	79,000	9,996	88,996
1999	76,100	8,628	84,728
2000	75,800	7,794	83,594

Source: Husin *et al.*, 1982

With a great amount of replanting annually, there is an enormous amount of lignocellulosic residue generated principally in the form of felled trunks and fronds. These by-products in general consist of cellulosic fibres cemented by lignin which is similar to wood. The trunks and fronds are generally not utilised, posing a serious disposal problem. The present practice of burning creates a serious pollution in the area.

The Oil Palm Tree Utilisation Committee (OPTUC), comprising of the Palm Oil Research Institute of Malaysia (PORIM), the University of Agriculture (UPM) and the Forest Research Institute of Malaysia (FRIM), was set up in 1982 to find better uses of these lignocellulosic by-products. The main function of the committee is to identify and coordinate their research activities on the non-agricultural aspects of utilisation. One of the major projects of the committee is in the utilisation of the oil palm trunk as a raw material for various end-products such as wood-based panel and pulp and paper (Ayub, 1985).

1.2 Availability of oil palm trunks and fronds

Husin *et al.* (1986) estimated that the amount in dry weight of oil palm trunks and fronds available are 84 tonnes/ha and 16 tonnes/ha respectively, and the annual rate of pruned fronds is about 11 tonnes/hectare/year. With the present rate of replanting and area in production, the total availability of oil palm trunks, fronds and pruned fronds for 1985 alone exceeded 13.5 milllion tonnes. This would have doubled by the year 2000. Table 2 summarises the total annual availability of trunks and fronds from the year 1985 to 2000.

During replantation, the trunks and fronds are allowed to mulch *in situ*, a practice that raises some technical objections since it takes five to six years to completely decompose. It also encourages the breeding of insect pests and diseases which pose a threat to the subsequently planted young palms. Burning has been tried but this is a lengthy and costly operation and not always successful because the trunks do not burn easily.

Pruned fronds, stacked in various ways in palm inter rows has been reported to be beneficial to feeder roots because moisture is conserved in the soil. Surface erosion is limited and the fronds also provide nutrients to the palms. However, their utilisation in oil palm plantations has been reported to harbour rats, snakes and insect pests (Husin *et al.*, 1985).

The mid-ribs from the leaflets are used to make local brooms or "penyapu lidi". This is usually carried out by the female members of the oil palm estates on a part-time basis with little income gained.

Table 2: Estimated total annual availability of trunks and fronds from year 1985 to 2000 (in million dry tonnes)

YEAR	TRUNK	FELLED FRONDS	PRUNED FRONDS	TOTAL
1985	0.26	0.05	13.29	13.60
1986	0.37	0.07	14.21	14.65
1987	0.49	0.09	14.97	15.55
1988	0.72	0.12	15.69	16.53
1989	0.97	0.19	16.34	17.50
1990	1.32	0.25	16.92	18.49
1991	2.39	0.46	17.35	20.20
1992	3.29	0.64	17.64	21.57
1993	4.06	0.77	17.85	22.68
1994	4.60	0.88	17.89	23.46
1995	4.37	0.83	18.17	23.37
1996	4.36	0.83	19.09	24.28
1997	6.15	1.17	19.39	26.71
1998	7.48	1.42	18.18	27.08
1999	7.12	1.36	17.92	26.40
2000	7.02	1.34	17.85	26.21
Total:	54.97	10.47	272.84	338.28

Source: Husin *et al.*, 1986

1.2.1 Physical properties of the trunks and fronds

At replanting age, the trunk ranges between 7 to 13 metre in height and measures 45 to 65 cm in diameter.

A mature palm may carry a crown of 25 to 40 fronds. The frond or leaf is pinnate with the leaflets (pinnae) arranged in two or more planes on each side of the rachis. The leaf consists of leaflets, each with a lamina (leaf blade) and midrib, a spiny petiole (the part of the leaf stalk between the lowest leaflets and the trunk) and a leaf sheath (Corley *et al.*, 1982).

1.2.2 Morphology of the trunks and fronds

The fibre dimensions of the trunk and frond are presented in Table 3. Comparison with other agricultural residues is found in Table 4.

Generally, the fibres from both trunks and fronds are short and thin, and are comparable in length to the fibres from deciduous woods but much shorter than that from coniferous woods.

Table 3: Morphology of the trunk and frond of the oil palm

	TRUNK*	FROND**
Average fibre length (mm)	0.96	1.59
Average fibre diameter (μ)	29.6	19.7
Average lumen diameter (μ)	20.0	11.8
Average cell wall thickness (μ)	4.8	3.95
Coefficient of suppleness (%)	67.7	59.9
Runkel ratio	0.5	0.67
Felting power (length/diameter)	32.5	80.7

Source: * Khoo and Lee, 1985

** Khoo, 1989

Table 4: Fibre dimensions of the oil palm in comparison with some agricultural residues and woody plants

FIBRE	AVERAGE LENGTH (mm)	AVERAGE DIAMETER (μ)	LENGTH/DIAMETER
Oil palm frond*	1.59	19.7	81
trunk**	0.96	29.6	32
Straws and Esparto	1.1-1.5	9-13	110-120
Rice straw	1.45	8.5	170
Stalks and reeds	1.0-1.8	8-20	80-120
Sugarcane fibres	1.7	20	85
Woody stalks with bast fibres:			
woody stems	0.2-0.3	10-11	<30
bast fibres	20-25	16-22	>500
Leaf fibres	6-9	11-16	250-300
Bamboos	3-4	14	200
Coniferous woods	2.7-4.6	32-34	750-90
Deciduous woods#	0.7-1.6	20-40	<50

Source: * Khoo, 1989

** Khoo and Lee, 1985

Ibrahim and Fouad, 1973

1.2.3 Chemical properties of the trunks and fronds

The chemical composition of the oil palm trunk and frond in comparison with that of some Malaysian hardwoods is found in Table 5. Table 6 presents the analytical comparison to some non-wood fibres.

