# Pilot Scale Pulping & Bleaching of Malaysian Oil Palm Empty Fruit Bunch: Part 2

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## ABSTRACT

At the Tappi 2015 PEERS conference, we presented the results for Bench Scale Pulping & Bleaching of Malaysian Oil Palm Empty Fruit Bunch (EFB). In this paper we are presenting the results for pilot scale EFP pulping and bleaching based on our earlier work. The EFB was chopped, screened and washed prior to cooking in a 2,300 liter spherical digester using the soda process. Bleaching trials were carried out using a three stage ECF bleaching sequence. Unbleached and bleached EFB pulps were tested for physical and optical properties. Comparisons are made between the properties of the bleached EFB pulp and bleached Kraft eucalyptus pulp. The EFB unbleached and 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).

In this study which is a continuation of the bench scale work reported earlier, pilot scale quantities of unbleached and bleached EFB pulp were produced.

## 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.

## EFB Fiber Preparation

The EFB fibre raw material was chopped to 2 - 3 cm lengths by running it twice through 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 dry screened using a vibrating screen and stored in drums for later use.

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

## Cooking

Pilot soda pulping was carried out using a 2,300-litre spherical digester, rotated at 10 rpm. Prepared EFB material was loaded into the digester, followed by caustic and adequate water to achieve the desired liquor-to-fiber ratio. The digester was then closed and heated with direct steam injection during rotation. When the target temperature/pressure was achieved, the digester was allowed to rotate, with periodic injections of steam, until the target H-factor was achieved. Rotation was then terminated, followed by de-pressurization (no blowing) and dumping. A sample of black liquor was obtained and saved for testing.

Table 1 provides the cooking conditions.

## Pulp Washing, Screening & Cleaning

The cooked material was collected in a catch box covered with fine mesh wire. Black liquor passed through the wire and was separated from the pulp. The pulp was then washed in the box to remove the bulk of the black liquor. The resulting brownstock was then pumped into a 9,500-litre tank and diluted to approximately 1% consistency. This slurry was then passed through an Alstrom pressure screen equipped with 0.25-mm slots. Material passing through the screen was collected in a separate tank. Rejects were directed back into the feed tank, to minimize good fiber loss. This process was continued until there was no more good fiber observed in the accept stream. The screen accepts were cleaned using a Beloit Posi-Flow cleaner, with a feed pressure of 25 psig and an accept pressure of 10 psig. The cleaner accepts were dewatered in the wire-bottom catch box described above. Screen accepts were tested for the following tests: Kappa number, alkali consumption, total yield, screened yield, fiber length distribution, viscosity, brightness, and Canadian Standard Freeness. All tests were conducted according to TAPPI standards.

### Bleaching

All pilot-scale bleaching was done at 10% consistency, in a 950-liter stirred tank. Bleaching was done using a 3-stage ECF sequence. After each stage, the slurry was tested for chemical consumption. It was then dumped into the wire-bottom catch box to separate most of the residual liquor. The pulp was washed thoroughly and tested at each stage for chemical consumption, yield, brightness, freeness (CSF), and CED viscosity. All testing was conducted in accordance with TAPPI standards.

Table 2 provides the bleaching conditions and bleaching chemical charges.

## RESULTS AND DISCUSSION

### EFB Raw Material (Table 3)

As reported in our previous paper, 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 4)

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.

Earlier bench-scale cooking showed that the fines/dust fraction had a negative effect on alkali consumption, yield and pulp quality. This fraction along with the hulls was not used in the pilot-scale cooks.

**Cooking** (Table 5)

Three cooks were carried out to produce pulp for unbleached papermaking and five cooks were carried out to produce pulp for bleached papermaking.

Pulp washing, screening and cleaning was done in three batches grouping together several cooks:

- Group 1 - for pulp for unbleached papermaking, cooks 13, 14 and 15
- Group 2 - for pulp for bleached papermaking, cooks 16 and 17
- Group 3 - for pulp for bleached papermaking, cooks 18, 19 and 20

For Group 1 and 2 pulps the total yield was 42.6% and 43.6% respectively, and the screened yield was 40.9% and 41.2% respectively, even though the average Kappa was 22.2 for the Group 1 cooks and 27.4 for the Group 2 cooks.

