Bench Scale Pulping & Bleaching of Malaysian Oil Palm Empty Fruit Bunch

Robert W. Hurter, President, HurterConsult Inc.
Medwick V. Byrd, Associate Teaching Professor, North Carolina State University

ABSTRACT

Oil palm empty fruit bunch (EFB) was evaluated as a raw material for papermaking pulp production. The EFB was chopped, screened and washed prior to cooking using the soda and soda-AQ processes. Bleaching trials were carried out using both ECF and TCF bleaching sequences. Bleached EFB pulps were tested for physical properties. Comparisons are made between the properties of the bleached EFB pulp and bleached kraft eucalyptus pulp. The EFB bleached pulps were acceptable for papermaking.

Keywords: Elaeis guineensis, oil palm fibers, empty fruit bunches, physical characteristics, pulping, bleaching, pulp properties

INTRODUCTION

Oil palm (*Elaeis guineensis*) is cultivated on a large scale as a source of edible oil in Central and West Africa where it originated, as well as in Indonesia, Malaysia and Thailand.

Malaysia has a total of about 4.7 million hectares of palm oil plantations which annually produce about 19 million tonnes of palm oil and 2 million tonnes of palm kernel oil per year.

A typical plantation yields about 20 tons of fruit/ ha/year but some new clones yield up to 28 tons/ha/year.

Oil palm plantations generate a significant amount of biomass in the form of fronds from harvesting and pruning, trunks and canopy from replanting, and empty fruit bunches (EFB).

Fronds have no significant commercial uses and are normally returned to the soil as mulch. Trunks and canopy are typically pulverized and returned to the soil; some trunks are converted to plywood in combination wood veneers.

Empty fruit bunches (EFB) have been commercially used to produce low-value products such as construction materials, fiberboard and molded fiber products. However, most EFB is returned to the plantations as mulch.

Estimates of Malaysian EFB production vary but it is conservatively estimated at about 20 million tonnes per year (1).

This study was carried out to establish pulping and bleaching conditions for EFB to produce paper grade pulps and to evaluate the pulp properties.

EXPERIMENTAL

All work was carried out at the North Carolina State University Department of Forest Biomaterials laboratory under the direction of HurterConsult.

All tests were conducted in accordance with TAPPI Test Methods.

Materials

Malaysian EFB fiber was used for all experiments.

The fiber raw material had been extracted from the EFB, thoroughly washed and cleaned and then forced dried.

The EFB fiber was light brown (tan) in colour and contained a range of fiber lengths from approximately 0.5 to 15 cm, with most of the fibers in the 5 to 12 cm range. The longer fibers were extensively intertwined in a manner similar to a “bird nest”. The EFB appeared to be free of stones and dirt but dust and seed hulls were present.

Composite samples were taken from random boxes and tested for moisture content and hot water solubility.

For the hot water solubility test, the samples were immersed in hot water (54 ^{0}C) for 24 hours.

EFB Fiber Preparation

Through trial and error, it was found that the as-received EFB needed to be chopped, screened and soaked overnight before cooking.

For chopping, a pilot scale Appleton wood chipper which featured a 24-inch flywheel equipped with two knives, driven by a 20-HP motor at 300 RPM was used. The EFB raw material was fed normal to the disk rotation, and the resulting kinetic energy, along with the high volume of air flow produced by the flywheel, propelled the chopped material out of the discharge chute. The chopped material was stored in drums for later use.

Dry screening was done using a vibrating screen.

The chopped and dry screened EFB fiber was soaked in warm water (30 ^{0}C) overnight, and then drained prior to introduction to the digester.

Cooking

The cooking processes tested were the soda and soda-AQ processes.

A range of test conditions was used (Table 1) to determine the optimum cooking conditions.

A total of 11 cooks were carried out (5 using 3-liter bombs and 6 using a 30-liter batch digester). Only the results for the optimum test conditions are reported in this paper.

Bleaching

Two bleaching sequences were tested: DEDED and OZPP, both with a target brightness of 90% ISO.

Medium-consistency bleaching with chlorine dioxide, caustic and hydrogen peroxide was carried out in sealed plastic bags immersed in a heated water bath. Chemicals were mixed into the pulp using an industrial kitchen mixer fitted with a kneading spade. The pulp was then sealed into the bags. The bags were kneaded periodically during the reaction.

Low-consistency bleaching using ozone (Z) was carried out by sparging ozone gas into a mixing vortex of pulp slurry.

Bleaching with oxygen was carried out in 3-liter pressure vessels placed on a rotating rack in a hot-air oven.

After each stage, the pulp was tested for the following: chemical consumption, yield, brightness, freeness (CSF), and CED viscosity. All testing was conducted in accordance with TAPPI standards.

Tables 2 and 3 provide the bleaching conditions and bleaching chemical charges, respectively.

RESULTS AND DISCUSSION

EFB Raw Material (Table 4)

The moisture content of three random samples ranged from 6.1% to 6.7% with an average of 6.5%. The results show good uniformity between the samples. However, the moisture content was lower than one would expect from nonwood plant fiber raw materials. Over time, many lignocellulosic materials will achieve equilibrium of about 10% moisture content. The lower than expected moisture content was likely due to the forced drying of the EFB fiber raw material.

The solubles losses in the two hot water solubility tests were 7.2% and 13.0% with an average of 11.1%. There was no evidence of oily residue in the filtrate, which was light tan in colour, with a very small amount of fine crill which settled out. It appeared that there may be considerable variability in the hot water solubles content of EFB raw material. However, as the samples were small, it is likely that pulping larger samples will result in lower variability. That there was no evidence of oily residue in the filtrate indicates very well washed material. The fine crill likely was residual dust from the fiber extraction process, and it would be mostly washed out in a good fiber preparation system in a commercial operation.

Fiber Preparation (Table 5)

The wood chipper did a good job of separating the EFB material and reducing the length of long strands. It did not appear to be doing any excessive cutting or fiber damage. There was, however, a large amount of dust produced. The average length of the chopped EFB fiber was 2 - 3 cm.

Dry screening analysis showed that the chopped EFB contained a significant amount of fines/dust.

The longer/coarser and shorter/slender fractions appeared suitable for pulping and papermaking.

However, the fines/dust fraction was of concern, especially since it made up more of the material weight than anticipated. About half of this fraction was finely-powdered material and dust. The other half was fine filaments and hair-like fibers. This combined fraction could be responsible for the high alkali consumption and lower yields obtained from cooks #2 and #3.

Given the above, cooks # 4 and #5 were carried out with dry screened EFB raw material and cooks #6 to #11 were carried out using dry screened and washed EFB raw material. The fines/dust and hull fractions were not used in cooking.

Cooking (Table 6)

The optimum cooking conditions resulted in a total and screened yield on OD raw material of 44.2% and 43.6%, respectively.

The pulp had a Kappa number of 18.4 and 37.5% ISO brightness.

Alkali consumption was 99.1%.

Bleaching (Table 7)

a) **DEDED Sequence**

For the DEDED sequence, the final brightness was 90.7% ISO which met the target of +90% ISO. This was achieved using a total of 37 kg of chlorine dioxide per oven dry metric ton of unbleached pulp.

Since 100% of the chlorine dioxide was consumed in the D0 stage, increasing the chlorine dioxide charge in this stage likely would allow for achieving an 86% ISO brightness after the D1 stage.

The viscosity decreased from 20.3 cp for the unbleached pulp to 12.0 cp for the fully bleached pulp. Although this is a significant drop in viscosity, the final pulp viscosity is still reasonably good.

The final kappa number of 0.5 is in the range expected for fully bleached woodpulps.

Overall, pulp freeness after bleaching is high which indicates good drainability of the pulps.

The overall total bleaching yield was 85.3%. Normally, for nonwood fibres starting with an unbleached Kappa number of about 15, a total bleaching loss in the order of 6 - 7% is anticipated. For an unbleached pulp with a Kappa of 20, one could expect a yield loss in the order of 9 - 11%. However, the total bleaching yield is showing losses higher than normally anticipated. No explanation was found for the high bleaching losses.

b) **OZPP Sequence**

For the OZPP sequence, the final brightness was 85.5% ISO, well below the target of 90% ISO despite using 80 kg of hydrogen peroxide per OD metric ton of unbleached pulp.

Peroxide consumption in the first pressurized P stage was 94.8%, but only 59.5% in the second unpressurized P stage. It is possible that better brightness results may have been achieved with a second pressurized P stage rather than an unpressurized stage.

The viscosity decreased from 20.3 cp for the unbleached pulp to 8.3 cp for the fully bleached pulp. It appears that most of the drop in viscosity occurred in the oxygen delignification and pressurized peroxide stages. It is possible that using a second pressurized peroxide stage would result in a further viscosity drop. Further process optimization may reduce the drop in viscosity. Although this is a significant drop in viscosity, the final pulp viscosity is still in an acceptable range.

