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Log quality of Mountain Pine Beetle (MPB) infested wood in relation to lumber manufacture-Year 2 lumber and fibre properties

By

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Executive Summary

The largest Mountain Pine Beetle (MPB), *Dendroctonus ponderosae* Hopkins, epidemic in Canada's history is compelling BC's forest industry to utilize large volumes of dead and dying Lodgepole Pine, *Pinus contorta*. The morphology and chemistry of MPB killed wood is altered (1). As well, MPB killed timber contains blue stain in the sapwood and extensive checking which lowers its commercial value for use in lumber and pulp.

The first year project work investigated the fundamental properties of MPB infested wood and log quality in relation to dimensional lumber product value and recovery. Results showed increasing negative impact on the US and Japanese construction and home renovation markets with increasing time since beetle attack.

This second year project work intends to investigate the fundamental properties of MPB infested wood and log quality in relation to strength properties of full size material, fibre properties, and pulp strength properties. The rough sawn dimension lumber from Phase I has been tested for bending strength and gluing characteristics. Wood chips that were collected from the sawmill processing of green, red, and grey MPB attack samples has been characterized for pulping studies. Fibre and pulp quality has been related to the fundamental properties and log quality data determined in year one. The key objectives of this project are:

1. To develop a database on the bending strength properties of full size MPB dimension lumber in relation to green, red and early grey stages of attack.
2. Develop technical information on the gluing characteristics of 2 types of adhesives in relation to sap and heart wood and green, red and early grey stages of attack.
3. To investigate the effect of MPB infested wood quality at green, red and grey attack stages on fibre and pulp quality

This second year project work completes the characterization of the material from the first year's primary breakdown. This proposal integrates fundamental and practical research to develop strategies for the extraction of the highest value from MPB infested wood.

This report focuses on Objective 3 and provides a database on the fibre and pulp quality of the green, red, and grey attacked MPB wood. As the lumber strength data under objectives 1 and 2 are influenced by many factors including the geo-climatic conditions of the sampling sites, the collected information showing trends of strength reduction is considered preliminary. Additional sampling and testing will be needed to confirm finding and detailed results will not be provided in this report.

METHODS AND MATERIALS

Sampling

Approximately 10kg each of wood chips from MPB attacked wood in green, red, and grey stages were collected from Clear Lake sawmill, Prince George BC in October 2004. Sampling was done during the trial when six to seven truckloads of logs from each condition were run through the sawmill with mill cleanout between each condition.

A standard mill furnish of digester feed SPF chips were obtained from Prince George pulp mill as a reference condition. Approximately 10kg each of mill screened and unscreened chip samples were collected in May 2005.

Kiln dried chips (10kg) were received from Brink Forest Products in Prince George, also in May 2005 and served as a dry SPF reference.

All chip samples were stored in a deep freeze (-20°C).

Fibre Properties

Chip Size Distribution and moisture content

Samples were equilibrated to ambient temperature and moisture contents were determined on oven dry basis. A grab sample of 400g for chemical analysis was taken prior to screening.

Chip screening was done on a Linden Chip Classifier according to standard mill method. Batch weight (10L volume) and fraction weights were recorded. Fractions of 10mm bar, 16 mm round, 7 mm round, 2mm bar and fines were collected after 10 minutes of agitation. Bark was removed from each fraction prior to weighing.

Chip mixtures of 70% 16mm round and 30% 7 mm round fractions were prepared for the pulping study and stored in a cooler at 5°C.

Moisture Re-absorption

Approximately 300g each of MPB attacked and SPF chips (70% +16mm and 30% +7mm) were weighed and then placed into 3000mL of water at room temperature. Chips were de-watered and re-weighed over a 10 day period after soaking times of 0.5, 1, 2, 3, 4, 5, 24, 48, 54, 96, and 216 hours. Initial moisture contents of the chips were determined and the moisture uptake calculated.

Decay

Decay of wood samples was determined by 1% caustic solubility as per T212 om-98.

pH

pH of wood chips was determined according to T252 om-98.

Chemical Composition

Lignin Content

Extractive free wood was prepared according to T264cm-97 with acetone as the solvent. Klason and acid soluble lignin were determined on wood and pulp according to T222 om-98.

Carbohydrate Content

Carbohydrate content was determined on wood and pulp by sugars analysis of the filtrate from the lignin content test. Arabose, galactose, glucose, xylose, and mannose were analysed by ion chromatography.

Total Extractives Content

Acetone extractives of wood chip and pulp samples were determined by weight according to T280 pm-99.

Resin Acid Content

Resin acid content was determined by HPLC analysis of dehydroabietic acid from the hot water extract of wood chips and pulp samples. Black liquor samples were analysed at 2% concentration.

Extractions

The wood chip samples were prepared by air-drying and grinding in a Wiley mill to 1 mm mesh.

Aqueous extractions for wood meal and pulp samples were carried out at PH 11 for 24 hours at 80 degrees Celsius. Fibre to water ratios were 1.5g to 150 ml.

High Pressure Liquid Chromatography

Analysis of dehydroabietic acid was conducted using a Shimadzu SCL-10A HPLC with LC-10AD pump and SPD-10AV variable wavelength UV/VIS detector at 200nm. The sample extracts were injected in duplicate at pH 11 into a 20 μ L injection port with a 0.45 μ m PTFE pre-filter and were carried with a mobile phase of 65% acetonitrile and 35% 0.1% acetic acid at 2mL/minute through a Whatman Universal RP guard column, Zorbax Rx-C8 guard column and a Zorbax Rx-C8 4.6 mm x 250 mm reverse phase column. Dehydroabietic acid peak appeared at approximately 7.6 minutes and was analyzed by external standard calibration in the range of 1 to 50 ppm (r^2 of 0.9993).

Chemical Pulping Properties

Kraft Pulping

PG digester feed chips underwent Kraft pulping to a Kappa target of 30 ± 2 in a batch digester. Chemical charge was 16% on OD wood based on AA grams Na_2O required and liquid to wood ratio was 4:1. The cooking cycle involved impregnation for 35 minutes to 115C, ramping to 168C and 120psi, and cooking to H factor of 1600. The MPB attacked wood and kiln dried samples underwent identical cook conditions. Pulps were disintegrated, washed, and screened.

Kappa Number

Kappa number was determined according to Tappi standard method T236 cm-85. The test was performed on a Radiometer KTS1 Semi Automatic Kappa Analyser which carries out the reagent addition, mixing, and potentiometric titration to 270 mV.

