

COMPARATIVE PAPERMAKING PROPERTIES OF OIL-PALM EMPTY FRUIT BUNCH

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ABSTRACT

Oil-palm empty fruit bunches (OPEFB) — an abundant agricultural residue in Southeast Asia — was chemically pulped in caustic soda. The physical and chemical properties of the resultant pulp were investigated and compared with Canadian aspen pulped under the same conditions. Physically, the OPEFB fiber had thicker cell walls and greater rigidity than aspen fibers. Chemically, the OPEFB fiber had particularly high solubility in hot water and in 1% NaOH, and it had a much higher ash content. The OPEFB pulps showed better response to peroxide bleaching than the aspen pulps. In general, they produced a sheet with lower tensile index but exceptionally high stretch, TEA, and tear index. The results suggest that OPEFB pulp can be blended with softwood pulp to produce liner, board, and printing–writing grades.

INTRODUCTION

Due to shortages in wood supplies, countries in Southeast Asia are expected to focus their attention on the development of alternative fiber sources such as bagasse and oil-palm fiber (1). It is reported that Malaysia produces 30 million metric tons annually of oil-palm biomass, including trunks, fronds, and empty fruit bunches (2). It makes good sense to fully exploit the potential use of this waste.

Oil palm, *Elaeis guineensis*, originally from the tropical forests of West Africa (3), is one of the most economical perennial oil crops. For its valuable oil-producing fruits, it was introduced to Southeast Asian countries such as Malaysia and Indonesia. Today, Malaysia is the largest palm-oil producer and currently accounts for 51% (6.5 million metric tons) of world palm-oil production. The economic life of the oil palm lasts only 25–30 years. During the pruning operation and upon each rotation of plantation, the felled trunks, empty fruit bunches, and fronds represent waste. Depending on the type of residue, it is mulched, burned as fuel, or burned in the fields. Although field burning is an economical option for disposing of the waste, it represents a major environmental problem. The potential use of these wastes in papermaking can solve most of the disposal problems. While this readily available material is of little cost, its processing for pulping is the main obstacle to commercial use.

This biomass has demonstrated potential as a raw material for paper and paperboard production. Since the 1980s, the suitability of this raw material for papermaking has been explored using a variety of pulping methods (4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15). Most of the studies used oil-palm trunks. Much less attention has been paid to the empty fruit bunches (EFB), which are the most important fibrous material left in the palm-oil mill after removal of oil fruit (seeds) from fruit bunches for oil extraction.

An earlier study (16) on chemical pulping of EFB fiber indicated that the alkaline process using sodium hydroxide alone appears to be the most interesting when its pulping efficacy and its environmental friendliness — in comparison with either sulfite or sulfate processes — are taken into account. The present work is a continued effort searching for a better process for converting the oil-palm EFB (OPEFB) into high-value paper products. The objective was to study the comparative pulping behavior and papermaking characteristics of OPEFB fiber vis-à-vis a common Canadian hardwood, trembling aspen (*Populus tremuloïdes* Michx.)

EXPERIMENTAL

Materials and characterization

The fibrous strands of OPEFB used in this study were obtained from an oil-palm mill in Malaysia. Fibers were prepared from fruit bunches of oil palm after being sterilized and stripped of their nuts. **Figure 1** is a photograph of a fruit bunch.



Figure 1. Photograph showing a fruit bunch of oil palm.

The OPEFB was mechanically treated to loosen the fibrous strands, which were washed, cleaned, sorted, and dried. **Figure 2** is a photograph of the fibrous strands from an empty fruit bunch. For comparison, chips of trembling aspen were also used.



Figure 2. Fibrous strands derived from empty fruit bunches.

Physical properties such as fiber diameter and cell-wall thickness were determined using 40- μm -thick cross-sections of the fibrous strands and a transmission light microscope (Zeiss Photomicroscope III). The cross-sections were prepared from the fibrous strands embedded in paraffin prior to microtoming. Some fibrous strands were macerated in a solution containing equal volumes of hydrogen peroxide and acetic acid, at 70°C, for about 3 h or until the fibers became readily separable by a gentle mechanical stirring. Fiber morphology data were obtained using a Fibre Quality Analyzer (OpTest Inc., Canada). The rigidity index (or the inverse of collapsibility of fibers) was calculated using $(T/D)^3$ (17), where T is the cell-wall thickness and D the external fiber diameter. The concept of using $(T/D)^3$ to determine fiber rigidity is based on the assumption that fibers act like a thin-wall cylinder whose collapse pressure is proportional to $(T/D)^3$.