However, Group 3 pulps had a significantly higher total and screen yield, 50.9% and 50.3% respectively. The average Kappa number for the Group 3 cooks was 28.3 similar to Group 2. We have no explanation for the significant yield gain seen for Group 3 other than the possibility that the EFB samples used for the Group 3 cooks may have been more heavily weighted towards the longer/coarser fraction that the Group 2 cooks.

**Bleaching** (Table 6)

The final brightness was 85.1% ISO which met the target of +85% ISO. This was achieved using a total of 65 kg of chlorine dioxide per oven dry metric ton of unbleached pulp.

The viscosity decreased from 16.1 cp for the unbleached pulp to 10.40 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 1.4 is in the range expected for 85.1% ISO bleached pulp but is still on the high side.

The freeness of the bleached pulp dropped substantially versus the unbleached pulp. This is an indication that mechanical action on the pulp using pilot scale equipment during bleaching had a significant negative effect on the pulp and likely was the source of fines generation. Minimizing mechanical action in the commercial mill will be important for good quality bleached EFB pulp.

Overall bleaching yield of 85.7% is low but is similar to that experienced with the bench scale test work for various bleaching sequences. Even though the average Kappa number of the unbleached pulp from the 5 cooks was 28.0, the total yield is still below what we would have anticipated. Normally, for nonwood fibres starting with an unbleached Kappa number of about 15, we anticipate a total bleaching loss in the order of 6 - 7%. For an unbleached pulp with a Kappa of 20, one could expect a yield loss in the order of 9 - 11%. The above total yield is showing losses higher than normally anticipated. We have no explanation for the high bleaching losses.

**Brightness Reversion** (Table 7)

Brightness reversion for the DEpD bleached pulp was low.

**Fiber length analysis** (Table 8)

The average unbleached pulp fiber length on a weight/weight basis is 16.5% shorter than that of the bleached pulp with no refining. Even with significant refining, the bleached pulp still has a longer average fiber length. 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 9)

The properties of the soda cooked EFB unbleached and DEpD bleached pulps are provided in Table 9.

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

Compared to eucalyptus bleached kraft pulp,

- The EFB DEpD bleached pulp achieved a Tear Index close to the maximum for eucalyptus pulp but with significantly less energy input.
- Tensile Index for bleached and unbleached EFB pulp was significantly lower.
- Burst Index and TEA for bleached and unbleached EFB pulp was significantly higher
- Bulk for unbleached EFB pulp was significantly higher.

## CONCLUSIONS

Malaysian oil palm empty fruit bunches (EFB) can produce an acceptable quality of papermaking unbleached and bleached pulps using the soda process and three-stage ECF bleaching.

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

Our next paper will present the results of unbleached and bleached papermaking.

**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 | | |
|---|---|---|
| | **For Unbleached Pulp** | **For Bleached Pulp** |
| Cooking Apparatus | 2300-liter batch digester - direct steamed | 2300-liter batch digester - direct steamed |
| Number of Cooks | 3 | 5 |
| Cook Size | 45 – 68 OD kg | 68 OD kg |
| Cutting / dry screening | cut EFB to 2 - 3 cm lengths, wash/screen EFB to remove nut hulls and fines | |
| Soaking | soaked in warm water (30 $^0$C) overnight, drained | |
| NaOH on OD fiber | 21% | 22% |
| AQ on OD fiber | 0% | 0% |
| Liquor-to-Fiber Ratio | 10:1 start | 10:1 start |
| Maximum Temperature | 165 - 170 $^0$C | 165 - 170 $^0$C |
| Time to Max Temperature | 20 – 60 minutes | 40 - 45 minutes |
| Time at Max Temperature | 115 – 147 minutes | 135 - 146 minutes |
| H-factor target | 1800 | 1750 |
| Post cooking treatment | mixed, washed and screened | mixed, washed and screened |

| Table 2 DEpD bleaching conditions & applied chemical charges | | | | |
|---|---|---|---|---|
| **Bleaching Conditions** | | | | |
| Sequence | Stage | Time (min.) | Temp ($^0$C) | Pulp cons. (%) |
| DEpD | D0 | 60 | 70 | 10 |
| | Ep | 60 | 70 | 10 |
| | D1 | 180 | 70 | 10 |