Black Liquor Analysis

Density

Density was measured with a hydrometer.

Solids Content

Solids content was determined gravimetrically.

Chemical Consumption

Residual effective and active alkali were determined by barium carbonate precipitation and potentiometric titration with hydrochloric acid to pH 8.3

Chemical Pulp Strength Properties

Analysis of fibre length and coarseness was done on a Kajaani FS-200.

Lab scale PFI refining was done at 1500, 5000, 8000, and 12500 revolutions for the evaluation of pulp strength, physical, and optical properties.

Refiner Mechanical Pulping

Refiner mechanical pulp (RMP) was prepared by Paprican¹ in the freeness ranges of 75-200 mL CSF. Chips from green stage, red stage, grey stage, and PG mill reference samples were refined in a 30.5 cm open-discharge, single-disc Sprout Waldron laboratory refiner using the following processing conditions:

Plate type:	D2A507
Number of passes	2 to 5 depending on freeness level
Plate gap, mm	0.51 (first pass) 0.051 to 0.15 (subsequent passes)
Refining consistency, %	16 to 23

Before each pass, the refiner was heated to 93C with saturated steam and the plate clearance set at zero. Chips (or pulp) were fed into the refiner by a vibratory feeder. After each pass, pulps were dewatered through a 280 mesh stainless steel screen with white water recirculation to minimize the loss of fines during the dewatering process. Pulps were fluffed into a uniform size suitable for feeding into the

¹ Johal S. and Yuen, B., Refining of four mountain pine beetle killed wood samples. Paprican Technical Service Contract Report, December 19, 2005.

refiner for subsequent passes. Following each final pass, latency was removed on a 24 g (o.d. basis) representative sample and unscreened Canadian standard freeness (CSF) determined.

Refiner Mechanical Pulp Strength Properties

Fibre length analysis was done on a Bauer Mcnett classifier.

Handsheets were prepared for the evaluation of pulp strength, physical, and optical properties.

RESULTS AND DISCUSSION

Fibre Properties

Chemical Composition

Table 1 shows that there was no significant difference among the lignin and carbohydrate contents of the wood samples. Table 2 displays the extractives content and fibre properties of the wood chip samples. Moisture contents of the MPB attacked and kiln dried fibre (figure 1) are lower in comparison to the SPF reference, by 18% for green stage, approximately 40% for red and grey stages and 80% for kiln dried. No significant difference in decay of the MPB attack wood samples relative to the SPF digester feed ($\pm 3\%$) was observed. Decay in the kiln dried SPF was higher by 14% which may be due to higher heartwood content and presence of heartrot.

Table 1. Lignin and carbohydrate composition of wood chip samples.

Wood	Lignin, %		Carbohydrate, %				
	Klason lignin	Acid-soluble lignin	Arabose	Galactose	Glucose	Xylose	Mannose
PG Reference	27.35 \pm 0.02	0.29 \pm 0.00	1.26 \pm 0.04	2.16 \pm 0.00	48.12 \pm 0.06	6.26 \pm 0.00	12.08 \pm 0.09
Green Attack	27.46 \pm 0.01	0.30 \pm 0.00	1.31 \pm 0.01	2.39 \pm 0.04	48.75 \pm 0.65	6.61 \pm 0.03	12.09 \pm 0.20
Red Attack	27.54 \pm 0.09	0.25 \pm 0.00	1.41 \pm 0.00	2.56 \pm 0.03	48.13 \pm 0.15	6.69 \pm 0.01	11.76 \pm 0.09
Grey Attack	27.64 \pm 0.01	0.28 \pm 0.00	1.35 \pm 0.09	2.45 \pm 0.02	48.65 \pm 0.87	6.55 \pm 0.24	11.79 \pm 0.24
Kiln dry	27.34 \pm 0.03	0.03 \pm 0.01	1.19 \pm 0.01	2.36 \pm 0.00	48.32 \pm 0.16	6.61 \pm 0.01	12.42 \pm 0.10

Table 2. Extractives content and fibre properties of wood chip samples.

Chip Sample	pH	moisture content (%)	acetone extractives (w%)	resin acid (mg/kg)	Decay (% solubility)
PG Digester Feed	5.19	73%	2.47%	893	15.71
Green Attack	5.01	60%	1.82%	1119	15.35
Red Attack	4.89	41%	2.25%	1938	16.23
Grey Attack	4.20	46%	2.44%	1713	15.30
Kiln Dried	4.10	13%	3.72%	1823	17.89

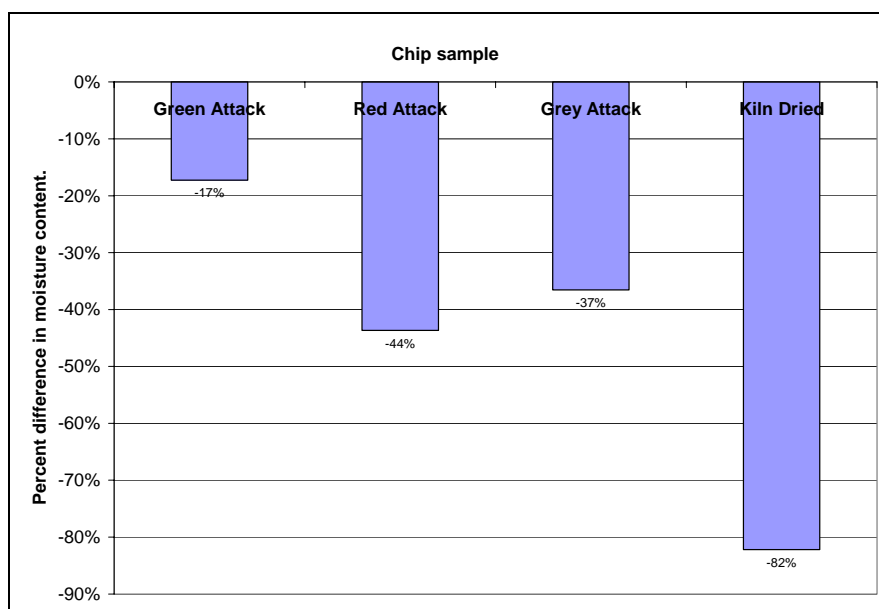


Figure 1. Percent difference in moisture content of MPB attacked and kiln dried wood relative to SPF digester feed reference.