The trunk has a composition similar to Malaysian hardwoods except for a higher pentosans content. The frond has a higher content of alcohol-benzene and alkali solubles compared to the hardwoods. The trunk with lower ash content, but higher in lignin, is more similar to bamboo than to grasses and straws. A low ash content is always desirable in the making of chemical pulp.

1.3 Potential uses of oil palm trunks

Studies on the utilisation of oil palm trunks for lumber and veneers, as a source of making fuel, panel products and pulp and paper have been conducted. These will be briefly outlined as follows.

1.3.1 Oil palm trunks as lumber and veneer

Little prospects are seen for the use of the oil palm trunk for sawn timber. Sawmilling trials have indicated that although it is possible to saw the trunks, it usually results in the rapid blunting of sawblades caused by the scattered vascular bundles.

Table 5: Analytical comparison of the proximate chemical composition of the trunk and frond of the oil palm to some Malaysian hardwood species (in percentage based on OD material)

CHEMICAL COMPOSITION	TRUNK*	FROND**	MALAYSIAN HARDWOOD SPECIES#
Ash	1.63	4.48	0.03-2.11
Alkali solubles	19.5	33.3	2.60-24.5
Alcohol-benzene	1.2	8.32	0.60-11.6
Hot water solubles	2.5	5.0	0.10-14.4
Lignin	22.6	16.1	12.70-34.2
Pentosans	25.9	23.4	4.20-20.7
Holocellulose	71.8	65.5	59.40-85.4
Alpha-cellulose	45.8	37.4	35.10-54.2

Source: * Khoo, 1989

** Khoo and Lee, 1985

Khoo and Peh, 1982

Table 6: Analytical comparison of the oil palm with some monocotyledon species (in percentage based on OD material)

RAW MATERIAL	Ash	Lignin	Pentosans	α-cellulose
Oil palm:				
frond*	4.48	16.1	23.4	37.4
trunk**	1.63	22.6	25.9	45.8
Straws and grasses#	6-8	17-19	27-32	33-38
Bamboo#	1-3	22-30	16-21	50+

Source: * Khoo, 1989

** Khoo and Lee, 1985

Misra, 1980

Ho *et al.* (1984) showed that the only part of the oil palm trunk having a better chance of being coverted into lumber is the peripherial zone of the butt end. The trunk could be peeled to produce reasonably good veneers from the inner zone, probably suitable as a core veneer in plywood manufacture.

1.3.2 Oil palm trunk as a potential source of energy

The estimated energy potential of the oil palm trunk is 17.5 MJ/kg (Shamsuddin and Nor, 1985). The potential energy available from the oil palm trunks generated by the Malaysian oil palm industry, was 4.6

million GJ in 1985 and is expected to reach about 120 million GJ by the year 2000. Presently the utilisation of oil palm trunks as an alternative renewable energy resource is absent due to the lack of an appropriate technology to harness the energy.

Studies by the Okura Company of Japan and a local company have indicated the feasibility of converting oil palm trunks in combination with empty fruit bunches and pressed fruit fibres into solid fuel pellets (PORIM, 1983). The pellets are made by briquetting 45% trunk, 45% empty fruit bunches and 10% pressed fruit fibres. The calorific value of this product at 4240 kcal/kg is similar to that of ordinary wood and the low sulphur content promises minimal pollution problems (PORIM, 1983).

1.3.3 Oil palm trunks in the production of panel products

The low average density of oil palm trunks renders the lignocellulosic material favourable for the manufacture of composite panel products such as cementboard, and particleboard due to less resistance to compaction. However, before the trunks can be used commercially, the problems of fungal attack on green trunks and the rapid blunting of knives in the flaking process must be overcome.

Research carried out at FRIM by Chew and Ong (1984) has indicated that is is possible to manufacture single-layer, homogenous particleboards made entirely from oil palm particles (vascular bundles) or in admixture with particles from other timber species, as well as three-layer particleboards, made from industrial wood wastes for the surface layer and oil palm particles for the core layer.

Preliminary studies have also indicated the potential of certain parts of the oil palm trunks in wood-cementboard manufacture provided the high carbohydrate content of the trunks can be reduced (Sudin *et al.*, 1987).

1.3.4 Oil palm trunks in pulp and paper

Research undertaken at FRIM on the potential utilisation of oil palm trunks in paper making has indicated positive results.

Fibre morphology has shown that the strands were rather similar to low density hardwoods in having a short average fibre length of 0.96 mm and a moderately low Runkel ratio of 0.48 indicative of thin cell walls (Khoo and Lee, 1985). These properties combined with a high coefficient of suppleness (>75%), suggested that good interfibre bonding is expected during sheet formation.

The proximate chemical analysis gave values close to those typical of Malaysian hardwoods except for a higher pentosans content (Khoo and Lee, 1985). The high pentosans content together with the high holocellulose content and low alcohol-benzene solubles were favourable in pulping of the trunk. The high pentosans content would be an added advantage as it imparts stiffness and low opacity to NSSC pulps.

A setback in the pulping of the trunks lies in the fact that the fibrous strands useful in pulping must first be removed from the embedment of non-fibrous tissue. This is necessary to provide not only a longer storage life of the pulping material but also to pave the way for a direct access to the papermaking fibre with a minimum consumption of chemicals.

The strands when subjected to sulphate pulping (Khoo and Lee, 1985) and NSSC pulping (Yusoff, 1985), were found to produce pulps of acceptable strength in moderate yields, both processes requiring low chemical input.

The raw material for sulphate pulping was usually first reduced to chips then broken up and screened to remove the pith (Khoo and Lee, 1985). Pulping was carried out in a six-litre M-K digester at 160°C for three hours with the active alkali at 10 -14% and sulphidity of 25%. According to Khoo and Lee (1985), bleaching of the pulp with a kappa number of approximately 20 by the chlorination-alkali extraction-hypochlorite (CEH) sequence gave a drop in yield of almost 10% and a low brightness of 67%, as well as a general drop in strength properties. However, on beating, the tearing strength of the bleached pulp remained practically constant down to the lowest beating point.