The chemical characteristics of the fibrous strands are listed in **Table I**. These results were determined using TAPPI test methods: lignin (T 222), holocellulose (T 9), hot-water solubility (T 207), 1% NaOH solubility (T 212), alcohol–benzene solubility (T 204), dichloromethane (DCM) solubility (T 204), and ash content (T 211).

Pulping

Pulping trials were carried out using a laboratory minidigester (MK Systems Inc., USA) with a 6-L capacity. The digester is equipped with a recirculation system and an external electric heat exchanger. Caustic cooking (20% NaOH on an oven-dry (o.d.) basis of raw material) was conducted at 160°C for 30 and 90 min. A liquor-to-material ratio of 6:1 was used. The time to 160°C was about 25 min. The treated materials were first defiberized by means of a commercial blender (Waring, 4-L capacity) for 1.5 min at 5% consistency. The resulting coarse pulp (24 g o.d.) was beaten in a PFI mill at 10% consistency (CPPA method C.7) to produce several levels of freeness.

Bleaching

Prior to bleaching, the pulp was pretreated with 0.5% DTPA to sequester any metal ions that might be in the pulp. The pretreatment was conducted at 70°C, 5% consistency, for 5 min in a standard pulp disintegrator. The pulp was filtered, washed with deionized water, and thickened to a consistency of about 25%. The pulp sample impregnated with bleaching agents at 15%

consistency and sealed in a polyethylene bag was heated in a water bath at 70°C for 60 min. The furnish was intermittently mixed during the process. The other bleaching conditions were: 0.05% magnesium sulfate; 4.5% sodium silicate; 2.1%, 2.7%, 3.5%, and 4.5% NaOH; 3.0% and 5.0% hydrogen peroxide. At the end of bleaching, the pulp was diluted to 6% consistency using tap water, and its pH was adjusted to 5.5 using sodium metabisulfite.

Pulp characterization

Pulp freeness, handsheet formation, and the measurements of physical and optical properties were obtained using TAPPI test methods.

Property	Oil-palm empty fruit bunch	Trembling aspen
Length-weighted fiber length, mm	0.99	0.96
Fiber diameter (D), μm	19.1	20.8
Cell-wall thickness (T), μm	3.38	1.93
Fiber coarseness, mg/m	0.107	0.131
Fines (<0.2 mm), % (arithmetic mean)	27.6	18.1
Rigidity index, $(T/D)^3 \times 10^{-4}$	55.43	7.99
Lignin, %	17.6	18.1
Holocellulose, %	86.3	77.8
Hot water solubility, %	9.3	2.75
1% NaOH solubility, %	29.9	19.3
Alcohol–benzene solubility, %	2.83	3.7
Dichloromethane (DCM) solubility, %	1.12	1.5
Ash content, %	3.81	0.31

Table I. Physical and chemical characteristics of fibrous bundles of oil-palm empty fruit bunch and trembling aspen.

RESULTS AND DISCUSSION

Physical properties

As **Figure 3** shows, two vessels can be observed in the core region of a vascular bundle. The large open spaces surrounding the vessels are probably the areas where the phloem cells had been disrupted by the microtome knife. The vessel elements, which have a length many times longer than that of the fibers, are characterized with extensive pitting along their entire length, showing a springlike structure, as seen in **Figure 4**.