Figure 2 shows that the total extractives contents are higher by 51% in the kiln dried fibre in comparison to the SPF digester feed reference. This is likely due to a higher heartwood content in the kiln dried chips which are obtained from lumber trim ends. This fibre is also a mixture of SPF species. In the MPB attacked fibre, extractives content increased with increasing time since attack. However the SPF digester feed reference had the same level of extractives as the grey stage. Therefore, green and red attack stage fibre had lower extractives in comparison to the fibre which is normally being run at the pulp mill.

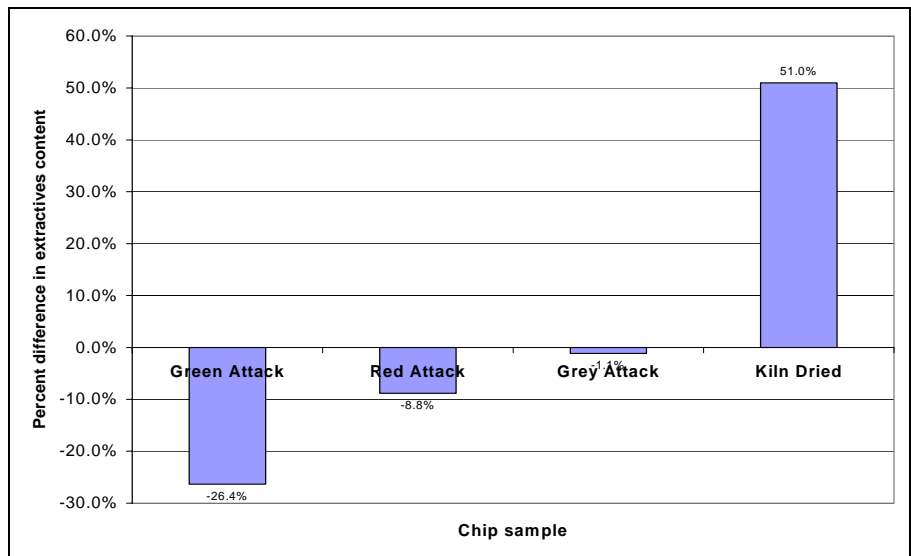


Figure 2. Percent difference in acetone extractives content of MPB attacked and kiln dried wood relative to SPF digester feed reference.

Figure 3 shows the percent difference in dehydroabietic acid content in the wood chips relative to the SPF digester feed sample. Resin acid is higher by 25% in green attack, 117% in red attack, 92% in grey attack, and 104% in kiln dried.

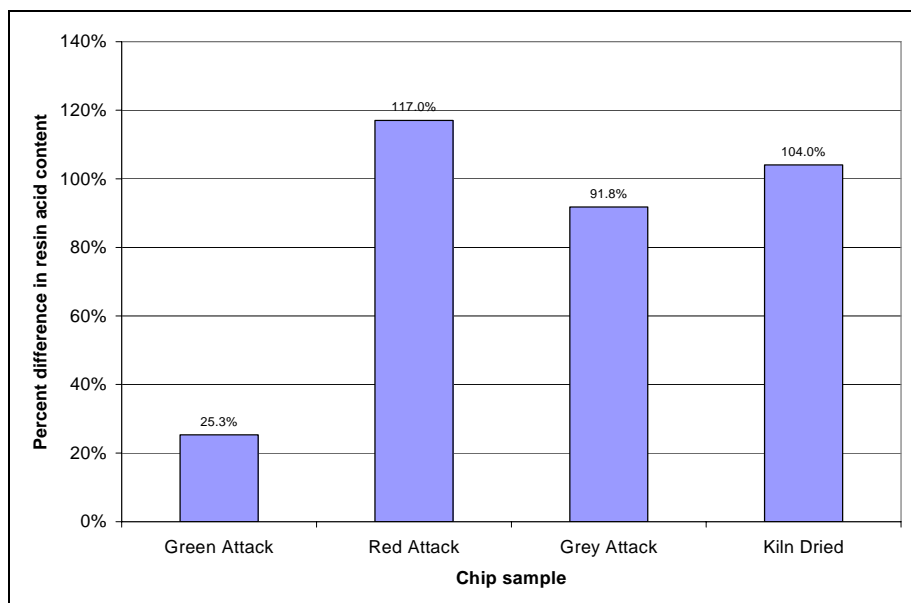


Figure 3. Percent difference in resin acid content of MPB attacked and kiln dried wood relative to SPF digester feed reference.

Although the total extractive contents in the MPB attacked woods is lower than the reference SPF, the particularly toxic resin acid composition is higher.

Chip Size Distribution

Table 3 and figure 4 show the chip size distribution of the SPF reference and kiln dried and MPB attacked wood. The 16 mm and 7 mm fractions are the most ideal for pulping. The MPB attacked and kiln dried woods had lower amounts of the 16 mm fraction in comparison to the digester feed reference. Green attack was lower by 5%, red attack by 3%, grey attack by 10%, and kiln dried by 44%. The 7 mm fractions were 24% lower for green and red attack, not significantly different in grey attack, and 67% higher for kiln dried.

Table 3. Percentage chips retained on a Linden Chip Classifier

Chip Sample	% Retained				
	10 mm Bar	16mm Round	7mm Round	2mm Bar	Fines
PG Digester Feed	10%	66%	21%	1%	2%
Green Attack	20%	63%	15%	1%	1%
Red Attack	16%	64%	17%	1%	2%
Grey Attack	15%	59%	23%	1%	2%
Kiln Dried	21%	37%	35%	4%	3%