In NSSC pulping, the trunks which had been soaked under waterr to prevent rotting, were normally flattened under a hydraulic press and then manually pounded to separate the parenchyma cells from the fibrous strands. Thorough cleaning of the strands was carried out in a hydrapulper. According to Yusoff (1985), pulping the fibrous strands in six-litre M-K digesters at 170°C for 1.5 to 2 hours, produced partially softened material that can pass through a Bauer refiner. A low chemical charge of 4 - 10% sodium sulphite was needed for moderate pulp yields (62 - 70%) but excessive addition of sodium carbonate (up to 12%), a buffering agent, was required to maintain non-acidic pulping conditions. Sulphate pulps, although not exceptional in properties could possibly be converted into medium grade wrapping and packaging papers and paperboards. Writing and printing papers could also be made provided the brightness of the bleached pulp is improved. NSSC pulps could be used to make coarser grades of paper such as corrugating medium and printing and writing papers.

1.4 Potential uses of oil palm fronds

1.4.1 Potential uses of oil palm petiole

The fronds consist of petioles on which the leaflets are attached.

Studies on the papermaking potential of the petiolles conducted by Joedidobroto (1982) indicated good strength properties.

Fibre morphology indicated that the fibres were slender and that there was distinct difference in cell wall thickness between the peripherial and inner fibres. The fibres at the periphery had thicker walls, small lumen diameter and longer lengths compared to the fibres at the inner layers.

The falting power (length to diameter ratio) of the peripherial fibres (138) were similar to bamboo fibres while that of the inner fibres (91) were similar to that of the eucalyptus species (Joedidobroto, 1982).

The chemical composition of the oil palm petiole showed similarities to bamboo except for a higher lignin content (18.80%), a lower alcohol-benzene content (4.45%) and a higher ash content (4.08%).

The petioles were subjected to preliminary pulping trials by the soda, sulphate and soda anthroquinones process. Like the trunk, the petioles contain parenchyma cells useless in pulping. By putting the petiole chips into a refiner at a high clearance and screening afterwards 18% of the unwanted material was removed.

According to Joedidobroto (1982), pulping was carried out in digesters heated by hot air. The petioles were cooked for 4 hours at a temperature of 155^{o}C and 165^{o}C. Liquor to wood ratio was maintained at 4:1.

The soda process gave the least delignified pulp with high screenings. Delignification could be improved with the addition of a small amount of anthroquinone (0.15%), to give results similar to those from sulphate pulping with similar active alkali charge and 20% sulphidity (Joedidobroto, 1982).

Evaluation of the physical properties of the handsheets showed similarities to pine sulphate pulps except for burst values. Breaking length values were quite high, similar to softwood pulp (Joedidobroto, 19982).

1.4.2 Potential uses of oil palm leaflets

Studies carried out by Top and Kato (1985a) on the oil palm leaflets have indicated that the leaflets contain a high concentration of vitamin E in a chloroform-methanol extraction.

Thin layer chromatography, high performance liquid chromatography and mass spectrometry studies on the Vitamin E components showed that alpha-tocopherol was the major homologues. The estimated potential availability of Vitamin E from oil palm leaflets was reported to be about 89,000 tonnes in 1985 increasing up to 961,000 tonnes by 1990. In view of the concentration of tocopherols in palm leaflets, this renewable resource has been recognised as a potential source for industrial extraction of the compound.

Since the leaflets have so far found no economic utilization, a more thorough study on its utilisation should be implemented. The conversion to paper pulp is one approach.

INTRODUCTION TO PULP AND PAPER

1.5 The nature of paper

The word "paper" is used to describe a felted sheet of fibres formed by introducing a water suspension of the fibres onto a fine screen. The water drains through the screen, leaving a wet sheet of paper which is removed and dried. Additives of one or several kinds are usually introduced before or after the sheet is formed to obtain desired properties. There is no sharp line of demarcation between paper and paperboard. Generally, paperboard is thicker, heavier and less flexible than paper (Browning, 1977).

Paper is not defined uniquely by the composition of the fibres used in fabrication. Sheets of paper can be made from fibres of asbestos, wool, glass, plastics, metals and many other materials; some of these are in commercial production. The cost is generally greater than that of papers made from cellulose fibres, but the desirable and often unusual properties of many papers made from non-cellulose fibres justify their use in some applications (Browning, 1977).

Although the paper sheet is usually formed from a suspension of fibres in water, other fluids can be used. Water is common and inexpensive and the swelling and fraying of cellulose fibres in water during mechanical processing contribute unique properties to the paper (Browning, 1977).

Sheets of papyrus made by pressing the pith tissue of a sedge, *Cyperus papyrus*, were used for writing as early as 3000 B.C. in Egypt. In China, strips of bamboo were used for drawing and writing until the discovery of paper which is attributed to Ts'ai Lun in A.D. 105. The original paper was made in China from rags, bark fibre and bamboo (Hunter, 1930).

The craft spread to Korea and Japan and found its way westward. Paper making was introduced into Europe in the fourteenth century and to England and America in the fifteenth century (Browning, 1977).

Before the invention of the paper machine in 1800, paper was made by a tedious hand process. Fibrous material such as cotton or linen rags and hemp were stamped or pounded in water until they reached the desired condition for paper making (Hunter, 1930). With the introduction of the paper machine, the laborious hand process declined in importance.

The growing demand for paper exceeded the capacity of hand production and supply of fibres previously used. With the greater production now made possible, attention was directed towards other sources of fibres.

During the nineteenth century, methods were developed for the manufacture of mechanical and chemical pulps from wood, which gradually established a commanding position as the principal supply of fibrous raw material for papermaking (Browning, 1977).