The final kappa number at 3.3 is much higher expected for fully bleached pulp.

Overall, pulp freeness after bleaching is high which indicates good drainability of the pulps.

The overall total bleaching yield was 81.2%. Normally, for nonwood fibres starting with an unbleached Kappa number of about 15, a total bleaching loss in the order of 6 - 7% is anticipated. For an unbleached pulp with a Kappa of 20, one could expect a yield loss in the order of 9 - 11%. However, the total bleaching yield is showing losses higher than normally anticipated. We have no explanation for the high bleaching losses.

Brightness Reversion (Table 8)

For the ECF sequence, brightness reversion ranges from 0.9 to 2.6 units if the natural reversion is included. The OZPP sequence experienced higher brightness reversion.

Fiber length analysis (Table 9)

The average unbleached pulp fiber length on a weight/weight basis is 20 - 30% shorter than that of the bleached pulps. However, the average fiber width of the unbleached and bleached pulps is not significantly different.

Given the high fines content of the unbleached pulp, one would have thought that bleaching may have reduced the fines content thus giving the higher average fiber length for the bleached pulps. However, the fines content of both bleached pulps exceeds that of the unbleached pulp.

One possible reason for the fiber length discrepancy may be the samples used for the respective pulping and bleaching. However, there is insufficient data to determine if this is the reason and more work needs to be done for a definitive answer.

Foelkel (2) provides a selected list of some important eucalyptus fiber/pulp characteristics and their range of variation for the universe of eucalyptus pulps. In this list, the weighted average fiber length is provided as 0.6 to 0.85 mm for eucalyptus. This places the EFB pulp in the range of good quality eucalyptus pulp in terms of average fiber length.

Bleached Pulp Properties (Table 10)

The properties of the soda cooked EFB DEDED and OZPP bleached pulps are provided in Table 10.

Selected physical properties of the EFB DEDED and OZPP bleached pulps are compared with eucalyptus bleached kraft pulp in figures 1 to 7.

Comparing EFB DEDED and OZPP bleached pulps, they both exhibited similar Tensile Index and Burst Index. However, the EFB DEDED bleached pulp had significantly higher Tear Index, TEA and bulk.

Compared to eucalyptus bleached kraft pulp,

- The EFB DEDED bleached pulp achieved a Tear Index close to the maximum for eucalyptus pulp but with significantly less energy input.
- Tensile Index for both EFB pulp was significantly lower.
- Burst Index and TEA for both EFB pulps was significantly higher
- Bulk for both EFB pulps was significantly lower, especially for the OZPP bleached pulp.

CONCLUSIONS

Malaysian oil palm empty fruit bunches (EFB) can produce an acceptable quality of papermaking pulp using the soda process and either ECF or TCF bleaching.

The possibility remains that the EFC bleaching sequence used in this work (DEDED) could be reduced to a three stage sequence such as DED or D-Eop-D which would reduce both capital and operating costs of a commercial facility.

Given the vast EFB resource, further study of this interesting fiber raw material is warranted.

References

1. Wan Rosli Wan Daud and Kwei-Nam Law, “OIL PALM FIBERS AS PAPERMAKING MATERIALS: POTENTIALS AND CHALLENGES”, BioResources 6(1), 2011, pp 901-917.

2. Celso Foelkel, “THE EUCALYPTUS FIBERS AND THE KRAFT PULP QUALITY REQUIREMENTS FOR PAPER MANUFACTURING”, Eucalyptus Onlibe Book & Newsletter, February/March 2007.

Table 1 Cooking apparatus, procedures & conditions		
	Range	**Optimum**
Cooking Apparatus	a) two 3-liter stainless bombs placed on rotating rack in heated-air oven b) 30-liter batch digester - direct steamed	30-liter batch digester - direct steamed
Sample Size	200 OD - 1000 OD grams total batch size	1000 OD grams total batch size
Cutting / dry screening	no cutting or cutting & dry screening	cut EFB to 2 - 3 cm lengths, wash/screen EFB to remove nut hulls and fines
Soaking	no soaking or overnight soaking	soaked in warm water overnight, drained
NaOH on OD fiber	18 - 23%	21%
AQ on OD fiber	0 - 0.1%	0%
Liquor-to-Fiber Ratio	4:1 - 10:1	10:1 start
Maximum Temperature	160 - 170 ^{0}C	165 - 170 ^{0}C
Time to Max Temperature	45 - 90 minutes	45 minutes
Time at Max Temperature	90 - 187	135 minutes
H-factor target	1490 - 1750	1750
Post cooking treatment	mixed, washed and screened	mixed, washed and screened

Table 2 Bleaching conditions					
Sequence	**Stage**	**Time (min.)**	**Temp. (^0C)**	**Pressure (psi)**	**Pulp cons. (%)**
DEDED	D0	60	70		10
	E1	60	70		10
	D1	180	70		10
	E2	60	70		10
	D2	180	70		10
OZPP	O	30	105	100	10
	Z	9	20 (room temp)		3
	Pp	90	105		10
	P	240	90		10

Table 3 Bleaching chemical charges (kg/ODmt)											
Sequence	**Stage**	**ClO_2**	**NaOH**	**H_2O_2**	**O_2**	**O_3**	**DTPA**	**DTMPA**	**$MgSO_4$**	**$NaSiO_3$**	**H_2SO_4**
DEDED	D0	18									
	E1		24								
	D1	14	7								
	E2		5								
	D2	5									
OZPP	O		25		n/a				5	5	
	Z					21	5				9.8
	Pp		40	40				2	5	5	
	P		40	40				2	5	5	

Table 5 EFB raw material			
Moisture Content		**Hot Water Solubility Losses**	
Sample 1	6.6%	Sample 1	13.0%
Sample 2	6.1%	Sample 2	7.2%
Sample 3	6.7%		
Average	6.5%	Average	11.1%

Table 5 EFB chopped raw material dry screening analysis			
	% of AD Mass by Weight		
	Trial 1	**Trial 2**	**Average**
Longer/Coarser	64	73.2	68.6
Shorter/ Slender	22.4	10.9	16.6
Fines/Dust	12.8	15.7	14.3
Hulls	0.8	0.2	0.5

Table 6 Cooking results	
Kappa number	18.4
ISO brightness	37.50%
Total Yield	44.20%
Screened Yield	43.60%
Screened Rejects	1.53%
Alkali consumption	99.10%
Black liquor terminal pH	11.8

Table 7 Bleaching results

Stage	pH	Consumption			Residuals (kg/ODmt)	Yield (%)	Freeness (ml, CSF)	Brightness (% ISO)	Kappa number	Viscosity cp
			%	(kg/ODmt)						
DEDED Sequence										
D0	2.4		100	18.0	0	n/a	n/a	44.4	n/a	n/a
E1	12.5		n/a	n/a	n/a	92.3	577	56.9	3.8	16.6
D1	4.5		89.2	12.5	1.5	95.6	555	84.0	1.1	13.6
E2	11.6		n/a	n/a	n/a	n/a	n/a	84.2	n/a	n/a
D2	4.5		85.4	4.3	0.7	96.7	540	90.7	0.5	12.0
					Overall Yield	85.3				
OZPP sequence										
O	10.9	NaOH	73.5	18.4	6.6	95.8	660	48.2	11.3	16.1
Z	1.5		2.1	21.0	nil	97.2	540	57.5	8.2	14.5
P1	11.3	NaOH	86.9	34.8	5.2	93.1	510	80.1	4.1	8.7
		H_2O_2	94.8	37.9	2.1					
P2	11.7	NaOH	80.3	32.1	7.9	94.4	430	85.5	3.3	8.3
		H_2O_2	59.5	23.8	16.2					
					Overall Yield	81.2				

Table 8 Brightness reversion after final bleaching stage

Sequence	Initial Brightness (% ISO)	Brightness after aging (% ISO $_{1h}$)	Brightness Reversion (% ISO $_{1h}$)	Brightness after aging (% ISO $_{3h}$)	Brightness Reversion (% ISO $_{3h}$)
DEDED	89.2	88.5	-0.7	88.1	-1.1
OZPP	85.5	84.5	-1	83.9	-1.6

Note: The final brightness for the DEDED sequence was 90.7% ISO immediately after the bleaching trial. Some natural reversion (- 1.5% ISO) took place during the time between the completion of the bleaching trial and the brightness reversion test.