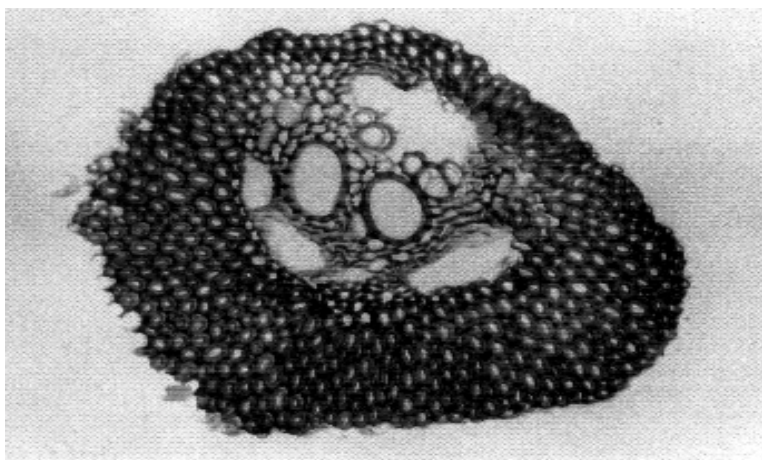


Figure 3. *Cross-sectional view of a fibrous bundle (magnification: 170X).*

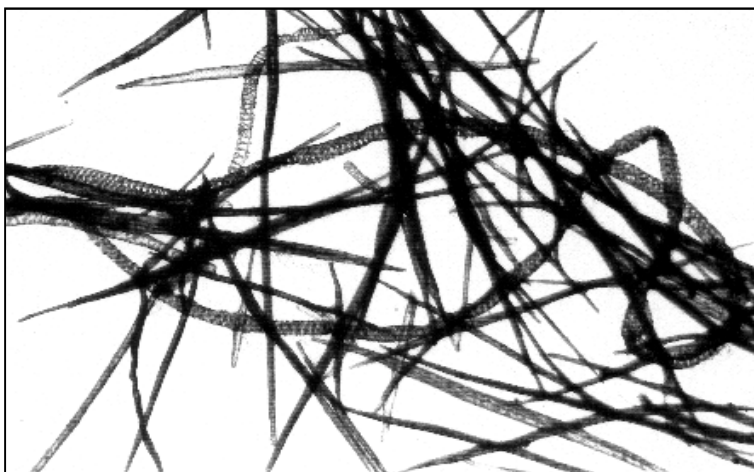


Figure 4. *Fibers and vessel elements from empty fruit bunches (magnification: 110X).*

The most striking physical characteristic of OPEFB fibers, in comparison with those of aspen, is their particularly thick cell walls (3.38 μm) and their high rigidity index, as seen in Table I. The low collapsibility of these fibers could have an adverse effect on their bonding capacity.

Chemical properties

Chemically, the fibrous bundles of OPEFB have a lignin content comparable with that of the Canadian aspen. Other studies have reported a similar lignin content for OPEFB (9, 18). The vascular bundles are rich in holocellulose (86.3%). Their considerably high solubility in hot water (9.3%) and 1% NaOH (29.9%) could contribute to low pulp yield and heavy loads in chemical oxygen demand (COD) and biological oxygen demand (BOD) of the resulting effluent. Oil-palm fibrous bundles are comparatively less resinous than those of aspen, as evidenced by the lower levels of extractives soluble in alcohol–benzene and dichloromethane (DCM). The high ash content (3.18%) of OPEFB bundles might have an undesirable impact on bleaching response and refining equipment.

Pulp properties

When cooked under the same conditions, the OPEFB gave substantially lower pulp yield than the Canadian trembling aspen, as seen in **Table II**. This difference can be attributed to the high extractable materials in the OPEFB, as indicated in Table I. This would mean that mills using OPEFB as a raw material would have higher BOD and COD charges in their mill effluents, in comparison with those using aspen as the main furnish. In future studies on OPEFB, attention should be paid to the toxicity level of the pulping effluent produced to evaluate its environmental impact on biological life.

	Oil-palm pulp 1	Oil-palm pulp 2	Aspen pulp 1	Aspen pulp 2
Cook time, min	30	90	30	90
Total yield, %	56.0	47.5	85.1	79.2
Kappa number ^a	48.7	48.0	104	85.5
Lignin ^b , %	6.14	1.79	15.4	12.0
Brightness, %	28.5	37.6	23.3	19.6
Light absorption, m ² /kg	13.7	10.1	13.9	15.9
^a TAPPI T 236				
^b TAPPI T 222				

Table II. Cooking data.

Due to their lower yields, the OPEFB pulps had lower kappa numbers when compared with aspen chemimechanical pulps, implying that the former is easier to be delignified. These kappa numbers are comparable with those of a softwood kraft pulp having similar pulp yield (19). Brightness of the unbleached OPEFB pulps was noticeably higher than that of aspen. Interestingly, the brightness of the former increased with decreasing yield, while that of aspen decreased. This suggests that the OPEFB is chemically different from the aspen wood and thus reacts dissimilarly with sodium hydroxide during cooking. In contrast to the aspen chips, OPEFB produced less of the chromophoric groups that are responsible for light absorption (Table II).

Table III indicates that the chemical pulp of OPEFB showed better response (brightness gain) to hydrogen peroxide bleaching than the pulps from aspen wood, which is the whitest hardwood in eastern Canada (20). The characteristics of the bleached pulps are shown in **Table IV**. In general, the bleach treatment improved sheet density and tensile strength and, as a result, reduced tear index, opacity, light scattering, and light absorption.

Bleaching conditions					
NaOH, %	0	2.1	2.7	3.5	4.5
H ₂ O ₂ , %	0	3	3	5	5
	Initial brightness	Brightness, point gain			
Oil palm 1	28.0	16.2	16.2	17.8	18.8
Oil palm 2	35.0	23.5	24.9	27.1	27.9
Aspen 1	23.5	13.3	13.3	14.5	16.9
Aspen 2	19.5	11.5	12.1	13.6	13.8

Table III. Brightness gains for unbleached and bleached oil-palm and aspen pulps.