| **Chemical Charges Applied (kg/ODmt)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Stage | $ClO_2$ | NaOH | $H_2O_2$ | DTMPA | $MgSO_4$ | $H_2SO_4$ | | |
| D0 | 35 | | | | | 12 | | |
| Ep | | 30 | 10 | 5 | 5 | | | |
| D1 | 40 | | | | | 14 | | |

| Table 3 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 4 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 5 Cooking Results | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | For Unbleached Paper | | | For Bleached Paper | | | | |
| Cook # | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Kappa number | 20.3 | 21.4 | 24.8 | 28.0 | 26.7 | 28.5 | 29.8 | 26.8 |
| ISO brightness | 36.1% | | | 33.9% | 34.4% | 32.0% | 30.9% | 31.5% |
| Total Yield | 42.6% | | | 43.6% | | 50.9% | | |
| Screened Yield | 40.9% | | | 41.2% | | 50.3% | | |
| Screened Rejects | 4.0% | | | 5.5% | | 1.1% | | |
| Black liquor terminal pH | 12.5 | | | 10.9 | 10.8 | 10.8 | 10.9 | 10.9 |
| Freeness, ml CSF | 622 | 428 | 320 | 430 | 529 | 445 | 510 | 530 |
| CED viscosity, cp | 20.3 | | | 16.5 | 15.8 | | | |

| Table 6 DEpD Bleaching Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Stage | pH | Consumption | | Residuals (kg/ODmt) | Yield (%) | Freeness (ml CSF) | Brightness (% ISO) | Kappa number | Viscosity (cp) |
| | | % | kg/ODmt | | | | | | |
| D0 | 3.3 | 97.1 | 34.0 | 1.0 | 92.6 | 250 | 62.0 | 2.7 | 12.9 |
| Ep | 10.8 | 98.0 | 29.4 | 0.6 | 94.1 | 210 | 68.5 | 2.0 | 12.8 |
| D1 | 3.6 | 78.5 | 31.4 | 8.6 | 98.4 | 201 | 85.1 | 1.4 | 10.4 |
| | | | | Overall Yield | 85.7 | | | | |

| Table 7 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 (% $ISO_{3h}$) |
| DEpD | 85.1 | 84.5 | - 0.6 | 84.3 | - 0.8 |

| Table 8 Fibre length analysis | | | | |
|---|---|---|---|---|
| | | Unbleached Pulp | DEpD Bleached Pulp | |
| | | 0 rev | 0 rev | 4000 rev |
| Avg. fibre length (w/w) | mm | 0.720 | 0.862 | 0.744 |
| Avg. fibre width | microns | 19.4 | 18.4 | 18.6 |
| Fines content by number | % | 25.76 | 32.55 | 39.02 |

| Table 9 Pulp properties | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Test** | **Units** | **Unbleached Pulp** | | | | | **DEpD Bleached Pulp** | | | |
| Beating | rev | 0 | 750 | 1500 | 2250 | 3000 | 0 | 1000 | 2000 | 3000 |
| Freeness | CSF, ml | 513 | 385 | 302 | 246 | 180 | 201 | 164 | 145 | 132 |
| Basis weight | $g/m^2$ | 65.0 | 66.2 | 66.9 | 66.2 | 62.7 | 65.2 | 65.3 | 64.9 | 64.9 |
| Thickness | µm | 151.8 | 116.6 | 109.8 | 97.0 | 83.2 | 96.8 | 80.2 | 80.4 | 79.6 |
| Bulk | $cm^3/g$ | 2.34 | 1.76 | 1.64 | 1.47 | 1.33 | 1.50 | 1.20 | 1.20 | 1.20 |
| Density | $g/cm^3$ | 0.427 | 0.568 | 0.610 | 0.680 | 0.752 | 0.667 | 0.833 | 0.833 | 0.833 |
| Tear Index | $mN \cdot m^2/g$ | 7.35 | 9.37 | 9.49 | 8.85 | 8.17 | 9.6 | 8.8 | 8.2 | 7.4 |
| Burst Index | $kPa \cdot m^2/g$ | 1.75 | 3.54 | 4.21 | 4.25 | 4.72 | 4.1 | 4.4 | 4.5 | 4.6 |
| Tensile Index | Nm/g | 27.95 | 41.38 | 45.76 | 48.11 | 49.29 | 49.19 | 50.48 | 54.86 | 53.52 |
| Fold | | 13 | 51 | 122 | 368 | 570 | 310 | 946 | 1397 | 1238 |
| Stiffness | mN | 7.1 | 6.8 | 6.8 | 5.7 | 4.1 | n/a | n/a | n/a | n/a |
| TEA | J/m2 | 51.3 | 138.2 | 166.2 | 138.1 | 115.0 | 156.0 | 108.5 | 120.0 | 85.3 |
| Stretch | % | 3.60 | 6.34 | 6.85 | 5.50 | 4.72 | 5.95 | 4.10 | 4.20 | 3.23 |
| Smoothness | Sheffield, s | 387 | 344 | 302 | 280 | 228 | 322 | 241 | 226 | n/a |
| Porosity | Gurley, s | 0.88 | 5.59 | 9.99 | 27.94 | 74.87 | 3.45 | 18.7 | 101.0 | n/a |
| 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 | | | | | | | | | | |