Table 9 Fibre length analysis			
Unbleached pulp	avg. fibre length (w/w)	mm	0.684
	avg. fibre width	microns	18.9
	fines content by number	%	24.79
DEDED	avg. fibre length (w/w)	mm	0.822
	avg. fibre width	microns	18.3
	fines content by number	%	28.6
OZPP	avg. fibre length (w/w)	mm	0.918
	avg. fibre width	microns	18.4
	fines content by number	%	34.2

Table 10 Bleached pulp properties

Test	Units	DEDED Bleached Pulp					OZPP Bleached Pulp				
Beating	rev	0	500	1000	1500	2000	0	300	500	1000	1500
Freeness	CSF, ml	540	423	364	306	252	430	300	248	195	143
Basis weight	g/m^2	67.5	66.9	65.9	66.6	65.9	66.6	66.5	65.3	65.2	65.5
Thickness	µm	123.2	102.6	95.4	91.2	84.6	107	94.6	91.4	82	76.8
Bulk	cm^3/g	1.83	1.53	1.45	1.37	1.28	1.61	1.45	1.4	1.25	1.17
Density	g/cm^3	0.546	0.654	0.690	0.730	0.781	0.621	0.690	0.714	0.800	0.855
Tear Index	$mN \cdot m^2/g$	9.78	10.19	9.77	9.84	9.84	7.57	8.04	7.57	7.26	7.05
Burst Index	$kPa \cdot m^2/g$	3.12	3.78	4.39	4.58	5.05	3.66	3.92	3.98	4	4.29
Tensile Index	Nm/g	37.85	47.75	47.55	47.81	50.95	39.49	44.85	45.05	47.47	48.42
Fold		48	115	203	340	700	67	131	177	312	652
Stiffness	mN	7.3	6.6	6.1	5.8	5.8	5.42	5.16	5.03	4.35	4.83
TEA	J/m2	111.9	195.5	153.8	125.6	140.5	113.3	130.2	122.3	119.6	88.1
Stretch	%	5.61	7.83	6.25	5.02	5.31	5.26	5.43	5.48	4.77	3.49
Smoothness	Sheffield, s	357	273	258	250	240	287	274	269	246	238
Porosity	Gurley, s	2.26	6.87	15.68	27.72	79.04	11.4	44.46	76.14	226.44	639.38

Notes: 1. Tear Index based on 4 ply 2. Fold test based on M.I.T. Double Fold (2.5P) 3. Stiffness test based on Gurley 1" * 1-1/2" test

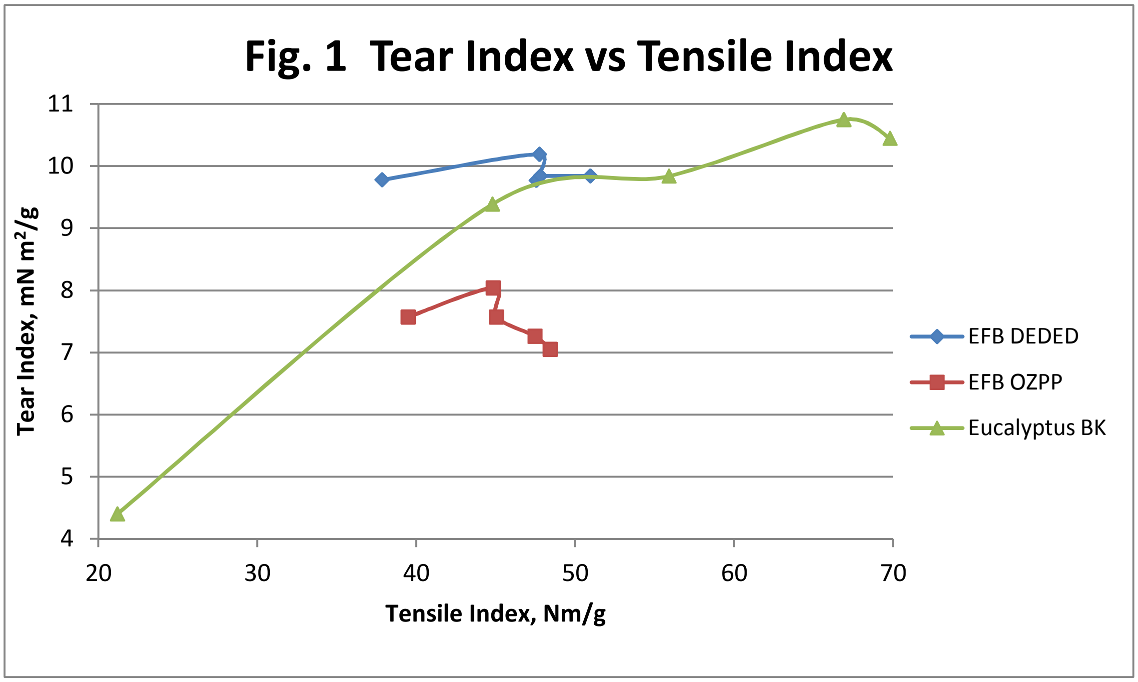


Fig. 1 Tear Index vs Tensile Index
Tear Index, mN m2/g
Tensile Index, Nm/g
11
10
9
8
7
6
5
4
20
30
40
50
60
70
EFB DEDED
EFB OZPP
Eucalyptus BK

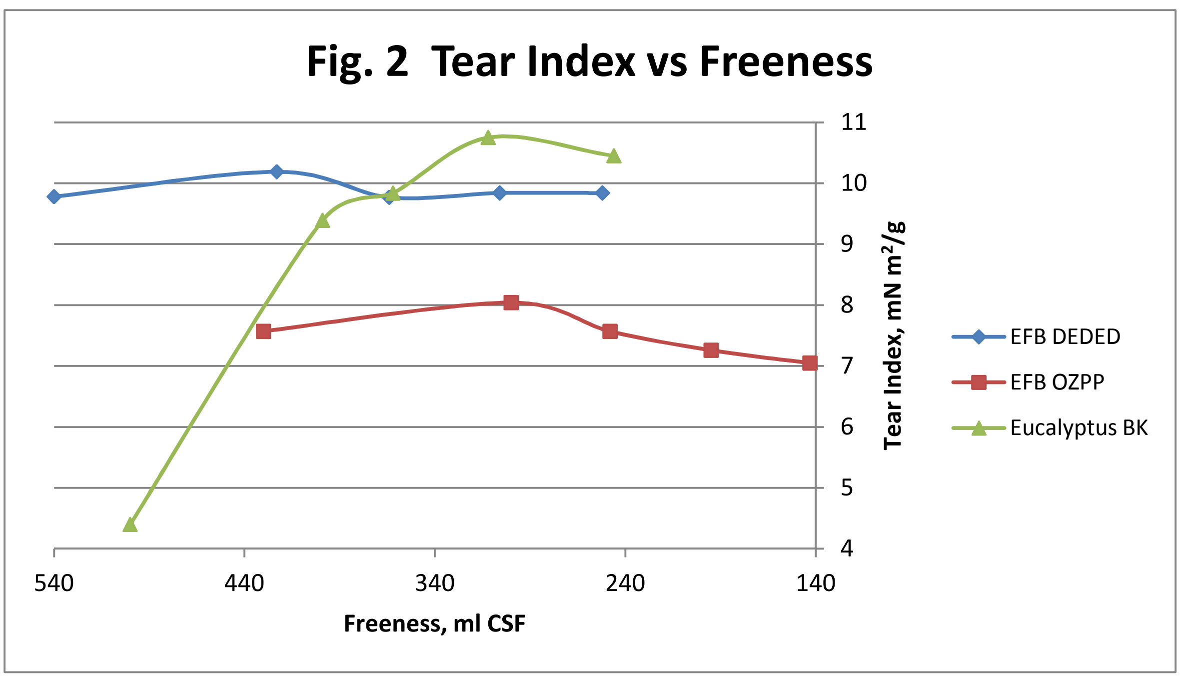


Fig. 2 Tear Index vs Freeness
Tear Index, mN m2/g
Freeness, ml CSF
11
10
9
8
7
6
5
4
540
440
340
240
140
EFB DEDED
EFB OZPP
Eucalyptus BK