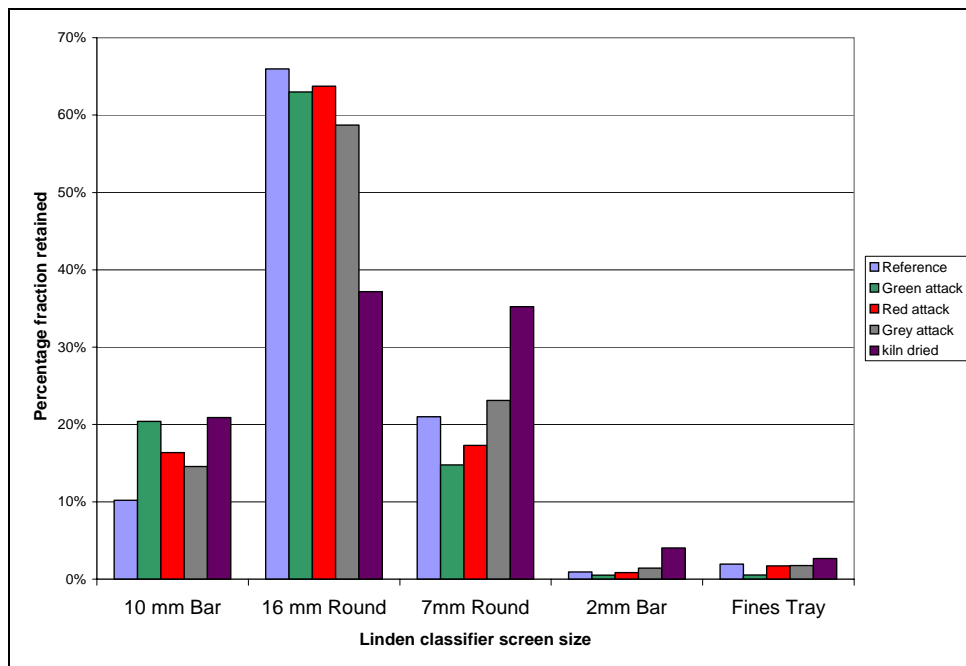


Figure 4. Chip size distribution of SPF reference and kiln dried and MPB attacked wood.

Moisture Re-absorption

Table 4 shows the moisture contents of MPB attacked and SPF chips during a water soaking treatment. Green attack attained the highest moisture content and kiln dried SPF the lowest. Figure 5 shows that grey attack chips had the highest rate of water absorption followed by red attack, then kiln dried SPF, green attack, and lastly PG SPF. This would suggest that white liquor impregnation may be improved in the MPB attacked fibre.

Table 4. Moisture content of chips soaked in water.

Soak time (hr)	Moisture contents (%) OD basis				
	Green	Red	Grey	PG SPF	KD SPF
0	58.1	35.8	37.0	68.5	13.1
0.5	107.2	99.9	101.3	112.6	75.9
1	109.1	102.8	104.2	116.0	78.0
2	109.3	104.1	108.2	114.2	83.3
3	113.3	108.3	110.9	119.4	85.3
4	116.2	108.0	115.2	114.7	88.3
5	116.8	111.1	115.2	120.9	90.5
24	140.1	132.9	136.2	141.4	111.0
54	151.7	148.5	151.1	148.7	130.2
96	159.7	153.6	155.7	155.0	138.8
216	181.3	173.5	172.3	172.1	160.4

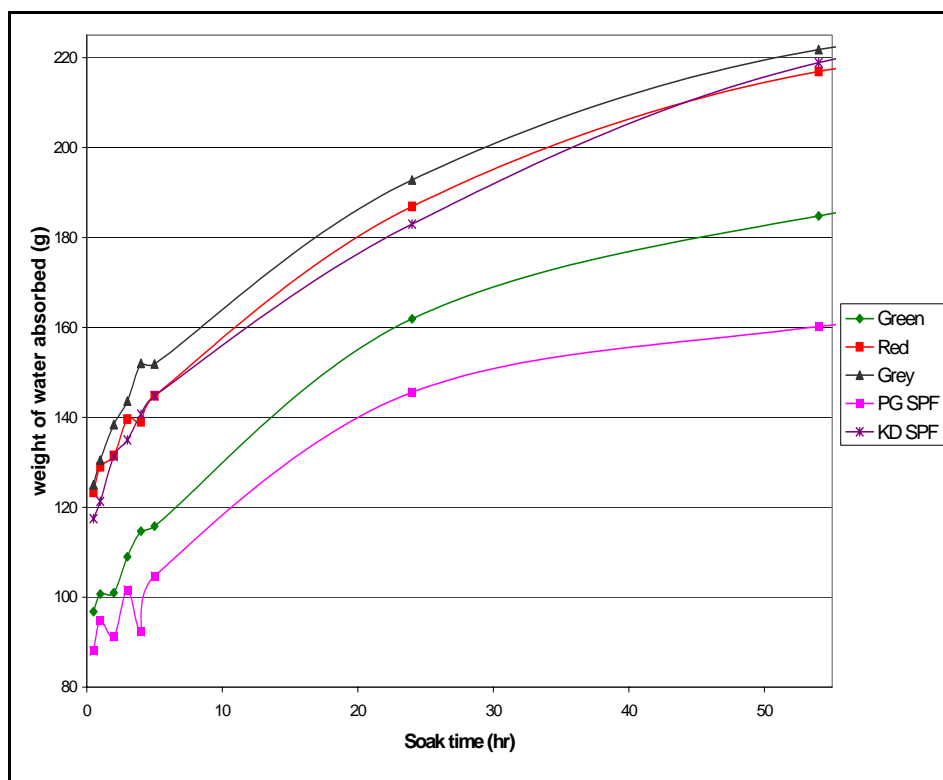


Figure 5. Water absorption rates of MPB attacked and SPF chips.

Chemical Pulping Properties

Table 5 shows the pulping properties of the wood chip samples pulped under identical conditions. Yields were higher for the MPB attacked woods and kiln dried relative to the digester feed reference by 3%, 7%, 9%, and 4% in green, red, grey, and kiln dried samples respectively. This is due to higher lignin and hemi-cellulose contents as shown by the kappa and viscosity. The Kappa numbers of the MPB attacked wood fell within the target range of 30 ± 2 , however there is an increasing trend in Kappa with increasing time since attack. Kappa values were higher by 3%, 5%, and 10% in green, red and grey samples respectively. Kiln dried had a significantly higher Kappa by 23%. Viscosity values were higher by 5%,

12%, 10%, and 20% in green, red, grey, and kiln dried samples respectively. Table 6 shows the black liquor analysis results. Lower residual alkali in the MPB attacked and kiln dried fibre cooks indicates a higher chemical consumption than that of the digester feed (figure 7) suggesting that the MPB attacked fibre and dry fibre were harder to cook. Moisture content is likely a factor and pre-steaming is recommended. Resin acid was significantly higher in the MPB pulped black liquor. Relative to the PG SPF, dehydroabietic acid concentrations were 7% higher in green attack, 27% higher in red attack, and 37% higher in grey attack black liquors. This has implications for impact on a mill's effluent treatment capacity.