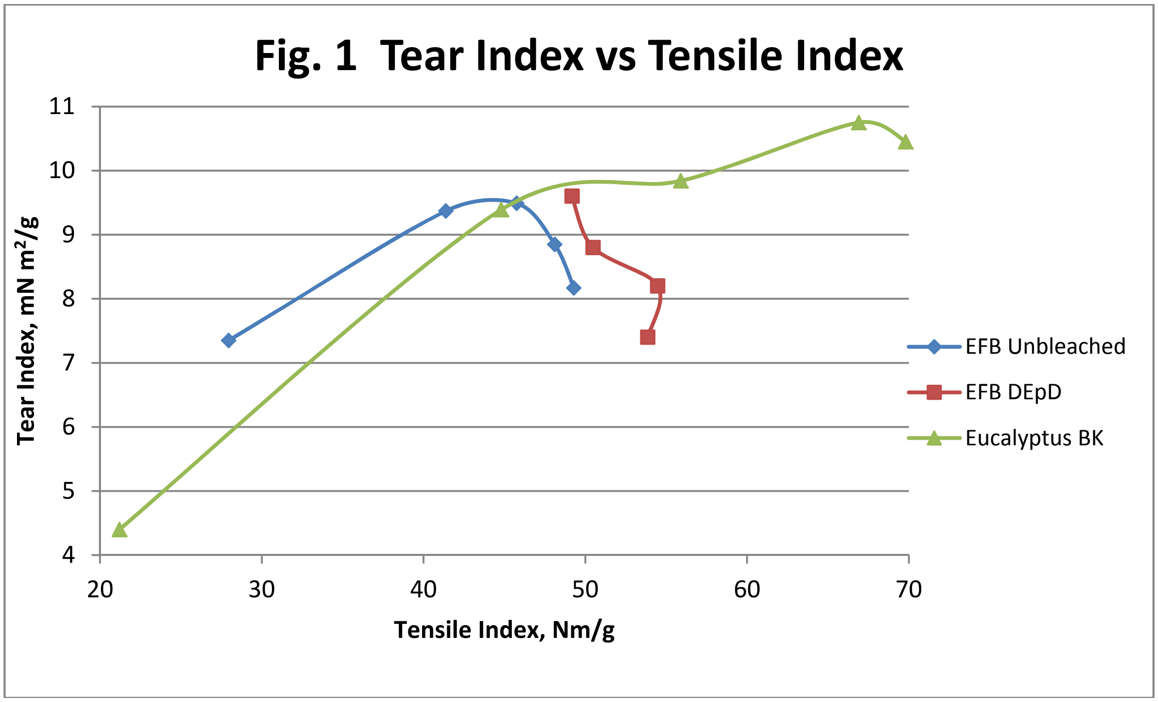
Fig. 1 Tear Index vs Tensile Index
Tear Index, mN m²/g
11
10
9
8
7
6
5
4
20
30
40
50
60
70
Tensile Index, Nm/g
EFB Unbleached
EFB DEpD
Eucalyptus BK