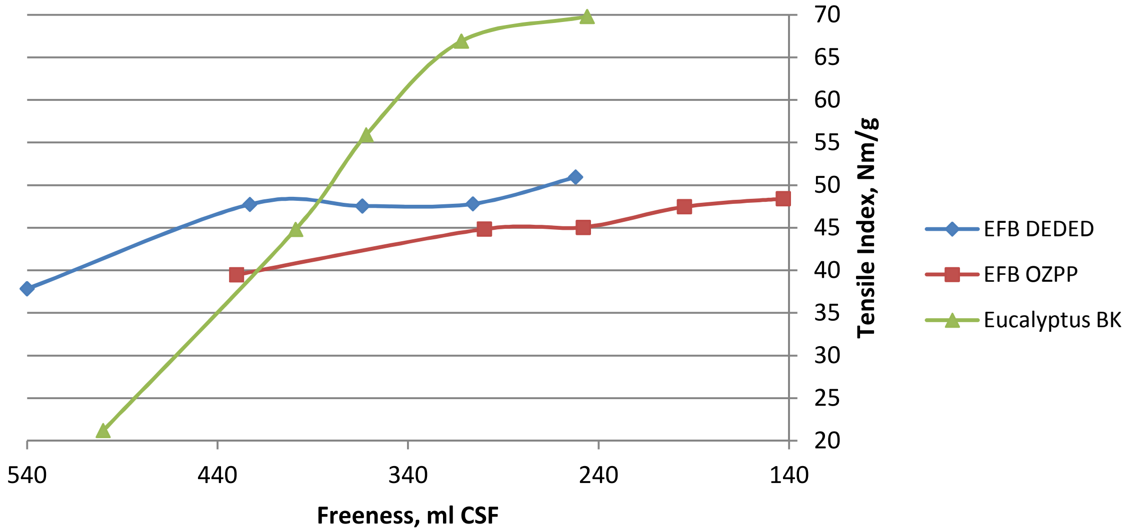


Fig. 3 Tensile Index vs Freeness

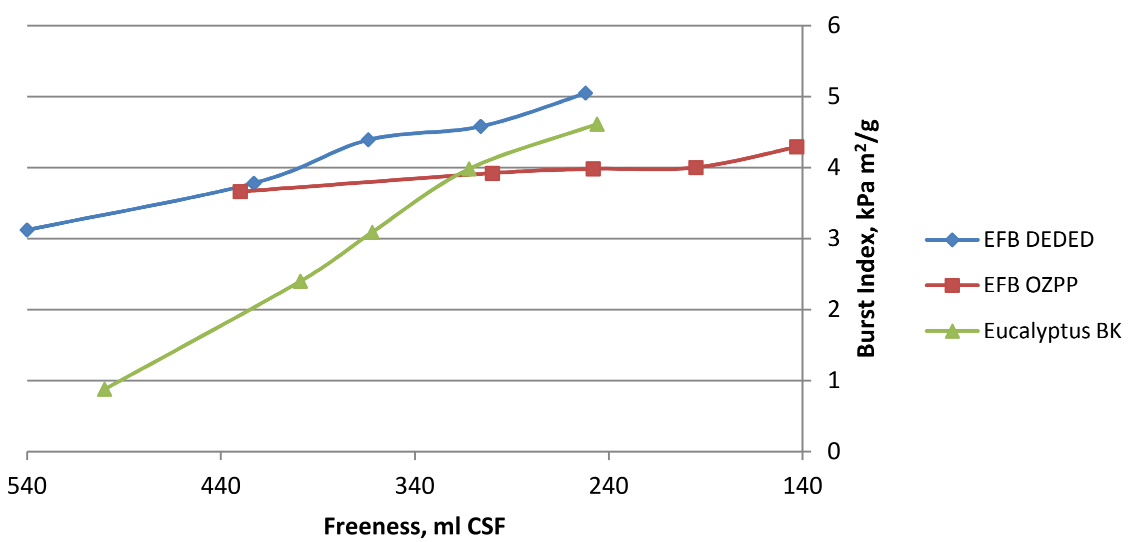


Fig. 4 Burst Index vs Freeness

Fig. 5 TEA vs Freeness

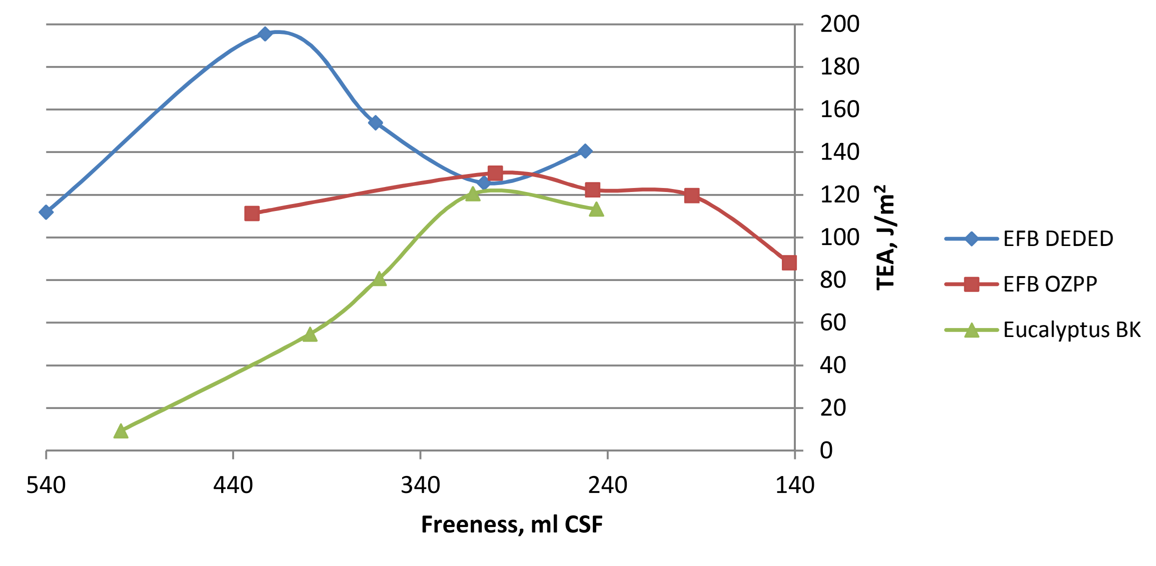
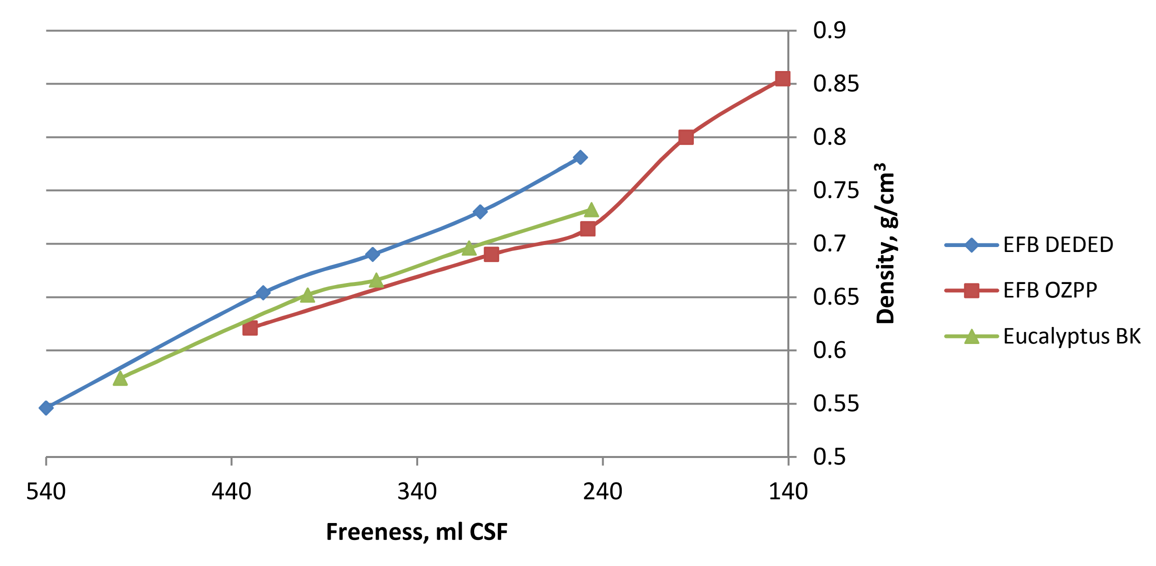


Fig. 6 Density vs Freeness



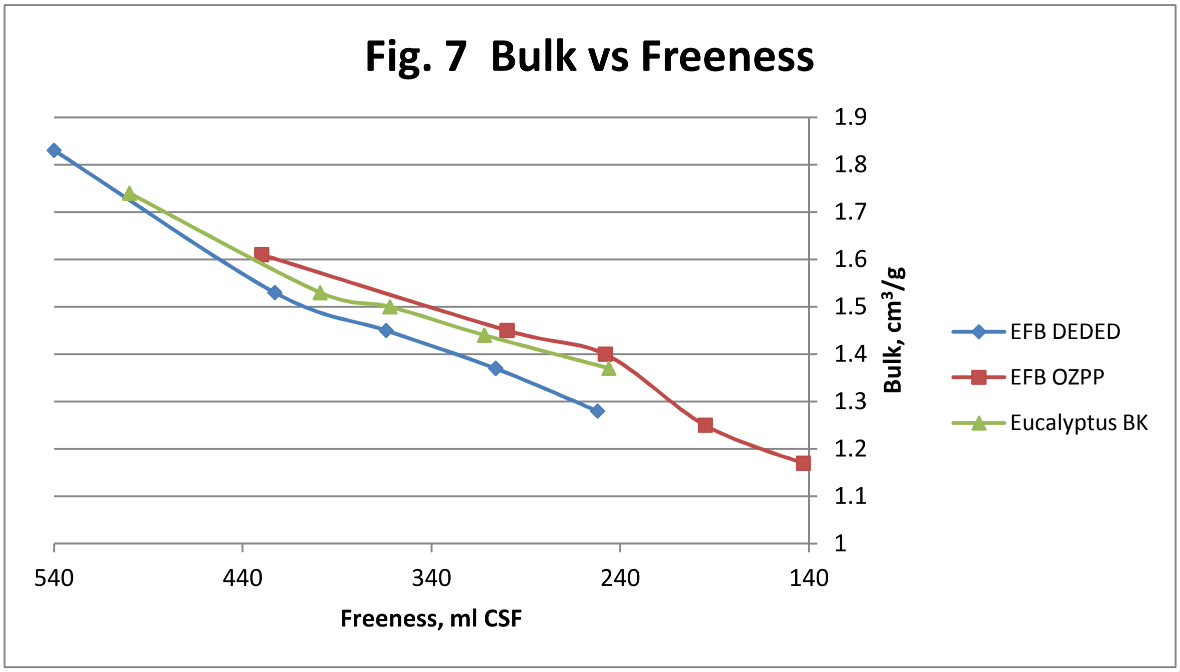


Fig. 7 Bulk vs Freeness
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
Bulk, cm3/g
540
440
340
240
140
Freeness, ml CSF
EFB DEDED
EFB OZPP
Eucalyptus BK

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Robert W. Hurter, HurterConsult Inc.