Table 5. Pulping properties of SPF reference and kiln dried and MPB attacked wood.

sample	yield (%)	reject (%)	Kappa #	Viscosity, mPaS
SPF	44.14	0.15	28.2	33.2
green	45.43	0.53	29.1	34.9
red	47.14	0.09	29.7	37.2
grey	47.83	0.26	31.1	36.5
kiln dry SPF	45.96	1.20	34.9	40.0

Table 6. Black liquor analysis from pulping of SPF reference and kiln dried and MPB attacked wood.

sample	black liquor density (g/cm ³)	black liquor solids (%)	Res EA (g/L Na ₂ O)	Res AA (g/L Na ₂ O)	dehydroabietic acid (ppm)
SPF	1.085	16.36	7.29	9.61	234.9
green	1.080	16.49	6.88	8.68	251.7
red	1.090	16.97	6.29	7.69	299.2
grey	1.090	16.61	6.51	8.31	323.0
kiln dry SPF	1.085	16.70	6.48	8.46	247.3

Figure 6 shows that a higher yield is obtained for the MPB attacked fibre and that the yield increases with time since attack. The yield increase is not as significant with the kiln dried fibre. As well the kiln dried fibre had significantly higher Kappa. This graph shows that at a similar Kappa target (30±2), higher yield can be achieved from the older MPB attacked fibre.

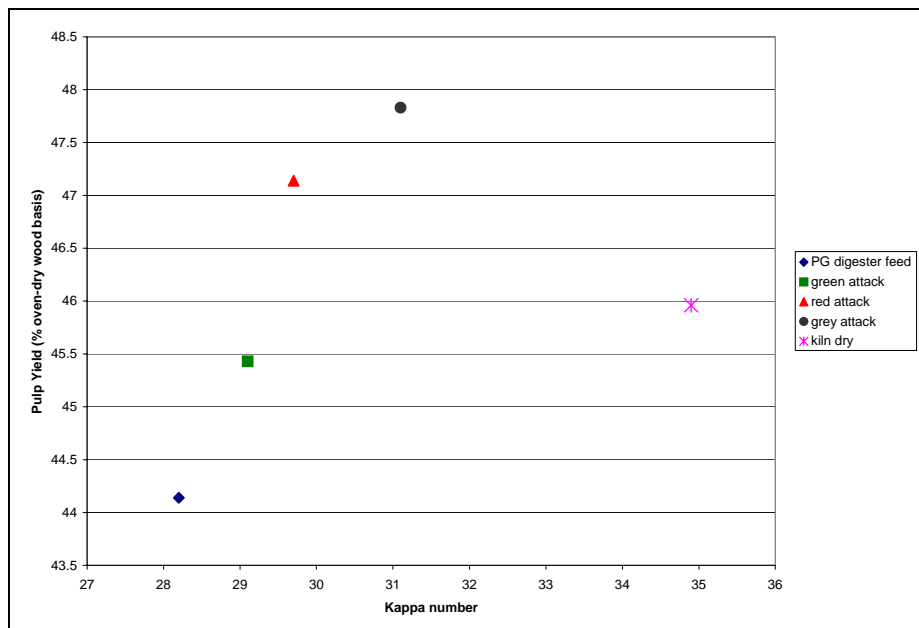


Figure 6. Pulp Yield vs Kappa for fibre pulped at conditions of 16% chemical charge and 1600 H factor.

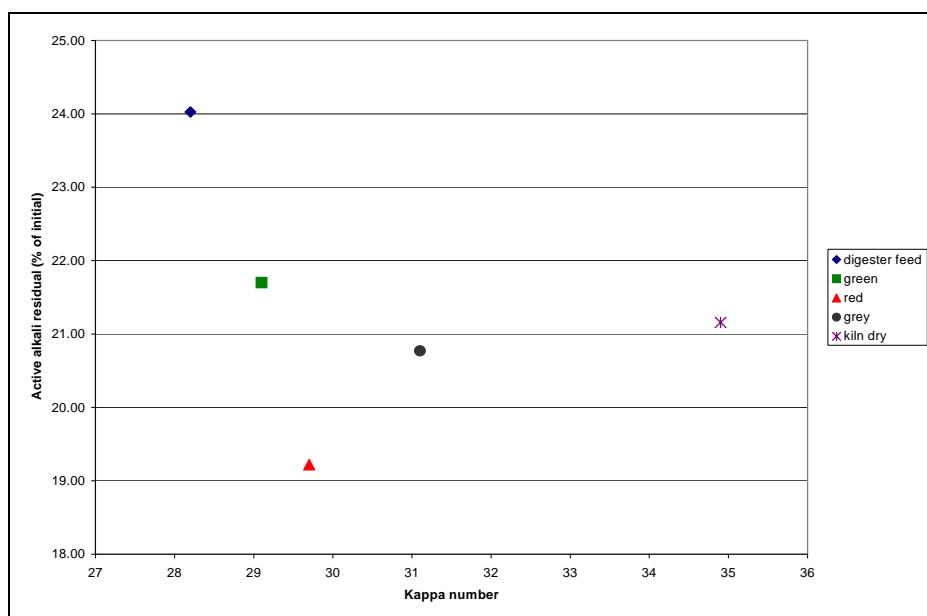


Figure 7. Residual active alkali of black liquor vs Kappa for fibre pulped at conditions of 16% chemical charge and 1600 H factor.

Chemical Composition of Kraft Pulp

Table 7 shows the extractive, lignin and carbohydrate composition of the SPF reference and kiln dried and MPB attacked pulp samples. The MPB attacked samples had higher residual lignin (reflected by the Kappa numbers), increasing with increasing time since attack. The kiln dried had the highest residual lignin. Moisture content is likely also a factor as the residual lignin increases with decreasing wood sample moisture. The red and grey attack pulps had higher total extractives content. Dehydroabietic acid was not detected in any of the pulp samples.

Table 7. Extractive, lignin and carbohydrate composition of pulp.

Sample	Pulp Chemical Composition							
	Acetone Extractives, %	Klason lignin, %	Acid soluble lignin, %	Arabose, %	Galactose, %	Glucose, %	Xylose, %	Mannose, %
PG	0.09	3.92±0.01	0.39±0.00	0.72±0.00	0.43±0.00	81.68±1.01	8.67±0.24	5.52±0.19
Green	0.09	4.16±0.00	0.46±0.00	0.71±0.01	0.42±0.02	82.37±0.24	8.65±0.02	5.40±0.09
Red	0.13	4.38±0.01	0.45±0.01	0.83±0.02	0.43±0.01	81.85±0.65	8.70±0.13	5.34±0.07
Grey	0.11	4.46±0.02	0.41±0.02	0.74±0.03	0.44±0.01	81.35±2.15	8.87±0.48	5.52±0.36
Kiln dry	0.08	4.96±0.02	0.45±0.00	0.68±0.00	0.49±0.01	82.20±0.02	8.83±0.03	5.58±0.02

Physical Properties of Kraft Pulp

The physical and strength properties of most significance to the quality of the pulp are plotted below. Complete tables of all the physical properties tested are shown in Appendix A, optical properties in Appendix B, and strength properties in Appendix C.