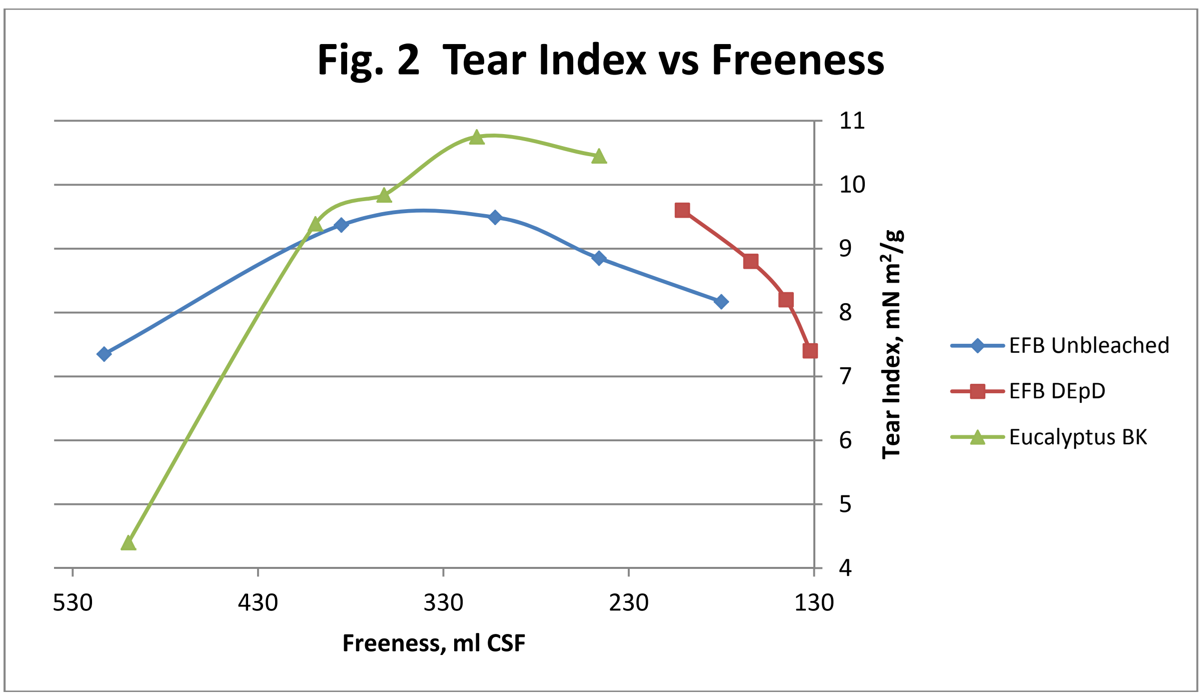
Fig. 2 Tear Index vs Freeness
Tear Index, mN m²/g
11
10
9
8
7
6
5
4
530
430
330
230
130
Freeness, ml CSF
EFB Unbleached
EFB DEpD
Eucalyptus BK