Pulp properties	Oil palm 1		Oil palm 2		Aspen 1		Aspen 2	
	Unbl.	Bl.	Unbl.	Bl.	Unbl.	Bl.	Unbl.	Bl.
Freeness, mL CSF	230	150	210	160	265	170	270	160
Sheet density, g/cm ³	0.55	0.58	0.67	0.70	0.65	0.71	0.72	0.74
Tensile index, N·m/g	46.5	51.5	52.9	55.1	61.4	73.7	74.6	80.3
Stretch, %	4.43	4.43	5.62	5.2	1.88	2.33	2.63	2.45
TEA, g·cm	99	109	146	193	49	73	86	85
Burst index, kPa·m ² /g	4.4	4.7	5.3	5.3	4.3	5.2	4.8	5.9
Tear index, mN·m ² /g	12.5	12.3	13.2	12.4	7.5	7.0	7.6	7.0
Brightness, % ISO	27.8	47.8	37.2	64.1	23.1	40.0	19.5	34.6
Opacity, %	98.5	86.6	97.9	83.7	97.7	79.6	97.8	79.5
Light scattering, m ² /kg	33	33	38	37	26	22	21	19
Light absorption, m ² /kg	13.7	2.4	10.1	1.2	13.9	2.2	15.9	2.6

* 0.05% MgSO₄, 0.3% DTPA, 4.5% Na₂SiO₃, 3.5% NaOH, 5% H₂O₂, 70°C, 60 min, 15% consistency

Table IV. Properties of unbleached and bleached * pulps from oil palm and aspen.

The properties of the unbleached pulps are presented in Figures 5–13. Although the cooking conditions were identical for both raw materials, there was a substantial difference between them in terms of yield. For this reason, a just comparison between them would be difficult.

Handsheet density — a good indicator of the conformability of individual fibers in the fibrous network — reflects the fibers' bonding potential. Despite its substantially lower pulp yield (56%), the oil-palm pulp 1 produces sheets of significantly lower density compared with the aspen counterparts, as seen in **Figure 5**. With a yield of 48%, the oil-palm pulp 2 produced

sheets similar to those of aspen pulps in terms of density. These differences might be attributed to the high rigidity index of the oil-palm fibers, as discussed earlier.

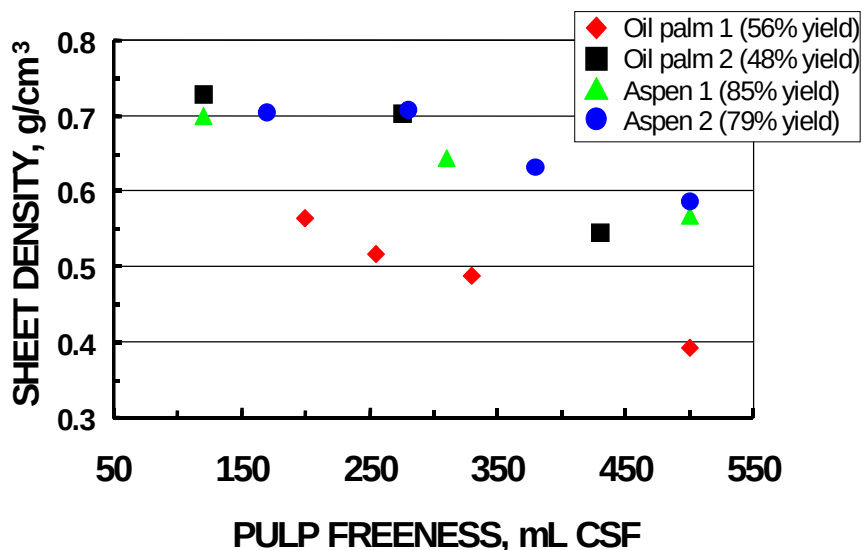


Figure 5. Sheet density as a function of freeness for unbleached aspen and oil-palm pulps.

The comparative bonding capacity of oil-palm fibers is illustrated in **Figure 6**, which reveals the low performance of these fibers in tensile strength. A pulp yield of 50% appears to be a critical upper barrier to produce good quality chemical pulp from the OPEFB.