Medwick V. Byrd, North Carolina State University

NC STATE UNIVERSITY

Agenda

- Oil Palm General Facts (Malaysia)
- EFB Opportunity
- Experimental
- Results
- Conclusions & Next Steps

Palm Oil General Facts (Malaysia)

- Oil palm (*Elaeis guineensis)* originated in Central and West Africa
- Malaysia
  - 4.7 million hectares of oil palm plantations
  - 19 million tonnes of palm oil per year
  - 2 million tonnes of palm kernel oil per year
  - Typical yield about 20 tons of fruit/ha/year
  - Some new clones yield up to 28 tons/ha/year

Palm Oil General Facts (Malaysia)

- Plantations generate significant amount of biomass
- Fronds - no significant commercial uses and normally returned to soil as mulch
- Trunks and canopy - typically pulverized and returned to soil, some trunks converted to plywood in combination wood veneers.
- Empty fruit bunches (EFB) – some used commercially for low-value products such as fiberboard and molded fiber products
- Most EFB returned to plantations as mulch

EFB Opportunity

- Estimates of Malaysian EFB production vary
- Conservative estimate - about 20 million tonnes per year
- Opportunity to produce higher value papermaking pulp

Fresh Fruit Bunch

EFB

Extracted & Dried EFB Fiber

Experimental

- Fiber raw material – dried extracted EFB fiber
- Pre-treatment – chipping/shredding
- Cooking process – soda and soda-AQ
- Bleaching processes - DEDED and OZPP
- Target brightness - 90% ISO
- All tests were conducted in accordance with TAPPI Test Methods

Experimental

Cooking apparatus, procedures & conditions		
	Range	**Optimum**
Cooking Apparatus	a) two 3-liter stainless bombs on rotating rack in heated-air oven b) 30-liter batch digester - direct steamed	30-liter batch digester
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Time to Max Temperature	45 - 90 minutes	45 minutes
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H-factor target	1490 - 1750	1750
Post cooking treatment	mixed, washed and screened	mixed, washed and screened

Experimental

Bleaching conditions					
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	D2	180	70		10
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	Z	9	20 (room temp)		3
	Pp	90	105		10
	P	240	90		10

Experimental

Bleaching chemical charges (kg/ODmt)											
	Stage	**ClO_2**	**NaOH**	**H_2O_2**	**O_2**	**O_3**	**DTPA**	**DTMPA**	**$MgSO_4$**	**$NaSiO_3$**	**H_2SO_4**
DEDED	D0	18									
	E1		24								
	D1	14	7								
	E2		5								
	D2	5									
OZPP	O		25		n/a				5	5	
	Z					21	5				9.8
	Pp		40	40				2	5	5	
	P		40	40				2	5	5	

Results

- EFB raw material
- Chopped EFB dry screening analysis
- Cooking results
- Bleaching results
- Brightness reversion
- Fiber length analysis
- Strength

Results

EFB raw material			
Moisture Content		Hot Water Solubility Losses	
Sample 1	6.6%	Sample 1	13.0%
Sample 2	6.1%	Sample 2	7.2%
Sample 3	6.7%		
Average	6.5%	Average	11.1%

Results

EFB chopped raw material dry screening analysis			
	% of AD Mass by Weight		
	Trial 1	Trial 2	Average
Longer/Coarser	64	73.2	68.6
Shorter/ Slender	22.4	10.9	16.6
Fines/Dust	12.8	15.7	14.3
Hulls	0.8	0.2	0.5

Results

Soda-AQ Cooking results	
Kappa number	18.4
ISO brightness	37.50%
Total Yield	44.20%
Screened Yield	43.60%
Screened Rejects	1.53%
Alkali consumption	99.10%
Black liquor terminal pH	11.8

Results

Bleaching results					
Stage	**Yield (%)**	**Freeness (ml, CSF)**	**Brightness (% ISO)**	**Kappa number**	**Viscosity cp**
DEDED Sequence					
D0	n/a	n/a	44.4	n/a	n/a
E1	92.3	577	56.9	3.8	16.6
D1	95.6	555	84.0	1.1	13.6
E2	n/a	n/a	84.2	n/a	n/a
D2	96.7	540	90.7	0.5	12.0
Overall Yield	85.3				
OZPP sequence					
O	95.8	660	48.2	11.3	16.1
Z	97.2	540	57.5	8.2	14.5
P1	93.1	510	80.1	4.1	8.7
P2	94.4	430	85.5	3.3	8.3
Overall Yield	81.2				

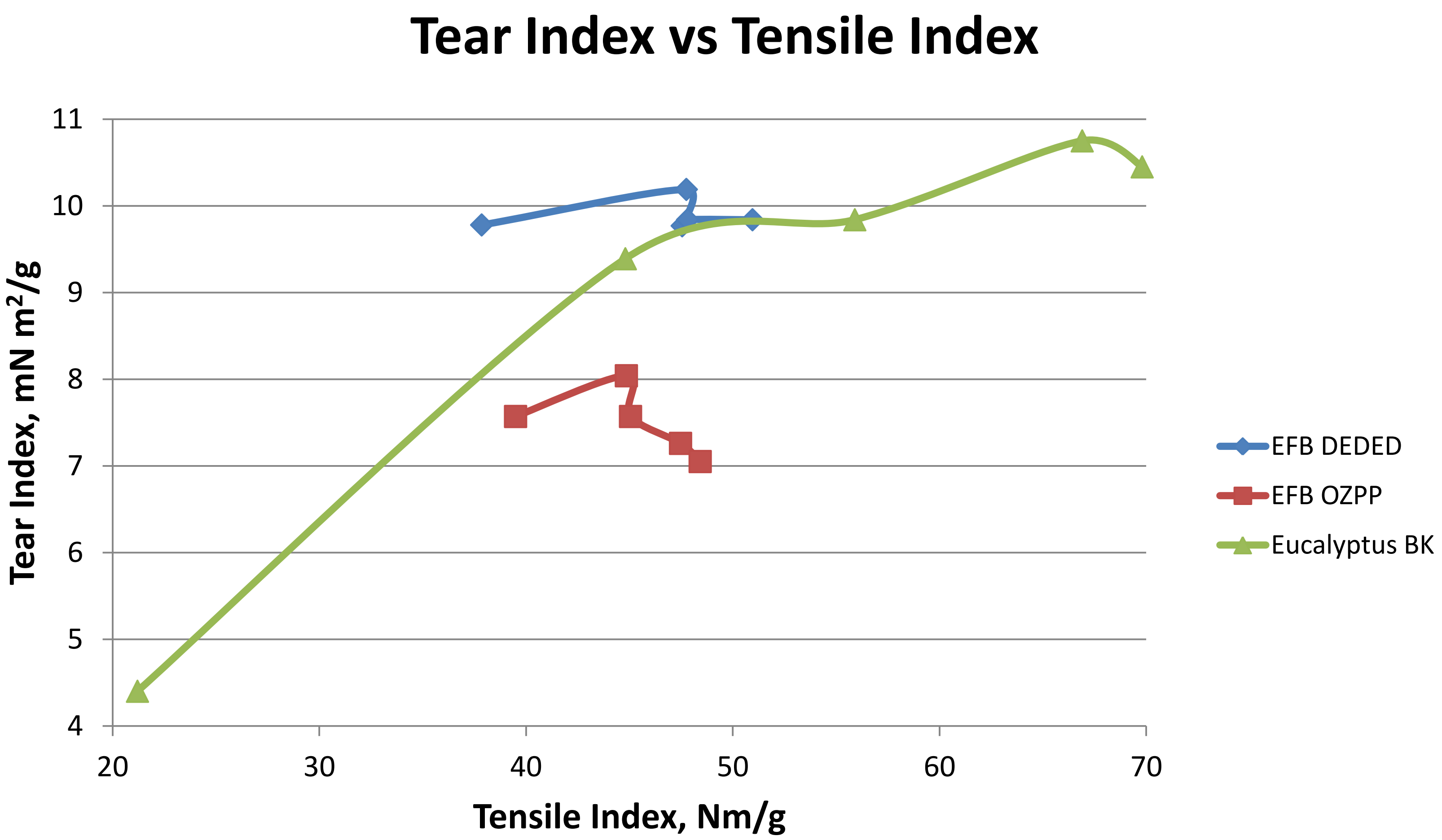
Results

Brightness reversion after final stage					
Sequence	**Initial Brightness (% ISO)**	**Brightness after aging (% ISO $_{1h}$)**	**Brightness Reversion (% ISO $_{1h}$)**	**Brightness after aging (% ISO $_{3h}$)**	**Brightness Reversion (% ISO $_{3h}$)**
DEDED	89.2	88.5	-0.7	88.1	-1.1
OZPP	85.5	84.5	-1	83.9	-1.6