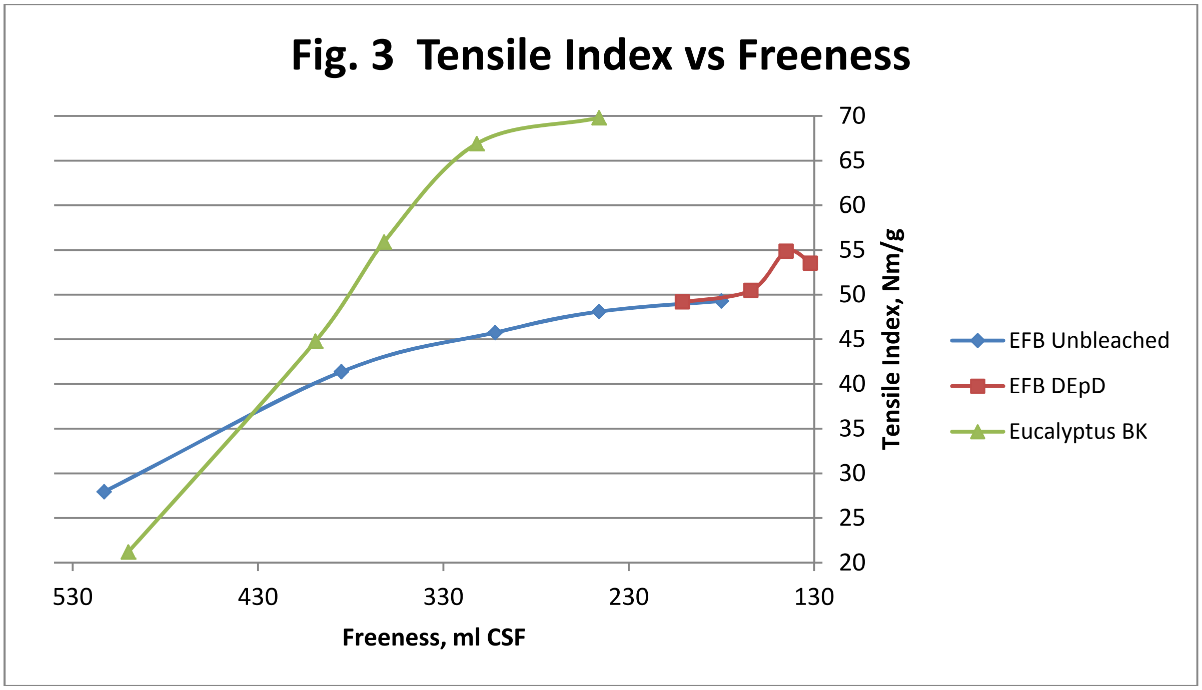

Fig. 3 Tensile Index vs Freeness
70
65
60
55
50
45
40
35
30
25
20
Tensile Index, Nm/g
530
430
330
230
130
Freeness, ml CSF
EFB Unbleached
EFB DEpD
Eucalyptus BK


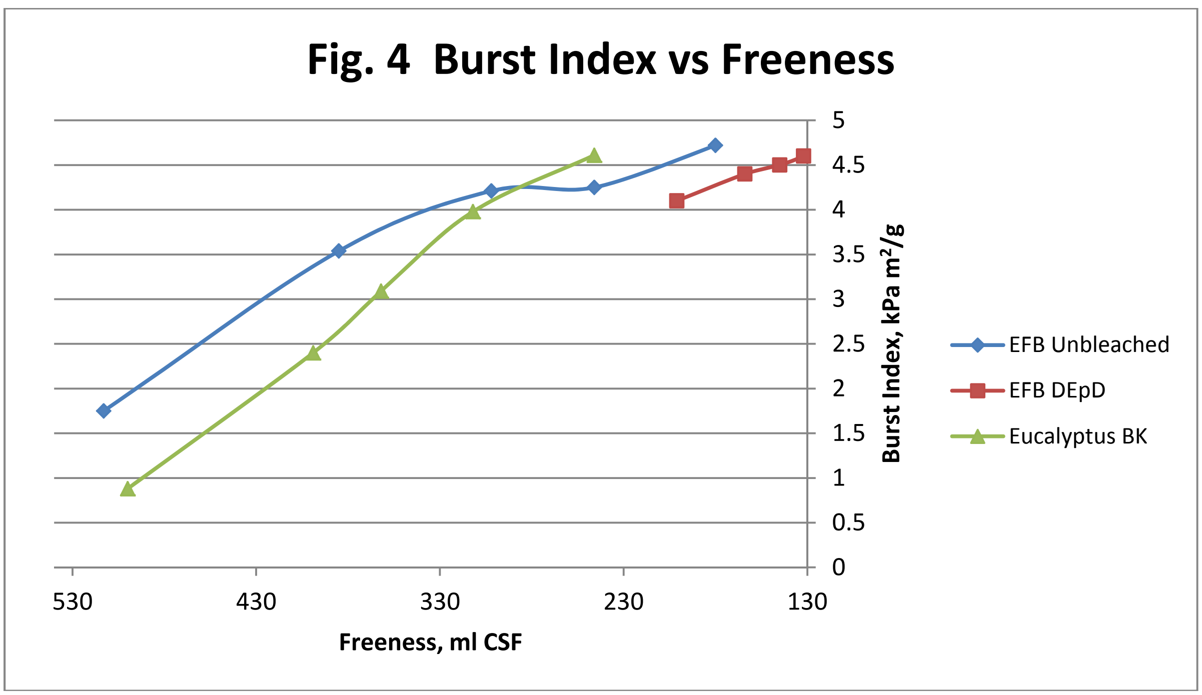

Fig. 4 Burst Index vs Freeness
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Burst Index, kPa m²/g
530
430
330
230
130
Freeness, ml CSF
EFB Unbleached
EFB DEpD
Eucalyptus BK