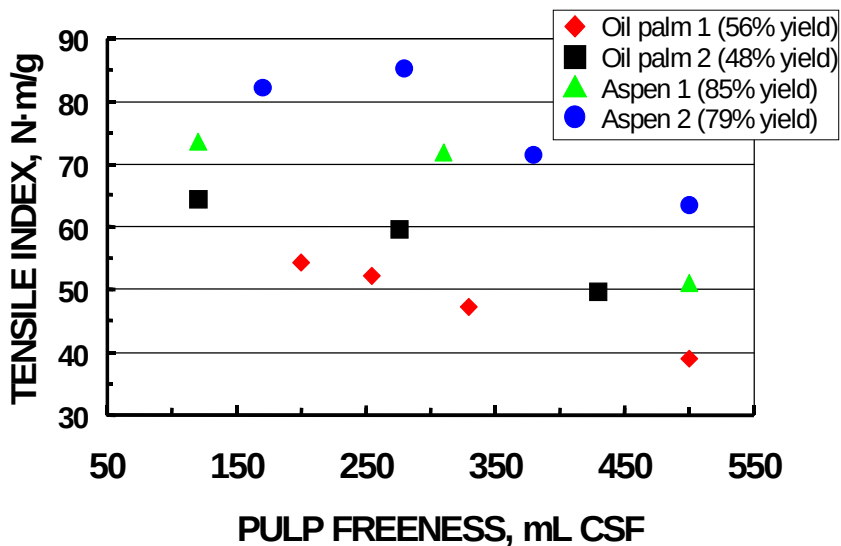


Figure 6. Tensile index as a function of freeness for unbleached aspen and oil-palm pulps.

For a given value of sheet density, the oil-palm fibers gave lower tensile index, as seen in **Figure 7**.

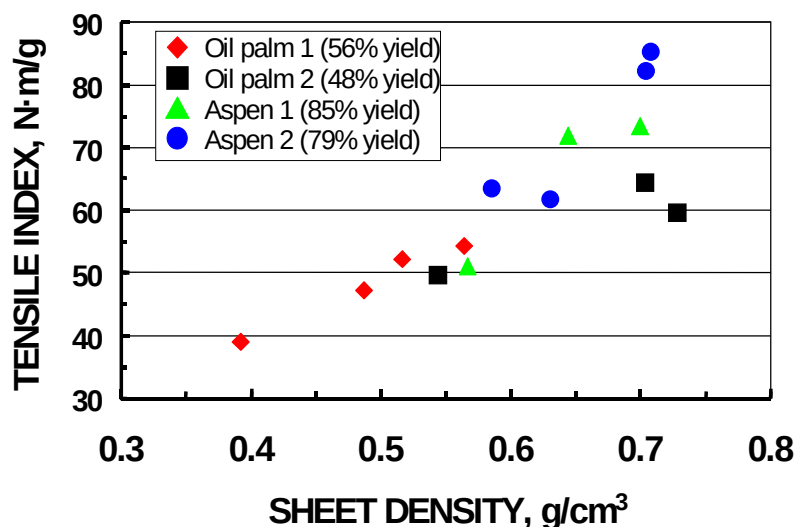


Figure 7. Tensile index vs. sheet density for unbleached aspen and oil-palm pulps.

In contrast to their relatively poor tensile strength, the oil-palm pulps showed exceptionally good tear index when compared with the aspen counterparts, as seen in **Figure 8**. It is believed that the relatively high rigidity index of fiber and the presence of long and springlike vessel elements in the oil-palm pulp are accountable for the excellent tearing resistance.

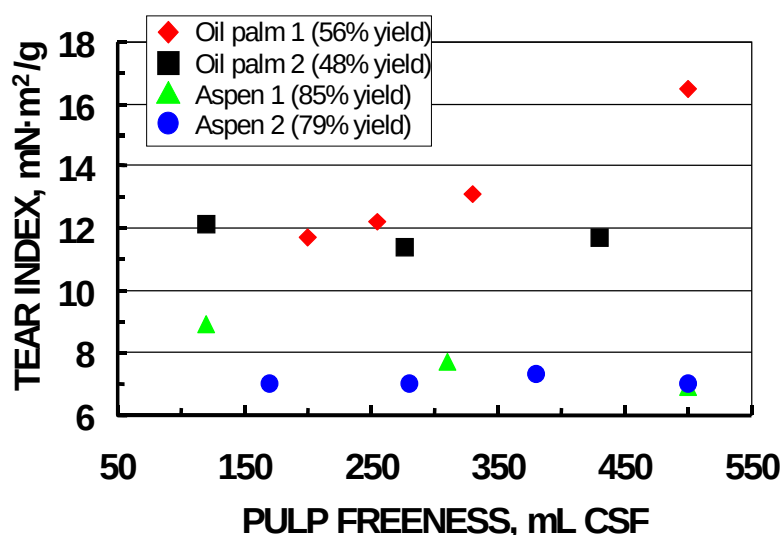


Figure 8. Tear index as a function of freeness for unbleached aspen and oil-palm pulps.