1.6 Cellulose and its properties

The plant cell walls in wood are composed of cellulose and hemicelluloses bound together by lignin. In the cell wall, cellulose chains aggregate to form long thin threads called microfibrils. Microfibrils, in combination with the other matrix materials provide the necessary rigidity and stress resistance in the plant (McGinnis and Shafizadeh, 1980).

For the pulp and paper producer, the degradation of the cellulose and hemicellulose must be kept at a minimum in order to obtain high yields and to retain many of the physical and mechanical properties of the fibre (McGinnis and Shafizadeh, 1980).

Cellulose is highly susceptible to oxidising agents such as chlorine and hypochlorite which are widely used in bleaching pulp (Casey, 1952).

1.6.1 Hemicellulose

The cellulose and lignin of plant cell walls are closely interpenetrated by a mixture of polysaccharides called hemicellulose. The name hemicellulose was proposed to designate those polysaccharides extractable from plants by aqueous alkali. Today the term hemicellulose designates the cell-wall polysaccharides of land plants, excluding the cellulose and pectin compounds (McGinnis and Shafizadeh, 1980).

1.7 Lignin

Lignin is a highly oxygenated aromatic polymer with a repeating phenylpropane skeleton. It is the structural component that provides wood with its unique elastic and strength properties. It is a material that absorbs compressive forces. It thus becomes of consequence not only to the development of a water-conducting system, but also to the tree's need to support a crown many feet above ground level (Glasser, 1980). If the concept of lignin is derived from morphology, it may be defined as a system of tridimensional polymers, which permeates the membranous polysaccharides and the spaces between the cells, thereby strengthening them (Pearl, 1962).

1.7.1 Delignification: separation from woody tissues and fibres

Delamination (removal of lignin) is made difficult by the gigantic molecular size of lignin and by the existence of covalent bonds between the binder and the carbohydrate components of the fibre. On the other hand, delignification is facilitated by the magnitude of differences in chemical properties between the lignin and the other fibre components, or in chemical terms, between the phenolic and the saccharidic wood components (Glasser, 1980)

Alkaline pulping operates on the basis of hydrolytic (or possibly homolytic) depolymerization of phenylalkylethers, thereby reducing the size of the lignin molecule and simultaneously generating new solubilizing phenoxide ions causing lignin to dissolve in alkali (Glasser, 1980).

1.8 Pulping

Pulping converts wood chips into separate fibres by the chemical reaction between lignin and the active chemicals in the cooking liquor (Nolan, 1970).

Pulping or cooking is achieved by chemical or mechanical means or their combinations. In a mechanical pulping the original chemical constituents of the fibrous material are unchanged except for removal of water solubles. Chemical pulping has as its main purpose, the selective removal of the fibre-bending lignin to a varying degree with a minimum removal of the hemicelluloses and celluloses (McGovern, 1980). If white papers are to be made, this purification is continued in the bleaching stage. Further purification for the production of chemical pulps with a high alpha-cellulose content may be carried out in the bleaching phase (Rydholm, 1965).

The properties of the end product, the paper and the paperboard, will depend on the properties of the pulps used in their manufacture. These in turn will vary with the wood species or nonwood plant fibre used and the pulping process employed. The major types of pulping processes will be discussed briefly in the following section.

1.8.1 Alkaline pulping

The two principal alkaline processes used for pulping of wood are the soda and the sulphate processes. Sodium hydroxide is the main cooking chemical. In the sulphate process, however, sodium sulphide is also involved (Rydholm, 1965).

In the soda process, the fibrous materials are digested in a solution of caustic soda (NaOH) at 170°C to 175°C. Soda pulp is made principally from material are unchanged except for removal of water solubles. Chemical pulping has as its main purpose, the selective removal of the fibre-bonding lignin to a varying degree with a minimum removal of the hemicelluloses and celluloses (McGovern, 1980). If white papers are to be made, this purification is continued in the bleaching stage. Further purification for the production of chemical pulps with a high alpha-cellulose content may be carried out in the bleaching phase (Rydholm, 1965).

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In the soda process, the fibrous materials are digested in a solution of caustic soda (NaOH) at 170°C to 175°C. Soda pulp is made principally from hardwoods. In combination with other kinds of pulp, it contributes bulk and opacity and is of particular value in book papers. However, soda pulping has declined in importance with the growth of the sulphate industry (Browning, 1977). Sulphate pulp has better strength over soda pulp while incurring less expenditure (Bryce, 1980).

The sulphate process is an offspring of the soda process. The term sulphate is perhaps a misnomer as it might cause one to suspect that sulphate rather than sulphide is used in the actual cooking. Sodium sulphate is however, the makeup chemical in the sulphate process, and sodium sulphide is a product of the sodium sulphate in the recovery furnace, where the makeup chemical is added (Bryce, 1980).

The name kraft (from the German and Swedish words for strong) has been applied to this process because the pulps produced are very strong particularly when the cook is terminated while the lignin content is still at a relatively high level. The kraft process is superior to the soda process with respect to the rate of pulping, pulp yield, pulp quality and production cost. It is also widely applicable as any wood species can be used, allowing wide flexibility in wood supply. The cooking cycle requires about 3 to 4 hours at a temperature of 170 to 175^{o}C (Bryce, 1980).

1.8.2 Sulphite pulping

The sulphite process has a significant role in the production of chemicals for nearly a century. That role has declined and the growth in chemical pulp production has been almost entirely in the kraft process. This is mainly due to two reasons: firstly, only a limited number of wood species could be pulped and secondly, the pulps produced were distinctly weaker (Bryce, 1980).

In the conventional acid sulphite process, the fibrous materials are pulped with a cooking liquor containing sodium bisulphite with an excess of free sulphurous acid. The maximum temperature during pulping is about 145°C. The mitscherlich sulphite pulp on the other hand is produced by digestion at lower temperatures but for longer periods of time than those applied in the usual acid sulphite pulping. The pulp is used extensively in glassine and greaseproof paper (Bryce, 1980).