Coarseness and Fibrelength

Figure 8 shows that the coarseness of the fibre increases with increasing time since beetle attack.

Figure 9 shows that red attack wood had the longest fibre length and grey attack wood had the shortest fibre length.

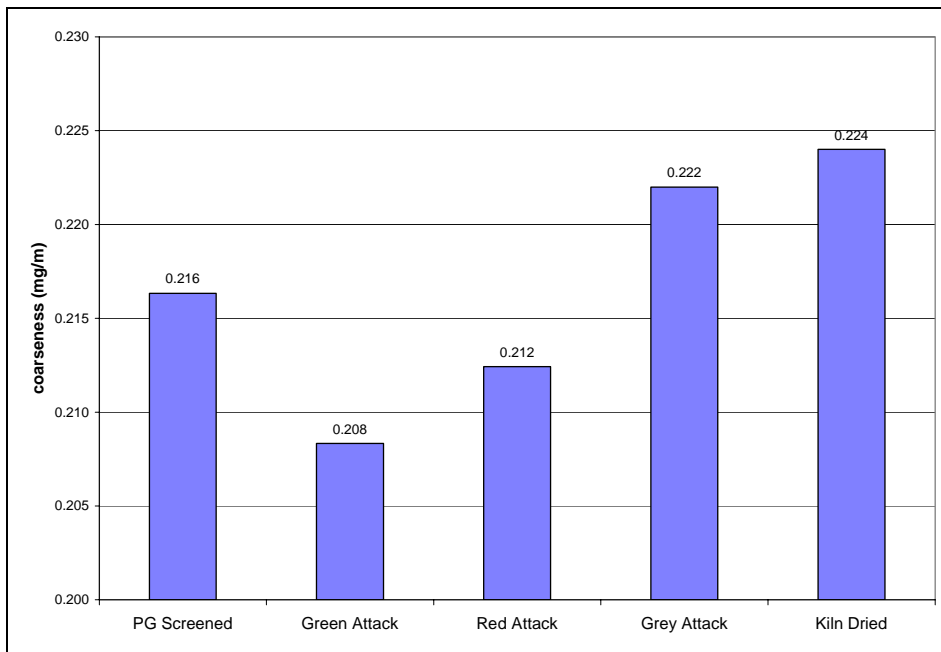


Figure 8. Coarseness of pulps.

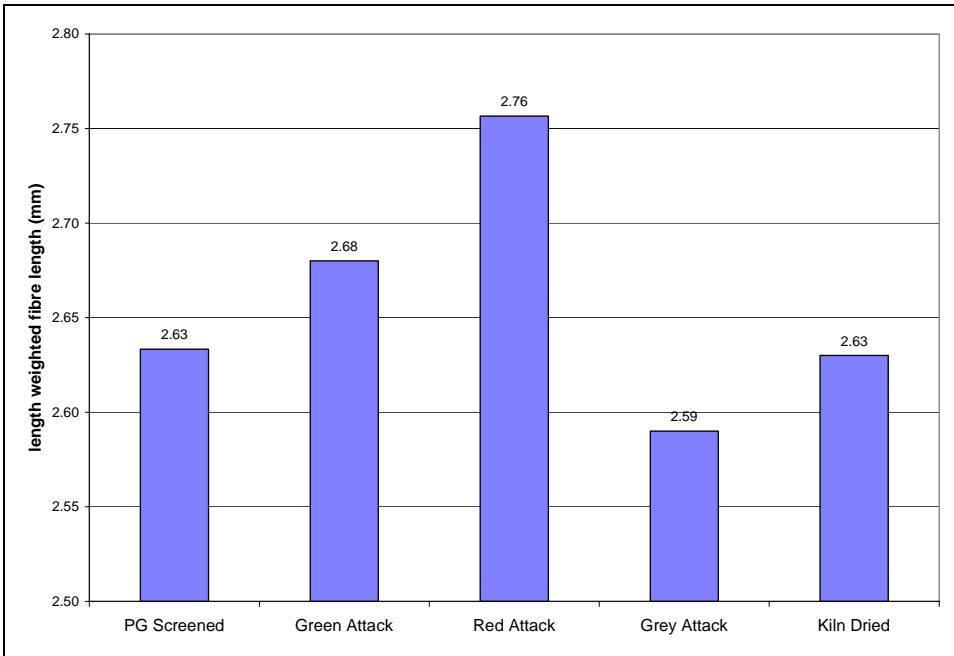


Figure 9. Length weighted fibre-length of pulps.

Canadian Standard Freeness

Figure 10 shows that the beetle infected and kiln dried chips refined easier. At the higher refining energies, the beetle attacked and drier pulps showed poorer drainage characteristics.