The distinct difference in tensile-tear relationship between these two groups of pulp is illustrated in **Figure 9**, which shows the possibility of making paper products with good tensile and tear strengths by blending the two types of fiber in optimum proportions that meet the desired requirement.

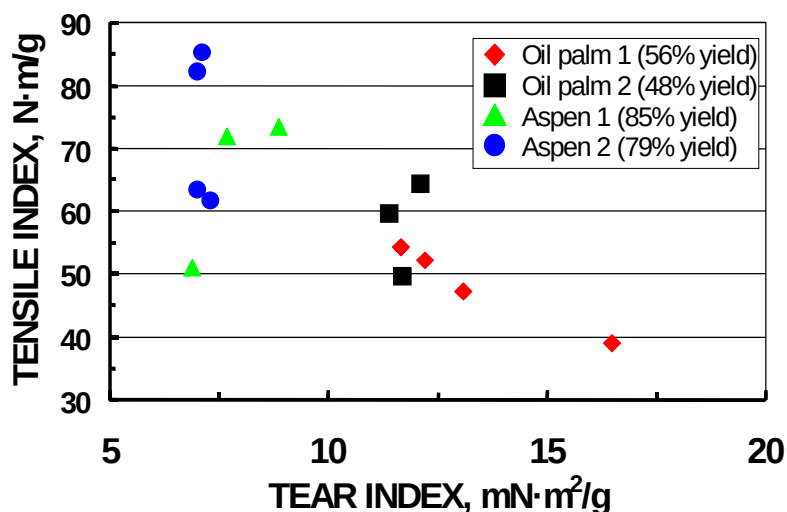


Figure 9. Tensile index vs. tear index for unbleached aspen and oil-palm pulps.

Figure 10 shows that the OPEFB pulp 1 (56% yield) produced sheets with good burst index, comparable with that of aspen pulp with 85% yield, while that at lower yield of 48% was comparable with that of aspen at 79% yield, within a range of freeness from about 100 mL to 500 mL.

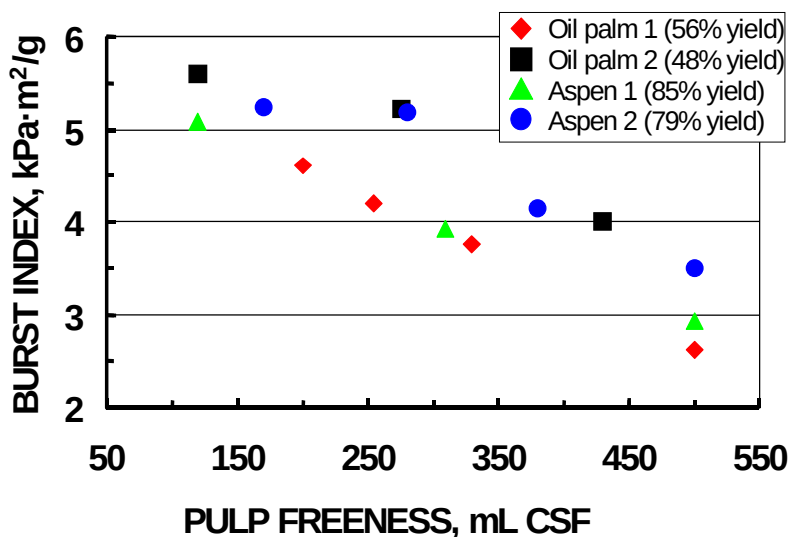


Figure 10. Burst index as a function of freeness for unbleached aspen and oil-palm pulps.

The OPEFB fibers produced paper with particularly high stretch and tensile energy absorption (TEA), as **Figure 11** and **Figure 12** reveal, respectively. The high performance in stretch and TEA for oil-palm fibers is believed to be attributable to the presence of the particularly long and springlike vessel elements in the material and lower sheet density, since the mean fiber length and diameter of the oil-palm fibers are similar to those of aspen.