1.8.3 Modified sulphite process

The bisulphite process employs sodium bisulphite or magnesium bisulphite as the active chemical. No free sulphurous acid is present and the pH of the cooking liquor is about 4.5. The pulping temperature is in the range of 155 to 170^{o}C (Bryce, 1980).

Neutral sulphite or neutral sulphite semichemical (NSSC) pulps are produced by digestion with a liquor containing sodium sulphite as the active chemical. The liquor also contains sodium carbonate to ensure that the cook remains slightly alkaline (Bryce, 1980).

NSSC pulping is mainly used for the production of high-yield pulps from hardwoods. The wood is delignified only partially and mechanical fibrerization is thus required. The product obtained, high in residual lignin, is especially suitable for use as corrugating medium (Sjostrom, 1981).

1.8.4 Bleaching of chemical pulps

The unbleached pulps produced by any of the common pulping processes contain residual lignin and coloured materials. Pulps with improved whiteness and greater stability are produced by a process known as bleaching (Casey, 1952).

The most important bleaching agents are chlorine (C), hypochlorite (H), chlorine dioxide (D) and hydrogen peroxide (P). They are usually applied in one of several sequences to conserve bleaching chemicals and to minimise degradation of cellulose and other carbohydrates in the pulp. Intermediate steps of washing or alkaline extraction (E) are usually introduced (Casey, 1952).

Many different sequences are used in a commercial bleaching, depending on the properties of the unbleached pulp and the characterisitcs desired in the bleached product.

Common sequences include CEH, CEHD or CEHP when higher brightness is desired. More extensive multistage bleaching include CEHP, CEHD, CEDEC, CEHEDP and CEHDPD.

A recent development is based on a first bleaching stage with oxygen under pressure (O), followed by conventional bleaching sequences, e.g., the sequence CEDED becomes OCEDED (Browning, 1977).

1.8.5 Mechanical pulp

Mechanical pulp of wood or groundwood is produced by mechanical action only in the presence of water. As only water-soluble constituents of the wood are lost in the process, a high yield of 95% or more is possible. Most groundwood is made from softwoods, although some of the lighter coloured hardwoods are also suitable (Daniell, 1980).

Groundwood contributes absorbency, bulk and opacity to a paper sheet and is lower in cost than chemical pulp. Important uses of groundwood are in book and catalogue papers, newsprint, wallpaper, wrapping papers and paperboards (Daniell, 1980).

1.8.6 Other processes

Semichemical pulps are produced by processes which remove less of the lignin than the full chemical process. They include NSSC pulp, described earlier, as well as sulphate pulps (semikraft) produced by a less complete pulping than normal.

Defibrated pulps are made from hardwoods or softwoods by passing chips through a "defibrator" at elevated temperatures. The pulps are used in hardboards, insulating boards and roofing felts (Browning, 1977).

1.8.7 Variables in pulping

There are a large number of variables that affect a pulping process. Some of the important variables in alkaline pulping are discussed below.

Chip quality affects a number of key aspects to the process: overthick chips result in nonuniform penetration of cooking chemical and high screen rejects. Fines and pin chips cause a high level of resistance to liquor flow and blockage of liquor-collection screens in both batch and continuous digesters. Chip-bulk density (which depends partially on chip shape) affects digester production. Over and under sized result in loss of material on screening and add to mill wood costs. Finally the ability of chips to flow in bins and feeders depends on their geometry and structure.

Among the parameters in a pulping process for a given species of wood, the most important are given below (Wenze, 1970).

(i) physical and chemical properties of the wood
(ii) degree of subdivision of the wood
(iii) composition of cooking liquor
(iv) concentration of cooking liquor
(v) ratio of active chemical to wood
(vi) temperature of cooking
(vii) time of cooking

1.9 Pulps from nonwood fibres

Paper has been made from a wide variety of fibrous raw materials, but only a few of these have reached a significant commerical production. Nonwood plant fibres for pulp are classified into three main categories, in terms of their source, availability and fibre characteristics (Misra, 1980).

1.9.1 Agricultural and agro industrial

Cereal rice straw and sugarcane bagasse fall under the category. Historically, cereal straw is the oldest papermaking material. 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 1920's. The decline of straw pulping began when straw collection, handling and storage became increasingly difficult in the face of rising labour costs and changes in harvesting methods. Straw pulping, which once thrived in the United States, gradually lost ground against rapidly expanding wood pulp production and it is now virtually abandoned.

On the other hand, straw as a base for the pulp and paper industry has made steady progress in many European countries where pulpwood supplies are extremely limited and the purchase of wood pulp from outside is too expensive to support local paper production. Corrugating medium, boards and packaging paper are produced from high-yield unbleached pulp and bleached straw pulps are used as a major furnish for fine quality writing, printing and other paper grades (Misra, 1980).

Bagasse is the fibrous residue of the sugar cane left after the crushing and extraction process. The quality of bagasse is dependent on the variety of cane, age at cutting, agronomic and soil conditions, and the extent of crushing and milling operations carried out on the cane in the sugar mill (Browning, 1977).

Bagasse, being a by-product of the sugar cane industry, enjoys a unique position among the non-wood fibres for pulp manufacture, mainly due to its availability in large quantities at a central collection point.

The high pith content of the stalk, which represents 30% by weight of the stalk is a major obstacle to pulping. The pith is separated by mechanical means and the stalk material is usually cooked by soda, kraft or neutral sulphite process. Bagasse pulp is used for the manufacture of wallboards and insulation boards (Browning, 1977).

1.9.2 Natural growing plants

Bamboo is the major source of raw material for pulp and papermaking in Asia. The pulp produces a soft and bulky sheet which finds applications in printing and writing papers. Better quality writing papers can be made by blending bamboo pulps with other pulps which provide improved strength properties (Misra, 1980).

Reeds or cane plants are becoming an important source of papermaking fibrese in Eastern Europe, Asia, the Middle East and Africa. The pulp is prepared by either the kraft or neutral sulphite process. The unbleached pulps are blended with wood pulp for manufacture of paper and paperboard and the bleached pulp in blends for printing and writing papers (Browning, 1977).