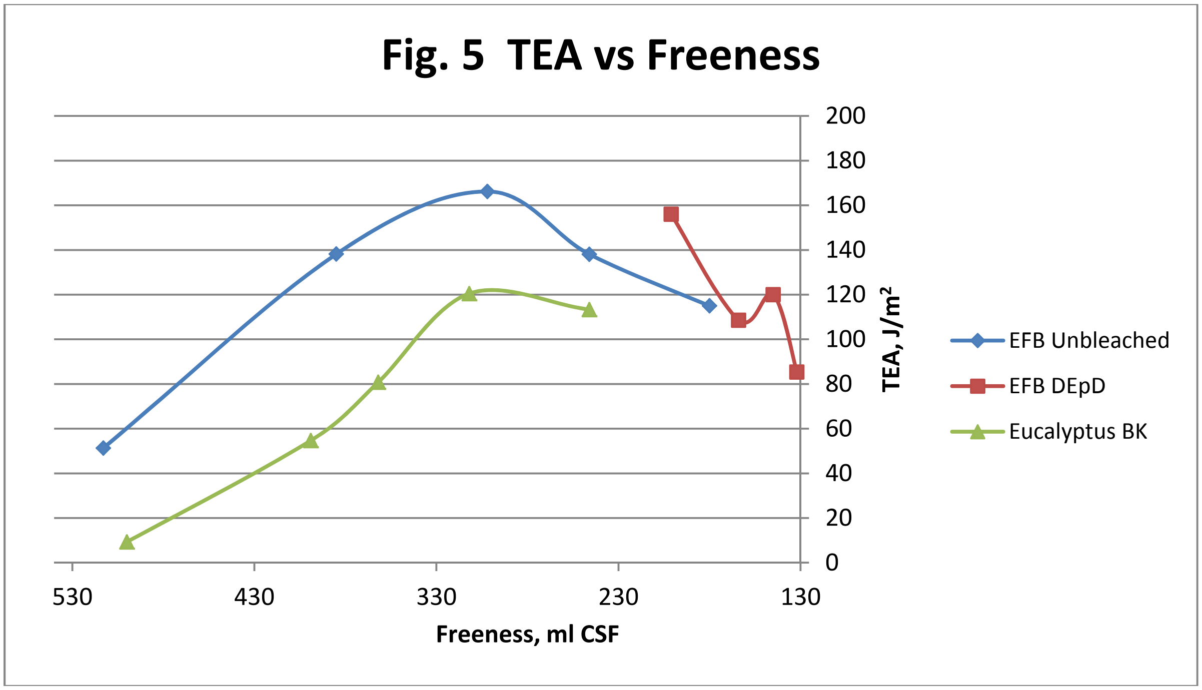

Fig. 5 TEA vs Freeness
200
180
160
140
120
100
80
60
40
20
0
530
430
330
230
130
Freeness, ml CSF
TEA, J/m²
EFB Unbleached
EFB DEpD
Eucalyptus BK