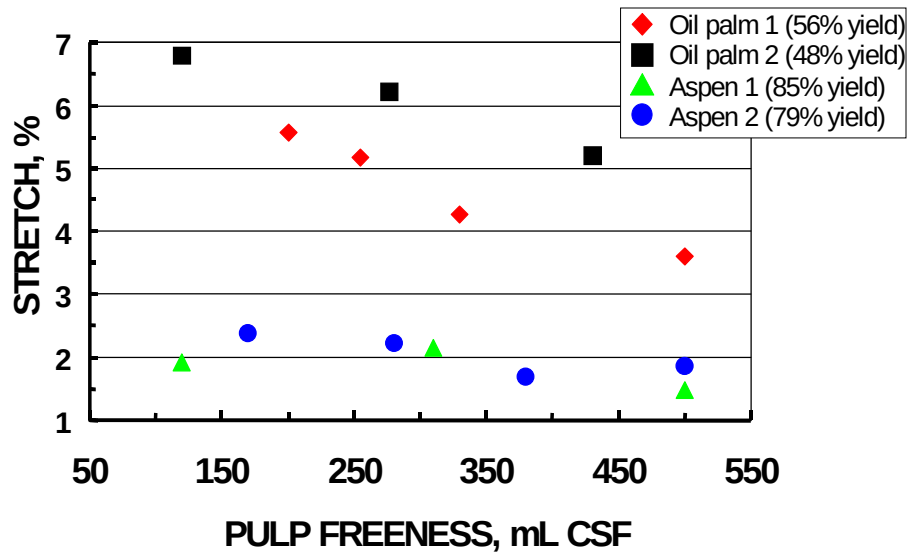


Figure 11. Stretch as a function of freeness for unbleached aspen and oil-palm pulps.

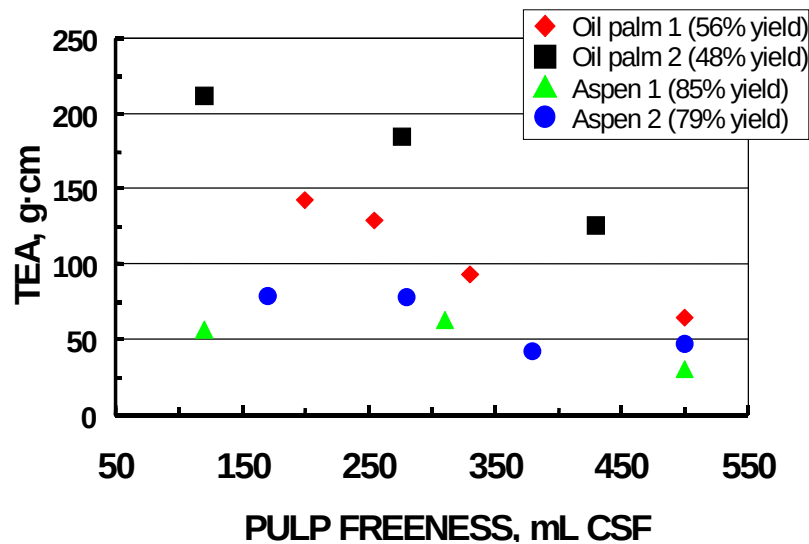


Figure 12. TEA as a function of freeness for unbleached aspen and oil-palm pulps.

Due to their thicker cell walls, and their resultant lower sheet density, the oil-palm fibers gave noticeably higher specific light-scattering coefficients compared with those of aspen pulps, as seen in **Figure 13**. This characteristic would help improve the opacity of paper.

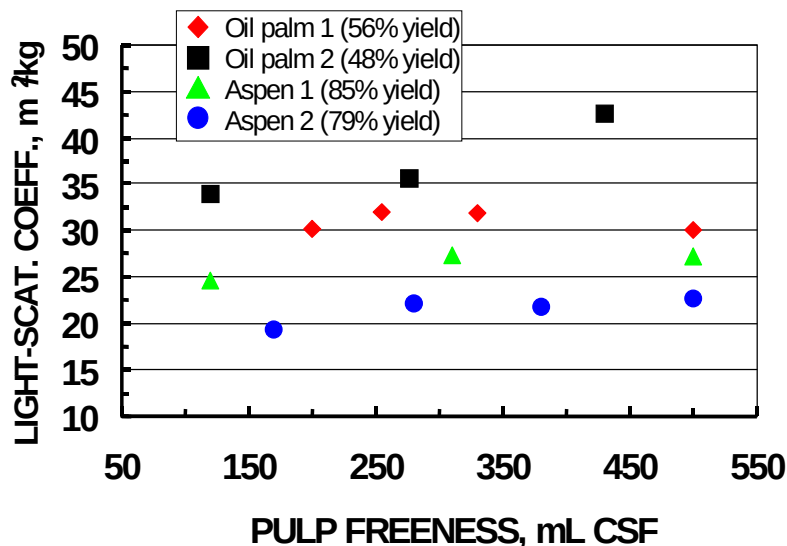


Figure 13. Specific light-scattering coefficient as a function of freeness for unbleached aspen and oil-palm pulps.