Esparto grass grows wild in North Africa and in the Mediterranean areas of southern Spain. It is a coarse grass, growing in large clumps. It has a longer fibre than most plants of this type, and the pulp is prized for special applications where good formation and strength is desired as in printing, books and some writing grades of paper (Misra, 1980).

Sabai grass is a supplementary source of raw material for production of bleached pulp in India and Pakistan. The grass is tough, strong and durable. Fibre length is 4.9 mm average.

Sabai grass is pulped in batch digesters by the soda process similar to the pulping of esparto grass. The quality of sabai grass pulp is also similar to esparto pulp and it is used in high-grade books and printing papers (Misra, 1980).

1.9.3 Cultivated fibre crops

These include bast or stem fibres such as hemp, flax, jute and kenaf. Bast fibres are present in hemp in the form of fibre bundles underneath the bark. The majority of these occur as strands, filaments or threads. The principal sources are Manila hemp, Sisal hemp and henequen (Mexican sisal). Used rope is one of the sources of these fibres (Misra, 1980).

These fibres are some of the longest in papermaking. They have outstanding strength and are used in applications where their properties cannot be matched by conventional wood pulps. Filter papers, condenser tissue and tea bags are examples of such uses.

Flax is grown extensively in Europe for use in the textile industry for the manufacture of linen fabrics. It is also cultivated in India and Argentina, primarily for the seeds, which are used to produce linseed oil for the paint industry.

Flax straw is treated by mechanical means to separate the long, strong bast fibres which are used for weaving. The leftovers are known as seed-flax straw tow. These are used for pulping. Flax fibres in the form of rags, spinning waste and threads are also used in pulp and papermaking. Although seed-flax straw contains the same long fibres as those present in waste linen fabrics, it also contains undesirable plant components, such as woody cells, epidermal cells and small vessels. Unbleached pulp produced from raw straw can be used where the presence of shives can be tolerated, as in bag and wrapping papers where the high strength is advantageous. However, to produce a high-grade pulp from the straw requires a substantial treatment to remove the unwanted woody fractions, hence the high cost involved.

The fibres are capable of making very thin papers with good formation, strength and opacity. Typical examples of such products are cigarette paper and Bible paper. Although flax pulp is expensive it can impart certain properties to paper that cannot be obtained from wood pulps (Misra, 1980).

Jute is an annual dicotyledonous, fast-growing plant cultivated exclusively in the hot and humid climate of India and Bangladesh. The fibres average 2 mm in length (Misra, 1980).

Whole jute is rarely used for pulp and papermaking. Salvaged products, such as old jute sacks and burlap, are the materials available to the paper mills. Jute is pulped by the soda process. Jute pulps are used in the manufacture of high-strength bags, wrappings, drawing papers and tags (Misra, 1980).

The kenaf plant is similar in appearance to corn and can be cultivated in semi tropical climates with high yields. It is grown as a source of bast fibre for twine and rope. Extensive research has been carried out on kenaf as a potential source of raw material for pulp and paper (Misra, 1980).

1.10 Reclaimed papers

Paper stock from reclaimed "waste" papers constitutes an important source of fibres and accounts for more than one-fifth of the total raw materials for the manufacture of paper and paperboard. The reclaimed papers and boards are disintegrated in water and the stock is processed to remove foreign materials. The most important uses are found in the manufacture of paperboards and in some grades of wrapping papers.

Deinking paper stock is produced from printed or unprinted reclaimed papers. A combination of mechanical disintegration and treatment with chemicals and dispensing agents removes most of the ink, filler and other extraneous materials. The stock is washed and usually bleached.

Deinked stock is used in the manufacture of book and printing papers, writing, office papers and tissues. Some newsprint is made from deinked old newspapers (Browning, 1977).

1.11 Noncellulosic fibres

Although noncellulosic fibres account for only a minor proportion of paper and paperboard products, they are finding use in specialities designed to meet the needs of specific end uses. Some synthetic fibres used in papermaking are polyethylene, polyesters, polyamides and many others based on cellulose derivatives.

Asbestos fibres have also been used in paper for many years. Usually they are combined with organic fibres to provide requisite strength in the sheet. Glass, quartz and ceramic fibres are now available for papermkaing; they are often blended with cellulose fibres. They contribute dimensional stability, heat resistance, low flammability, wet tensile strength and fluid permeability (Browning, 1977).

1.12 Fibre morphology

Wood quality affects the quality of pulp and ultimately the paper made from the pulp. Softwoods have been preferred to hardwoods for pulping because they have a predominance of tracheids, averaging 3 to 5 mm in length, that reputedly produce stronger paper than hardwood fibres. More careful analysis reveals cases where hardwood pulp are capable of certain values equal to or even greater than those of softwood pulps.

The most important parameters in determining pulp strength are the morphological features of the fibre such as fibre length, diameter and cell wall thickness.

The influence of fibre morphology on the paper making properties has long been established and the relation between fibre morphology and paper properties has been summed up by Dadswell and Watson (1962).

1.12.1 Fibre length

There are strong positive correlations between long fibres and tearing strength but not with other properties. Tensile strength, the property most commonly assocciated with strong paper, is more a function of fibre bonding than of fibre length; unbeaten softwood fibres produce paper very low in this property, even though they have long fibres.

Fibre length may actually be a detriment to good strength properties, as in the case of certain nonwood fibres, such as cotton, linen, flax and hemp. Fibres longer than 5 mm are difficult to handle due to their tendency to flocculate and form lumps in the paper. These fibres must actually be cut in order to fabricate paper with adequate formation and paper strength properties. There is little question, though, that tough paper requires relatively long fibres, i.e., softwood fibres (Bublitz, 1980).