Results

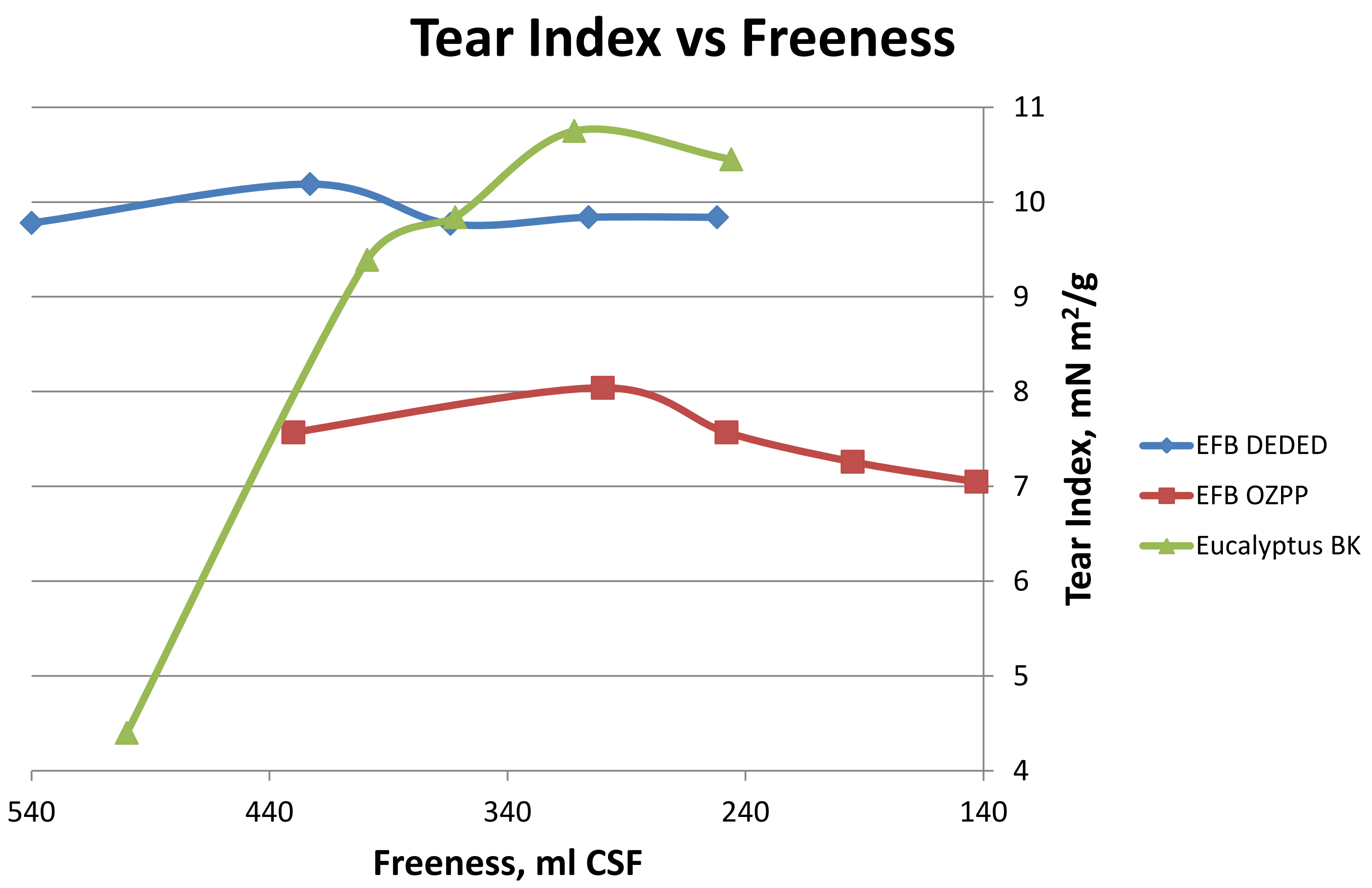
Fibre length analysis			
Unbleached pulp	avg. fibre length (w/w)	mm	0.684
	avg. fibre width	microns	18.9
	fines content by number	%	24.79
DEDED	avg. fibre length (w/w)	mm	0.822
	avg. fibre width	microns	18.3
	fines content by number	%	28.6
OZPP	avg. fibre length (w/w)	mm	0.918
	avg. fibre width	microns	18.4
	fines content by number	%	34.2

Results



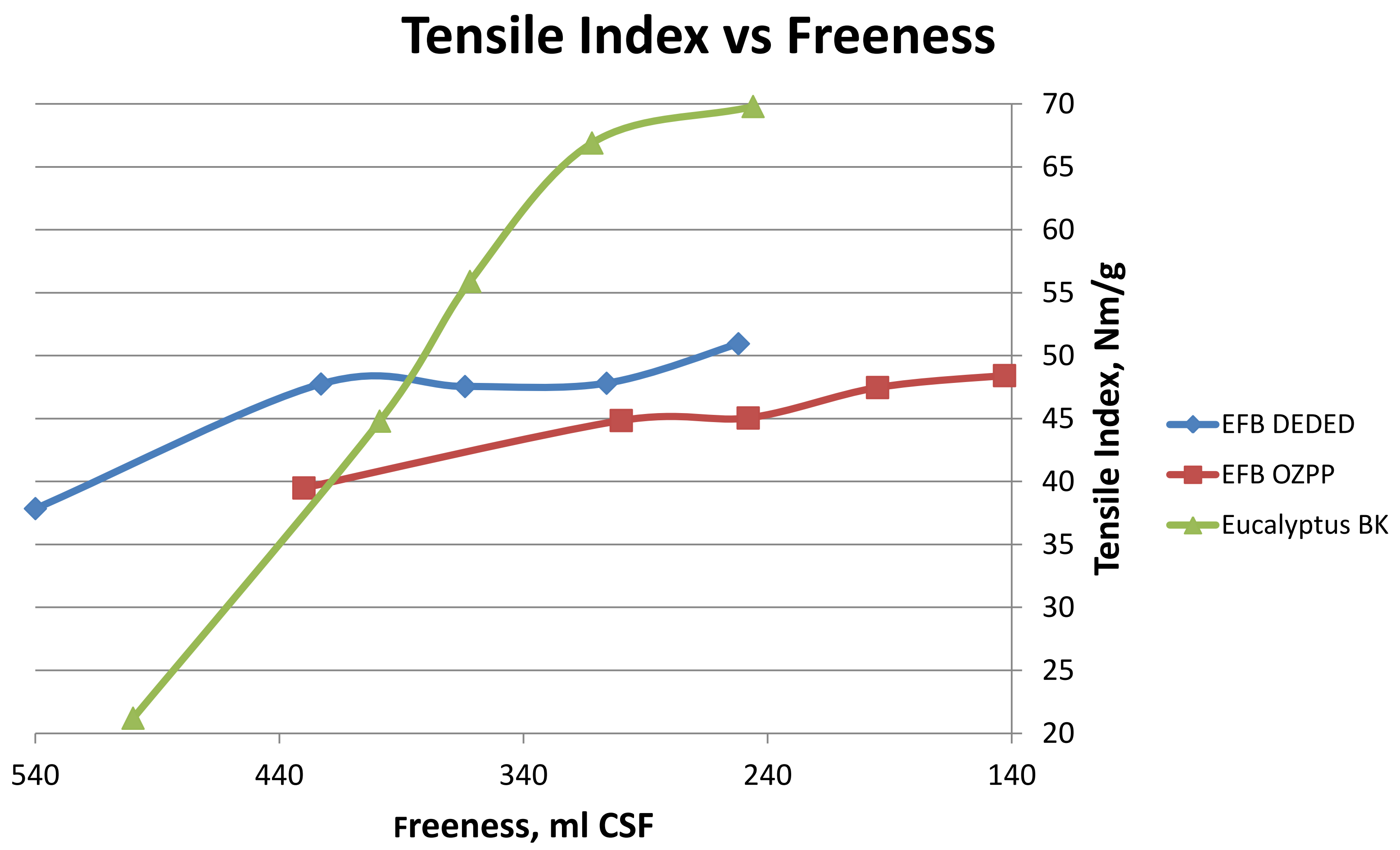
Tear Index vs Tensile Index
Tear Index, mN m²/g
11
10
9
8
7
6
5
4
20
30
40
50
60
70
Tensile Index, Nm/g
EFB DEDED
EFB OZPP
Eucalyptus BK