CONCLUDING REMARKS

Using a chemimechanical hardwood pulping method (caustic process), oil-palm empty fruit bunches can be transformed into pulps having a yield similar to that of a chemical pulp in the range of 48–56%. Given their thicker cell walls, the fibers in the oil-palm pulps produced sheets with lower tensile strength than the aspen CMP (79–85% yield). On the other hand, oil-palm handsheets had higher bulk, tear index, stretch, and TEA, suggesting that this pulp would be a suitable component for the manufacture of liner and board, particularly in the center ply. The bleached oil-palm pulp can also be a potential furnish for printing and writing grades when mixed with softwood BCTMP, for example. Given its relatively short fibers, the oil-palm pulp, like other nonwood fibers, needs to be reinforced with long softwood fibers to produce paper products with acceptable quality. However, the major disadvantage of oil-palm empty fruit bunch is its high solubility or low pulp yield, implying a higher cost for effluent treatment and sludge disposal than conventional woody materials. Its high ash content may also be a concern on mechanical wear of process equipment.

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LITERATURE CITED

1. *Asia Pacific Papermaker* 6(12): 9(1996).
2. *Appita J.* 50(2): 88(1997).
3. Khozirah, S. and Khoo, K. C., “Oil palm stem utilization — review of research,” Research Pamphlet No. 107-1991 (S. Khozirah, K. C. Khoo, and R. M. A. Abdul, Eds.), School of Industrial Technology, Universiti Sains, Malaysia, 1991, p. 1.
4. Choon, K. K. and Wan, L. T., *45th Appita Annual Conference Proceedings*, Vol. 2, Appita, Parkville, Australia, 1991, p. 195.

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5. Haroen, W. and Fansukri, L., *Berita Selulosa* 31(4): 2(1995).
 6. Kamarudin, H., Abdul, H. H., Ridzum, R., and Mohamad, Z. J., *Proceedings of the 3rd National Seminar on Oil Palm Trunk and other Palmwood Utilisation*, PORIM (Palm Oil Research Institute Malaysia), Kuala Lumpur, Malaysia, 1991, p. 219.
 7. Kamishima, H., Hosokawa, J., Akamatsu, I., Ramli, R., Miswan, O., Husin, M. B., Hassan, H. A., and Ikebe, Y., *Cellulose Chemistry and Technology* 24(4): 531(1990).
 8. Kamishima, H., Hosokawa, J., Akamatsu, I., Satoh, T., Hassan, K., Ramli, R. B., Husin, M. B., and Hassan, D. H. A. H., *J. Japan Wood Research Society* 40(7): 777(1994).
 9. Khoo, K. C. and Lee, T. W., *Proceedings of the National Symposium on Oil Palm By-products for Agro-based Industries*, Bulletin No. 11, PORIM (Palm Oil Research Institute Malaysia), Kuala Lumpur, Malaysia, 1985, p. 57.
 10. Khoo, K. C. and Lee, T. W., *Appita J.* 44(6): 385(1991).
 11. Mohamad, N. M. Y., Khoo, K. C., and Lee, T. W., *Malaysian Forester* 47(1): 28(1984).
 12. Mohamad, N. M. Y., *Proceedings of the National Symposium on Oil Palm By-products for Agro-based Industries*, Bulletin No. 11, PORIM (Palm Oil Research Institute Malaysia), Kuala Lumpur, Malaysia, 1985, p. 79.
 13. Mohamad, N. M. Y., Khoo, K. C., and Lee, T. W., *J. Tropical Forest Science* 2(1): 25(1989).
 14. Mohamad, N. M. Y., Khoo, K. C., and Lee, T. W., *Proceedings of the 3rd National Seminar on Oil Palm Trunk and other Palmwood Utilisation*, PORIM (Palm Oil Research Institute Malaysia), Kuala Lumpur, Malaysia, 1991, p. 352.
 15. Mohamad, N. M. Y., *Proceedings of the Nanjing International Symposium on High Yield Pulping*, Academy of Forestry, China, Nov. 21–23, 1997, p. 201.
 16. Wan Rosli, W. D., Law, K. N., and Valade, J. L., *Cellulose Chemistry and Technology* 32(1–2): 133(1998).
 17. Vidosic, J. P., “Mechanics of Materials,” in *Mark’s Standard Handbook for Mechanical Engineers* (Baumeister *et al.*, Eds.), McGraw-Hill, New York, 1978, p. 5/16.
 18. Sreekala, M. S., Kumaran, M. G., and Thomas, S., *J. Applied Polymer Sci.* 66(5): 821(1997).
 19. Lanouette, R., Law, K. N., and Valade, J. L., “Optimum utilization of larch,” internal research report, Pulp and Paper Research Center, University of Quebec in Trois-Rivières, Quebec, March 1997, 64 pp.
 20. Lee, J., Balatinecz, J., and Whiting, P., *J. Pulp Paper Sci.* 14(6): J145(1988).

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