1.12.2 Fibre coarseness

This is a broad term that encompasses lenght-to-width ratio and cross-sectional morphology (Bublitz, 1980). For the same length, some fibres are wider than others. The greater the length/width ratio, L/W, the greater the fibre flexibility and the better the chance of forming well-bonded papers.

Cross-sectional morphology can be broken into radial and tangential cell-wall thickness and lumen diameter. Each of these parameters must be considered relative to the other and as one approach to the problem, the Runkel ratio has been proposed.

$$\text{Runkel ratio} = \frac{2 \times (\text{radial cell-wall thickness})}{\text{lumen diameter}}$$

In general, fibres with a high Runkel ratio (>1) i.e., fibres with relatively thick walls, are stiffer, less flexible and form bulkier paper of lower-bonded area than low Runkel ratio fibres. This effect is related to the degree of fibre collapse during paper drying, a phenomenon affected by the cell-wall thickness and the degree of refining that the fibres undergo prior to papermaking. A Runkel ratio less than 1 indicates that the fibres have excellent paper making properties.

Chemical pulps made from thin-walled fibres swell in refining, collapse into ribbon-like shapes as they dry, forming large bonds.

The coefficient of suppleness (c.o.s.) can be expressed as:

c.o.s. = 1/W x 100,

where 1 = diameter of the lumen

W = diameter of the fibre

Generally a coefficient of suppleness greater than 75% indicates that the fibre has very thin walls and produces pulp of very good strength.

A coefficient of suppleness less than 30% indicates that the fibre has thick walls and produces pulp of very poor strength (Istas *et al.*, 1954).

The ratio of fibre length to diameter is more important than fibre length since it determines the felting characteristics of the fibre. The greater the ratio, the greater the tearing resistance of paper.

1.13 Outline of papermaking process

The process can be broken down into several stages as in the flow chart on the following page.

1.13.1 Pulp cleaning

Normally the pulp obtained after cooking will contain a portion of material that should be removed mechanically before bleaching or before the unbleached pulp is used in papermaking. Such material includes knots from the original wood, fibre bundles that have not been fullly disintegrated or other sources of shives. Such incompletely resolved materials consume large amount of bleaching agents, still remain poorer in colour than the pulp as a whole and may appear as specks, dirt or shives in the final paper.

The separation process employed in screening depends on differences between the dimensions of the fibres and of the materials to be rejected. It is continuous and requires low pulp concentration, hence large volumes of water are used.

Cleaning follows screening and is the final process of mechanical purification. It is a treatment specifically intended to remove small particles of dirt and grit that have been retained by the fibres. It employs density differences as the sorting factor.

OUTLINE OF PAPERMAKING PROCESS

PULP

Cleaning

Defribing

Papermaking machine
[sheet-forming, pressing and drying]

PAPER SHEET

Calendering
[produces glazed finish]

Sizing
[provides resistance to penetration of water, inks and oils]

Loading
[increases opacity and improves printing quality]

Colouring
[produces desired shade]

Coating

a. printing coating improves smoothness and printing quality and increases opacity

b. barrier coating provides resistance to water, oils and vapours

1.13.2 Defibring

The separation of the fibres in pulp is known as breaking or defibring. A hydrapulper can be used for this purpose. This method uses a large cup-shaped vessel, having at the bottom a propeller running at a very high speed. This throws the suspension of pulp and water towards and up the sides; it then falls down the centre towards the propeller again. This high-speed swirling can break up not only sheets of pulp or waste papers, but also whole bales.

After the breaking process, the pulp mixture is passed into a beater or refiner, whereby the fibres in water suspension are exposed to mechanical cutting and shearing actions of the machine. The fibres are shorten somewhat in length, but the main effect is the swelling and fraying or "fibrillation" at the fibre surfaces produced by the mechanical action. These changes are sometimes described as "hydration". The fibres become more flexible and conformable when the sheet is formed, and the paper has improved strength properties. A paper made from unrefined fibres is poorly bonded, weak, flabby and porous.

The quality and characteristics of the finished paper depend to a great extent on the treatment in the beater; this can be controlled to produce papers as widely different as a blotting or greaseproof papers. The type of fibre used and the type fo paper to be made are important factors to be considered in beating (Technical Section, 1949).

The Canadian freeness is a laboratory test that measures the readiness of the pulp to part with its water by drainage (Bublitz, 1980). In the test, the pulp is allowed to drain under standard conditions through a sieve. The resulting drainage water passes to waste through a small hole and the water over a certain level above it is taken off through an overflow and measured in a glass cylinder. A wet pulp gives a low Canadian freeness value. Freeness below 200 ml would render the pulp "wet" resulting in poor quality handsheets.

1.13.3 The papermaking operation

The paper machine is a complicated and elaborate mechanism for performing in a sequence the steps of sheet forming, pressing and drying. The fourdrinier and cylinder machines are the two most important types (Browning, 1977).

1.13.4 Calendering

The treatment known as calendering increases the smoothness and gloss of the paper surface. A calender comprises two or more cast-iron rolls with hardened surfaces, which are arranged in a set or "stack" and rest vertically on the other at the end of the dryer section in the paper machine. Almost all paper is passed through a calender as part of the papermaking process. A glazed finish is produced if the sheet is passed between rolls revolving at different peripheral speeds.

A supercalender is a calender stack which is constructed with alternate cast-iron rolls and soft rolls made up of highly compressed cotton or paper. Supercalendering alters the appearance and surface properties of the paper; the effects achieved are influenced by the temperature and moisture content of the paper during the process.

1.13.5 Sizing, loading and colouring

The manufacture of paper to meet the requirements imposed by specific end uses requires introduction of one or several materials in addition to the cellulose fibres. Resistance to penetration of water and ink is provided by sizing materials, particularly rosin, which are added to the stock before paper making. Starch,

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Loading of paper is accomplished by the addition of inorganic white pigments or fillers. Clay and calcium carbonate are used in the greatest volume. The pigments are introduced into papers intended for printing in which they increase the opacity and improve the printing quality.