Results

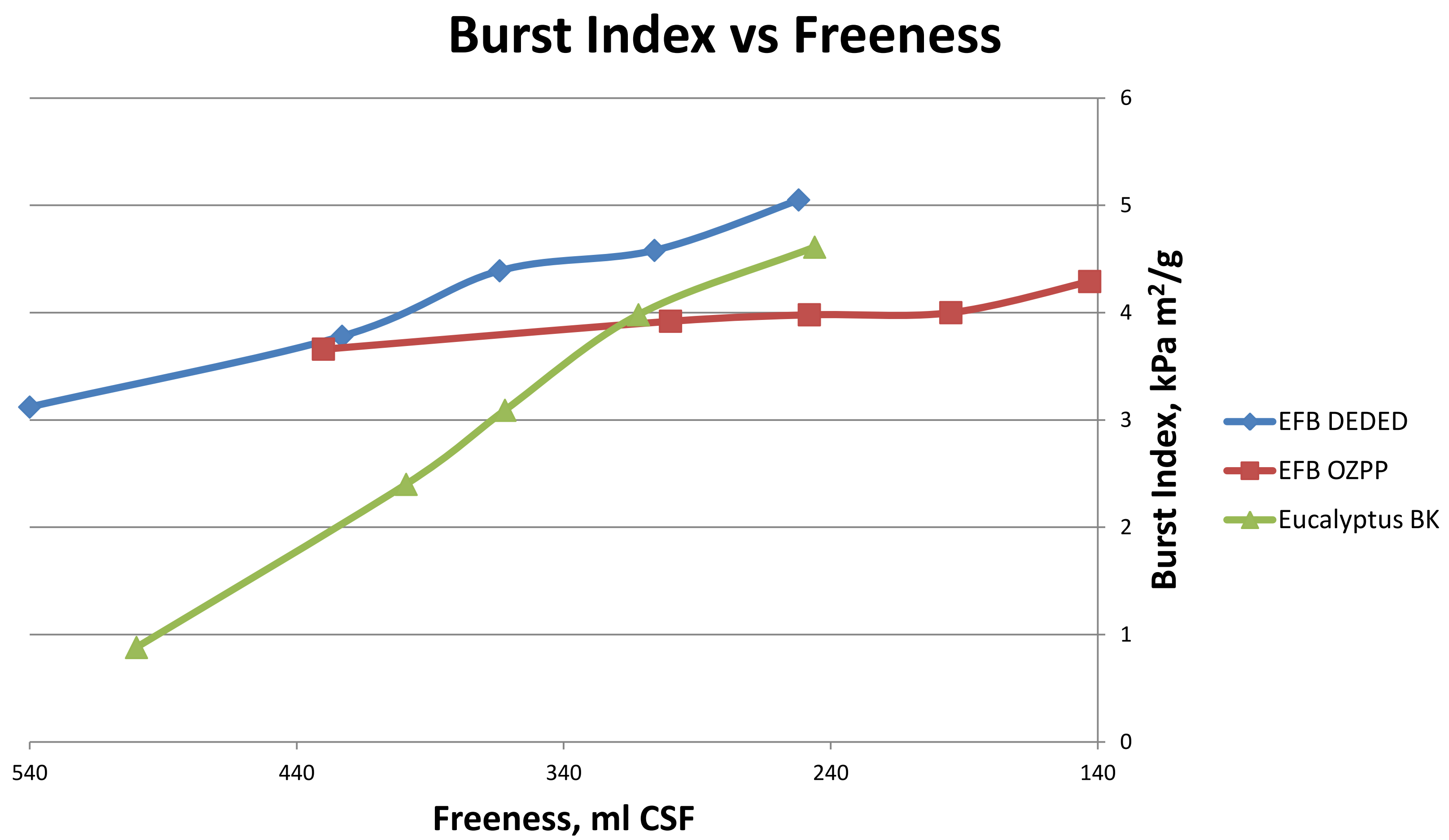


Tear Index vs Freeness
11
10
9
8
7
6
5
4
540
440
340
240
140
Freeness, ml CSF
Tear Index, mN m²/g
EFB DEDED
EFB OZPP
Eucalyptus BK

Results

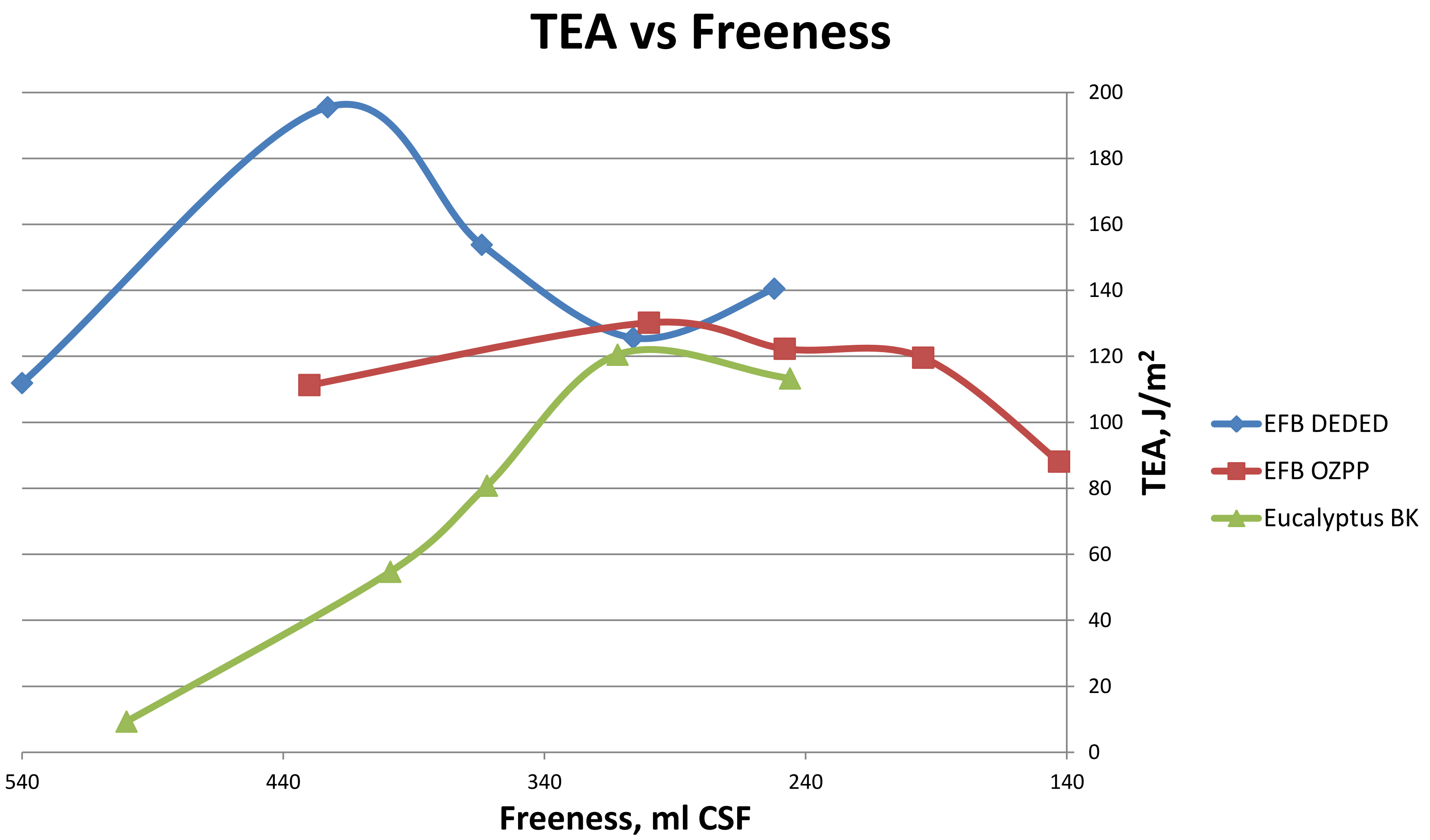

Tensile Index vs Freeness
70
65
60
55
50
45
40
35
30
25
20
540
440
340
240
140
Freeness, ml CSF
Tensile Index, Nm/g
EFB DEDED
EFB OZPP
Eucalyptus BK