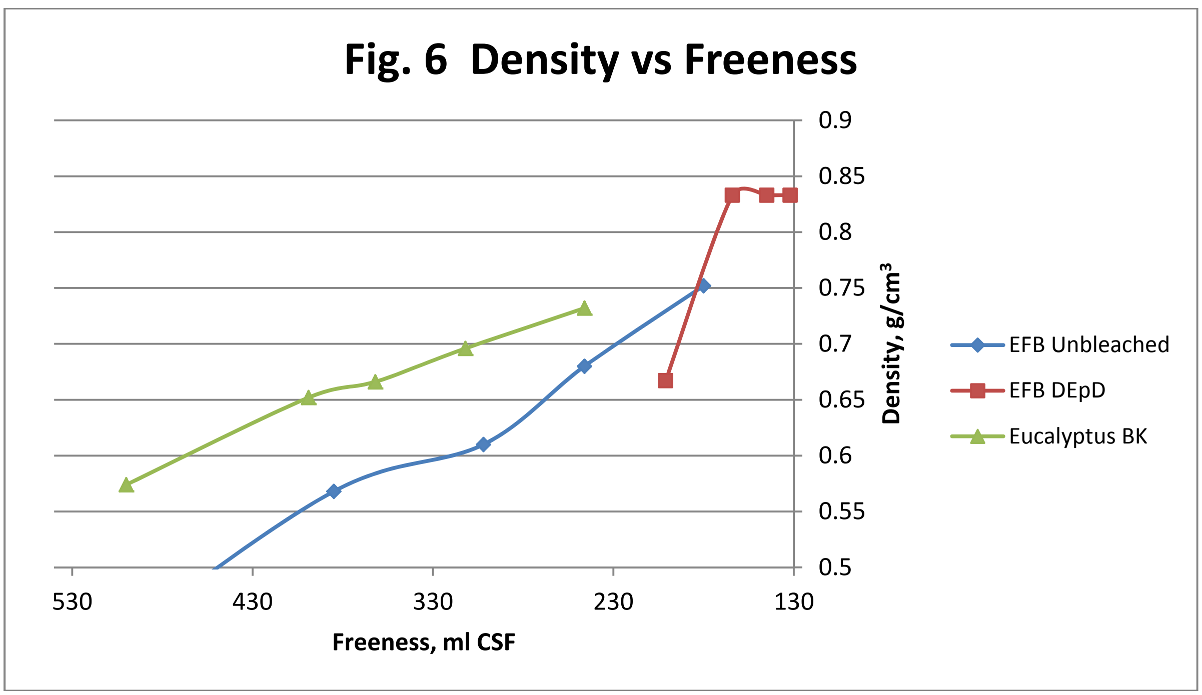

Fig. 6 Density vs Freeness
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
530
430
330
230
130
Freeness, ml CSF
Density, g/cm³
EFB Unbleached
EFB DEpD
Eucalyptus BK

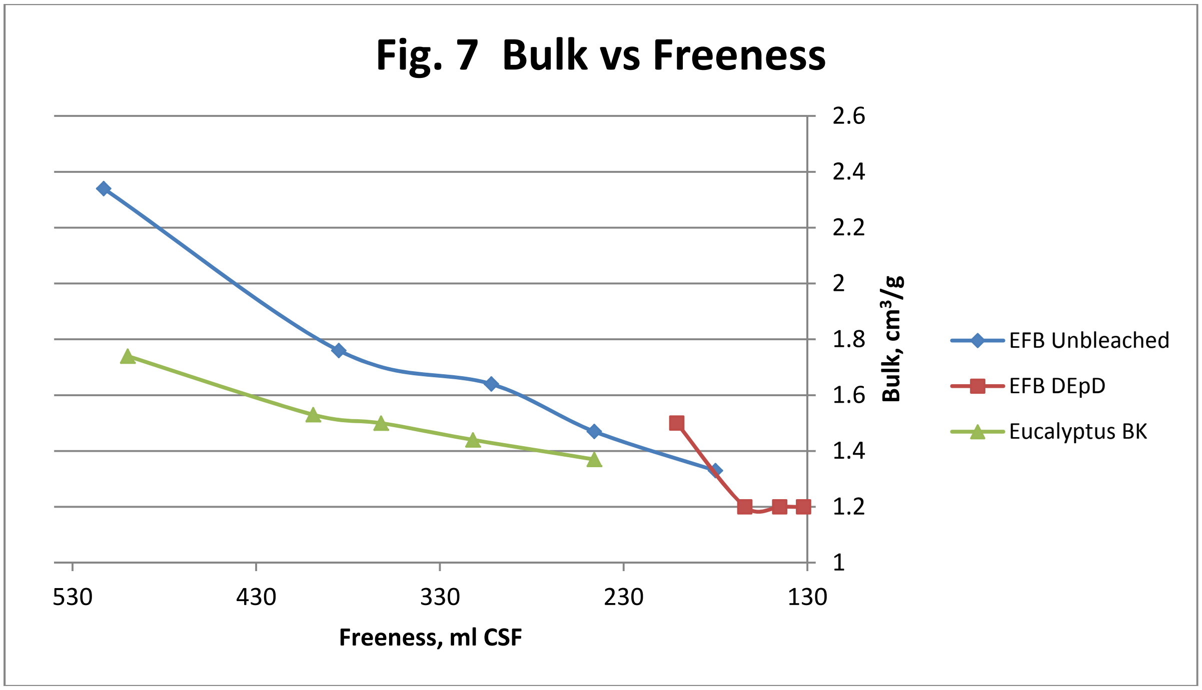
Fig. 7 Bulk vs Freeness
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Bulk, cm³/g
530
430
330
230
130
Freeness, ml CSF
EFB Unbleached
EFB DEpD
Eucalyptus BK