Paper is coloured by addition of synthetic dyes or coloured pigments. Most of the coloured papers are made by dyeing and the papermaker may choose among a wide avriety of dyes for production of the desired shades. The dye or pigment is usually introduced into the stock before the sheet is formed. Papers are coated for printing or barrier purposes. The coating papers to be printed improves the smoothness and printing quality of the surface and also increases the opacity. Barrier coatings provide high resistance to passage of water, oils and vapours (Browning, 1977).

1.14 Properties of the paper sheet

A paper sheet is made to have a definite thickness and basis weight. The paper sheet in the laboratory is made to a basis weight of 60 ± 2 g/m^2 oven-dry grammage.

The true quality of paper is relative, for it is based on the fitness of a paper for a particular purpose (Norris, 1952).

The measurable properties of a paper sheet include strength and optical properties. These are often judged objectively by instrumental measurements. The important strength properties are tensile strength, folding endurance and resistance to tearing. The bursting strength is determined as the presssure required to rupture a specimen and is related to tensile strength and extensibility of the sheet. The L & W electronic Mullen burst tester can be used. Folding endurance can be determined on a Kohler-Molin type of tester. Using the Intellect 500, tensile strength can be measured while the Elmendorf instrument can be used to calculate the tearing resistance. The Gurley-Hill apparatus measures porosity.

Optical properties include opacity, whiteness and brightness. A satisfactory degree of opacity is required in printing and writing papers to avoid undesirable "show-through" from the opposite side of the sheet. Opacity is decreased by increasing the beating or refining of the stock, by pressing the sheet before and after drying or by calendering. It is increased by the addition of inorganic filling and loading agents or by the application of pigment coatings.

Whiteness is determined by the degree to which light is reflected uniformly over the visible spectrum (wavelength of 400 to 700 nm). Most pulps have a yellowish tint, and the paper is made to appear whiter by adding a small quantity of a blue dye.

Fluorescent dyes are used in many papers to icrease the whiteness and brightness. The brightness of papers can be measured as the percentage reflectance of light in the blue end of the spectrum usually in the neighbourhood of 457 nm.

1.2 Objective

The oil palm, a major economic crop of Malaysia, has seen a vast expansion of the areas under plantation due to increasing world demand for oils and fats, local demands, potential profitability and the need for agricultural diversification. In 1984, the total area under oil palm cultivation in Malaysia was about 1.4 million hectares, an increase of nearly 25 times since 1960, while the crude palm oil production has increased by almost 40 fold during the same period (Salam, 1985).

The oil palm cultivation and industry generate four types of lignocellulosic waste material. These are empty fruit bunches and press fibre, kernel shell, mill effluent, palm trunks and fronds. While the first three types are poroduced continuously at harvesting and processing of the fruit for its oil, palm trunks and fronds appear as wastes only periodically on replanting and pruning. Nevertheless, the amount of wastes generated from the trunk and frond is tremendous.

The oil palm has an average economic life span of 25 years and it has been estimated that the amount of felled trunks and pruned and felled fronds would be 12 million tonnes by 1990 in Peninsular Malaysia (Muthurajah, 1981). The total estimated production of leaflets from frond pruning and replanting was 4.7 million tonnes (dry weight) in 1985 and is expected to reach 5.6 million tonnes (dry weight) in 1990 (Top and Kato, 1985b). Thus the leaflets form the bulk in terms of dry matter of the total amount of lignocellulosic wastes generated by the oil palm industry.

Felled trunks and fronds have so far found no avenues of economic utilization and their disposal constitute a problem on replanting. One possible area in which the lignocellulosic raw material could be utilised lies in the conversion into pulp and paper. Peh et al. (1976) reported that satisfactory chemical pulps could be produced from the empty fruit bunches. Studies by Khoo and Lee (1985) also indicated that the production of unbleached sulphate pulps from the oil palm trunk is also feasible. The trunks were also found to be suitable for producing NSSC pulps of acceptable strength (Yusoff, 1985).

In the search for new fibrous resources for papermaking at a time when the scarcity of cellulosic raw matrerial is a problem worldwide, it is worthwhile to consider the oil palm plantation as a possible source. In this respect, there will be no competition for arable land since the formation of residues are an integral part of the care and maintenance of the oil palm plantation. Application of the lignocellulosic raw materials for pulp and paper is extremely promising because the future demand for paper in Malaysia is expected to be enormous and a steady supply of raw materials permits continuous operation of the pulp and paper mills. At present there is only one pulping mill in

East Malaysia. The eleven paper mills found here utilise pulp from secondary fibres derived from waste papers for the production of low quality paper and paper products which accounts for only 4% of the paper requirement of West Malaysia. The rest is imported from China, Australia, Canada and Japan (Sulaiman and Musli, 1983). Although the per capita consumption of paper in Malaysia is rapidly increasing, it still remained low at 27 kg in 1982 (Kobayashi, 1985) in comparison with the world average of 40 kg.

In view of the fact that Malaysia imports over M$300,000,000 (Ayub, 1985) of pulp and paper products annually, and the fact that she has only one pulping plant, it is highly appropriate that a strong emphasis is put into this research.

Of the pulping processes, chemical pulping by means of soda and sulphate were found to be suitable for the dominant raw materials among the non-wood fibres such as bagasse, bamboo, cereal straw, esparto grass and reeds (Misra, 1980). Studies done by Ezzat (1974) on date palm leaves indicate that reasonably high yields of pulp of acceptable strength can be obtained by the soda and sulphate pulping processes. Clark *et al.* (1970) produced soda pulp from the bark and core of kenaf (*Hibiscus cannabinum*) and found the pulps to be reasonably strong.

Based on previous studies, the soda, sulphate and NSSC pulping processes were applied in this research. Attempts to study the technical feasibility of producing chemical pulps from the oil palm leaflets were carried out.

This work reports the morphology and chemical composition of the leaflets, the laboratory soda and sulphate pulping processes and the physical testing of the bleached and unbleached handsheets.