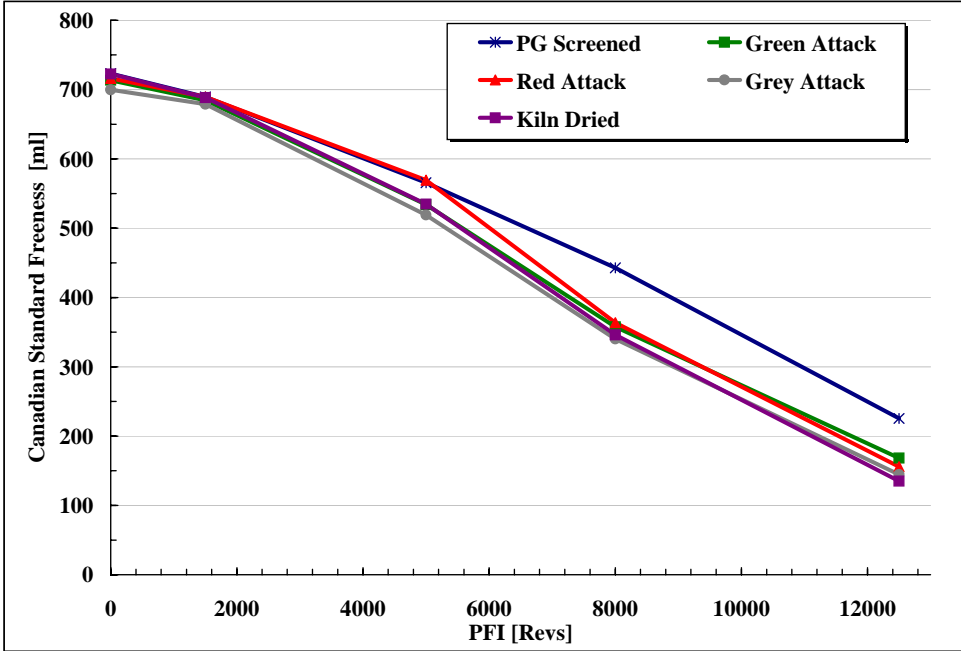


Figure 10. Canadian Standard Freeness vs refining energy.

Porosity

Figures 11 and 12 suggest that a more porous sheet is formed from the MPB attacked pulps compared to the digester feed pulp. The kiln dried pulp forms a less porous sheet.

Density

Figures 13 and 14 show that all the MPB attacked pulps and kiln dried SPF formed lower density sheets than the digester feed sample. The red attack condition however showed higher density at the higher refining energy. Grey attack pulp formed the lowest density sheet