Results

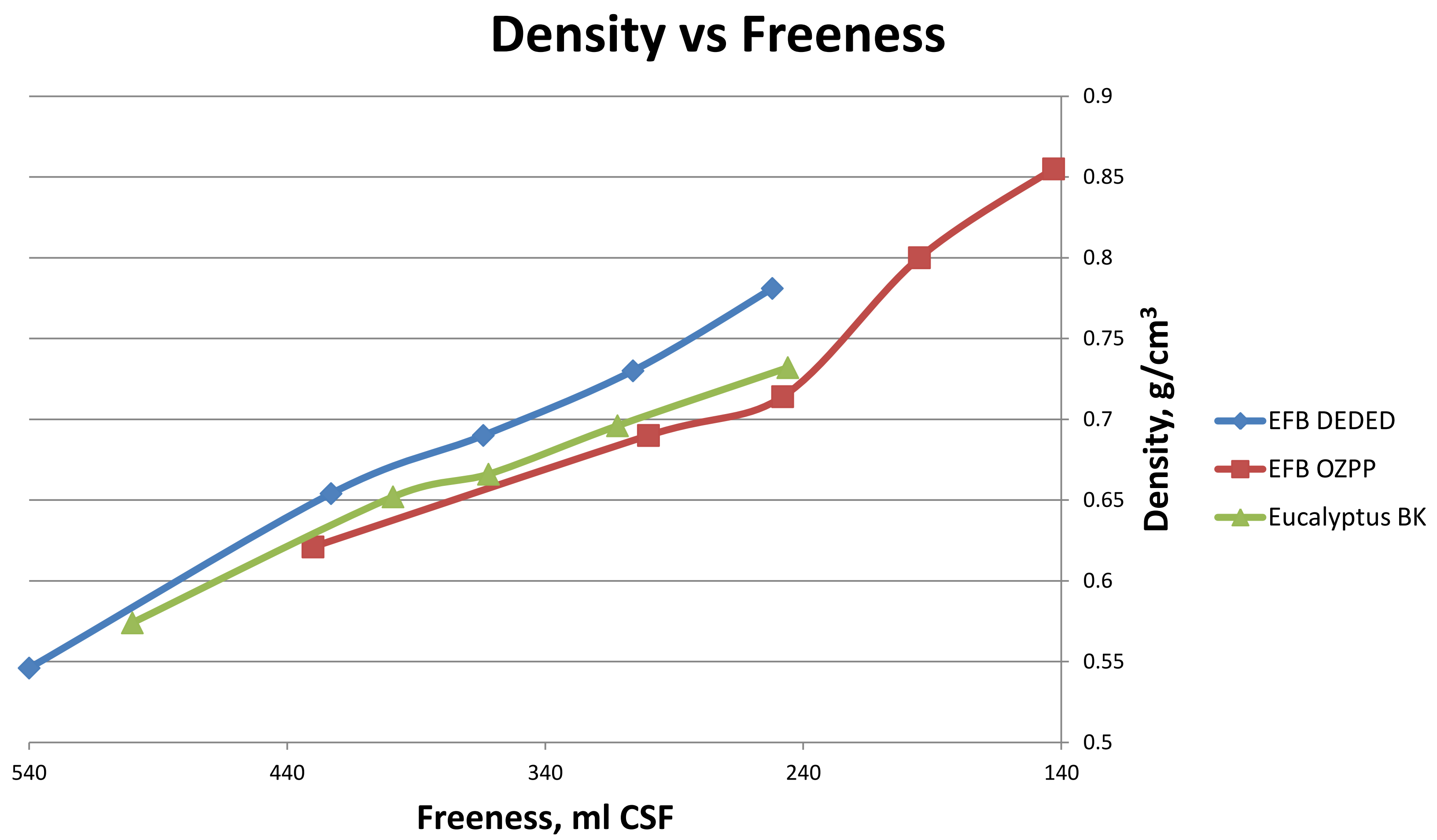


Burst Index vs Freeness
6
5
4
3
2
1
0
540
440
340
240
140
Freeness, ml CSF
Burst Index, kPa m2/g
EFB DEDED
EFB OZPP
Eucalyptus BK

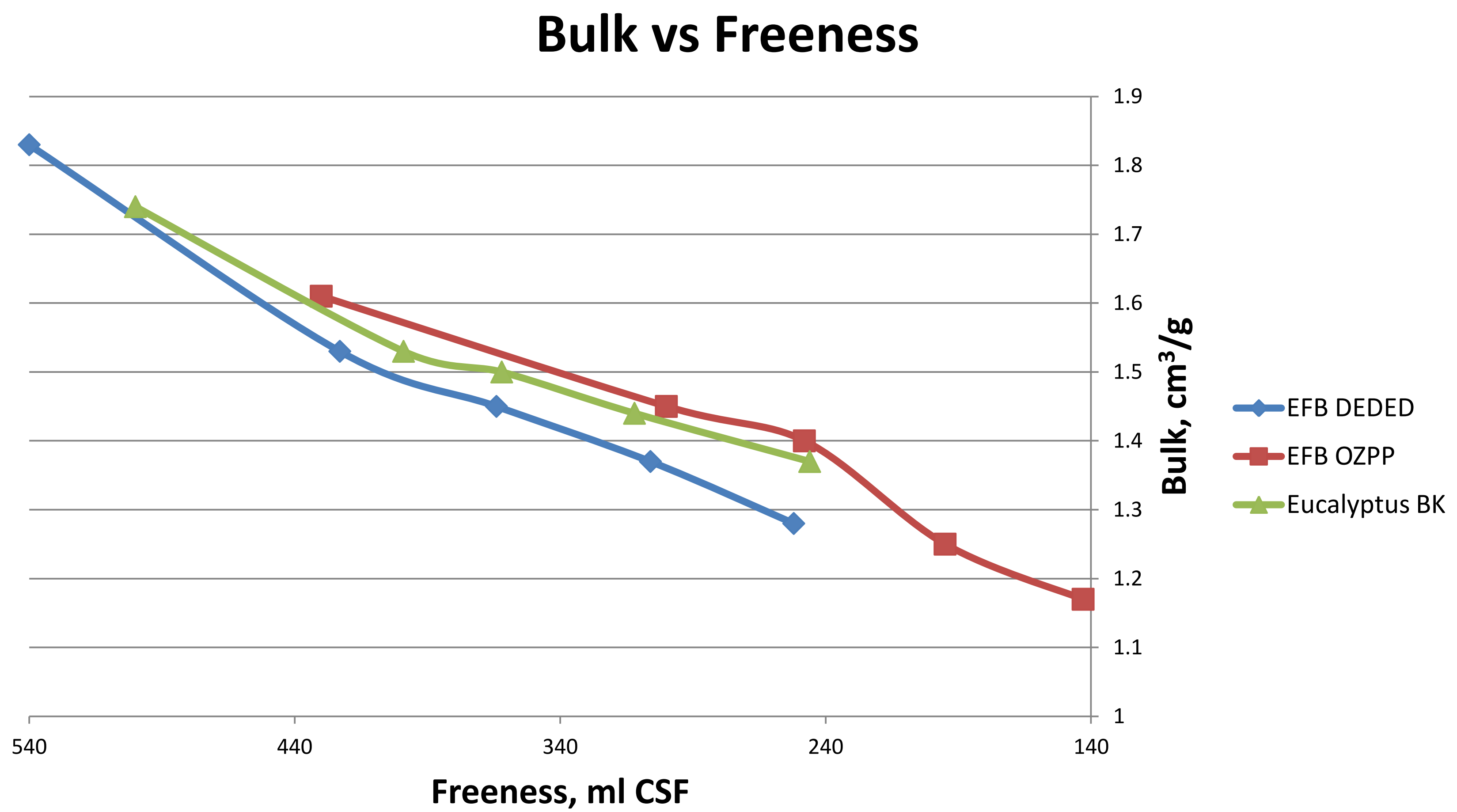
Results


TEA vs Freeness
200
180
160
140
120
100
80
60
40
20
0
540
440
340
240
140
Freeness, ml CSF
TEA, J/m2
EFB DEDED
EFB OZPP
Eucalyptus BK

Results


Density vs Freeness
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
540
440
340
240
140
Freeness, ml CSF
Density, g/cm3
EFB DEDED
EFB OZPP
Eucalyptus BK

Results


Bulk vs Freeness
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
540
440
340
240
140
Freeness, ml CSF
Bulk, cm^3/g
EFB DEDED
EFB OZPP
Eucalyptus BK

Conclusions & Next Steps

- Malaysian oil palm EFB can produce acceptable quality papermaking pulp using the soda process and either ECF or TCF bleaching.
- The EFC bleaching sequence used in this work (DEDED) could be reduced to a three stage sequence such as DED or D-Eop-D which would reduce both capital and operating costs of a commercial facility.
- Given the vast EFB resource, further study of this interesting fiber raw material is warranted.
- Next step will be EFB pilot scale cooking and bleaching followed by pilot papermaking.

Questions?

Bob Hurter bobhurter@hurterconsult.com

Med Byrd med_byrd@ncsu.edu