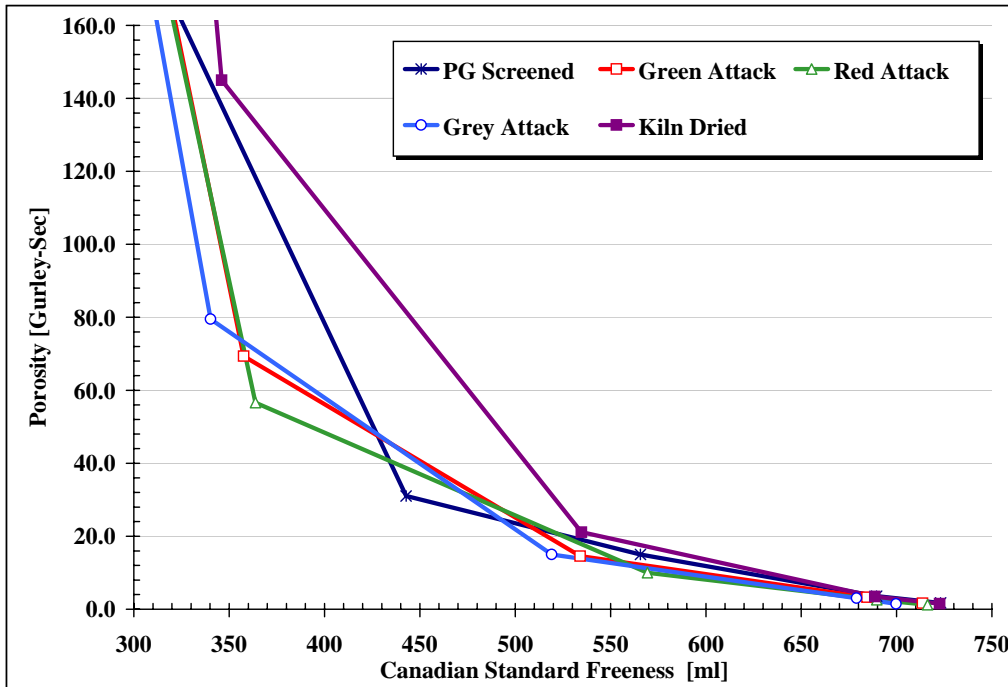


Figure 11. Porosity vs. Canadian Standard Freeness

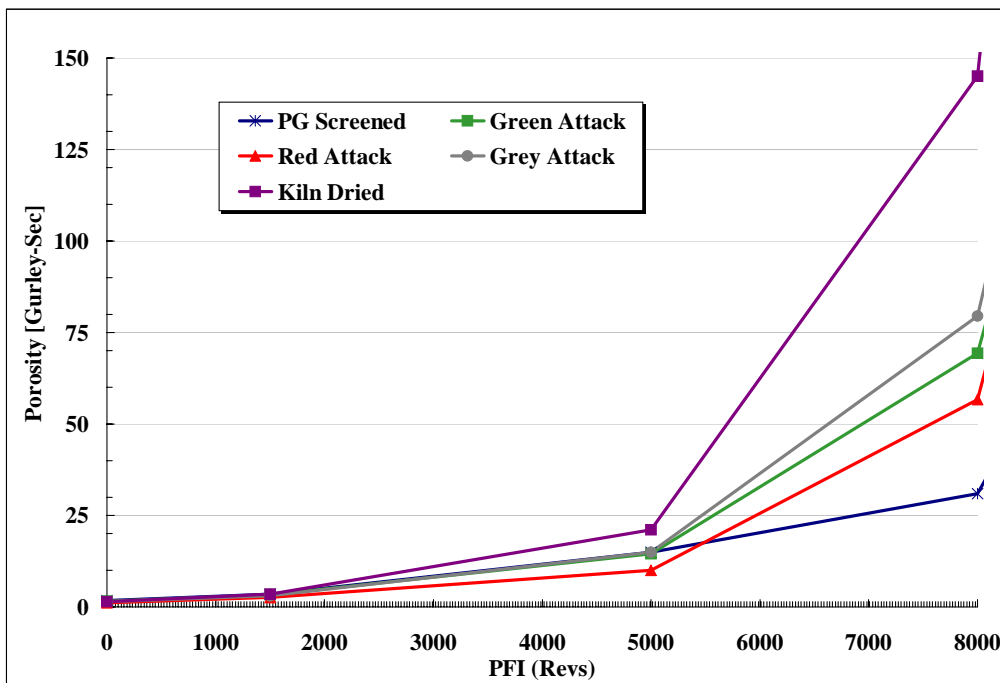


Figure 12. Porosity vs. Beating Energy

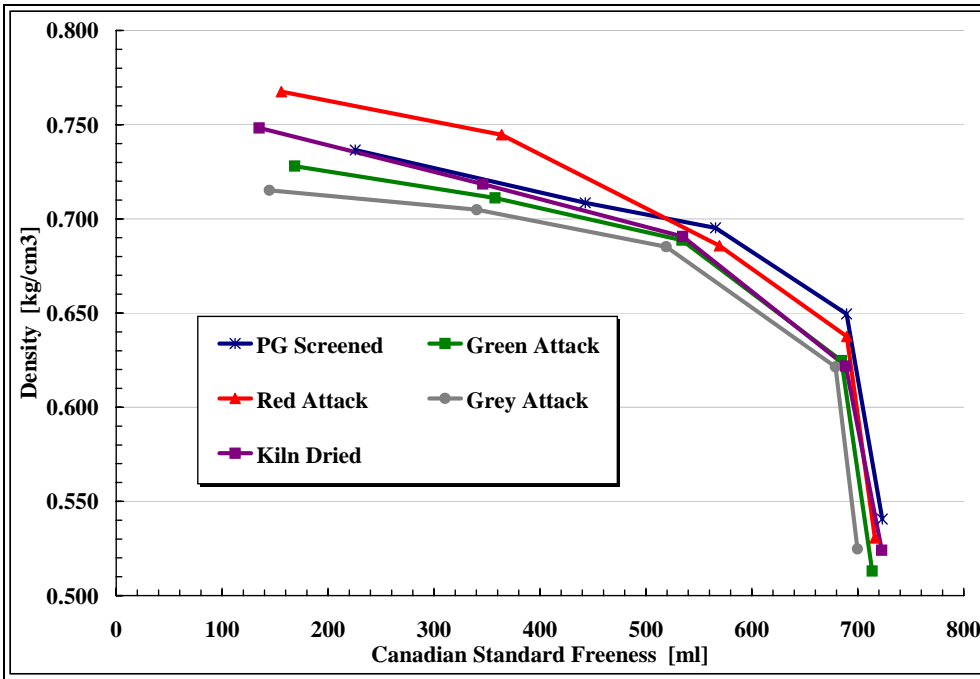


Figure 13. Density vs. Canadian Standard Freeness

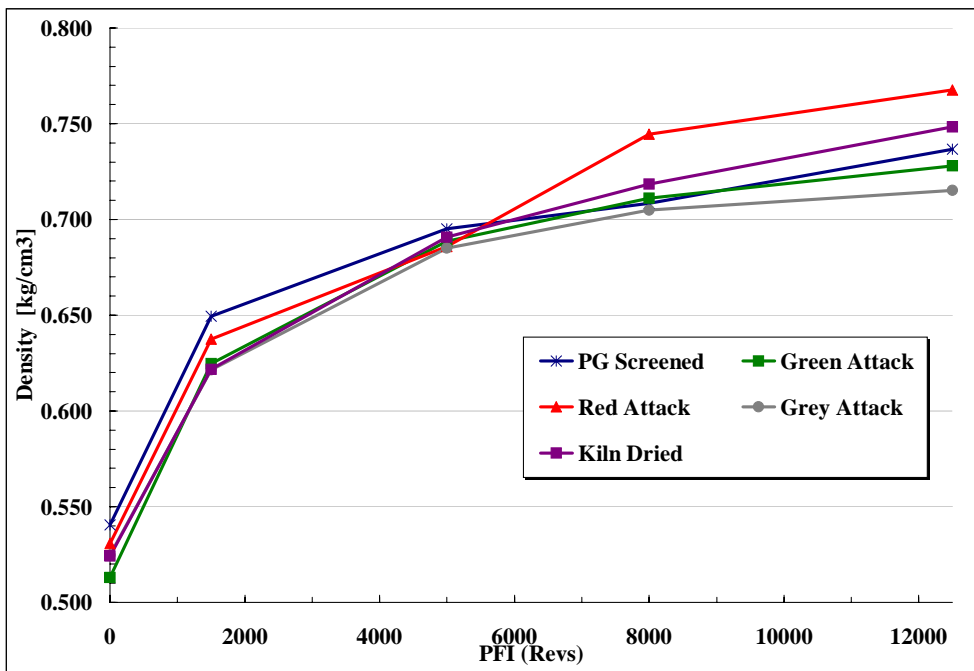


Figure 14. Density vs. Beating Energy

Tear, Tensile, and Burst Strengths

Figure 15 shows that the grey attack has the highest tear at given tensile. Green attack and kiln dried fall in the middle. Red attack is similar to the SPF reference.

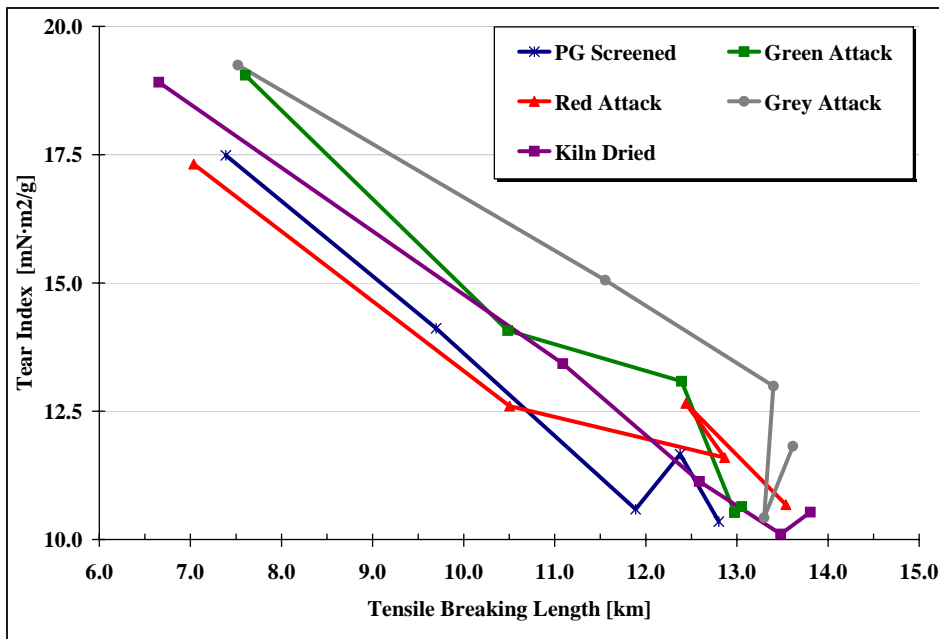


Figure 15. Tear vs tensile relationship

Figures 16 and 17 show that grey and green attack pulp have higher tear strength at the lower refining levels, but do not maintain the advantage at the higher energies. Red attack starts off with lower tear, but maintains strength at the higher refining energy.

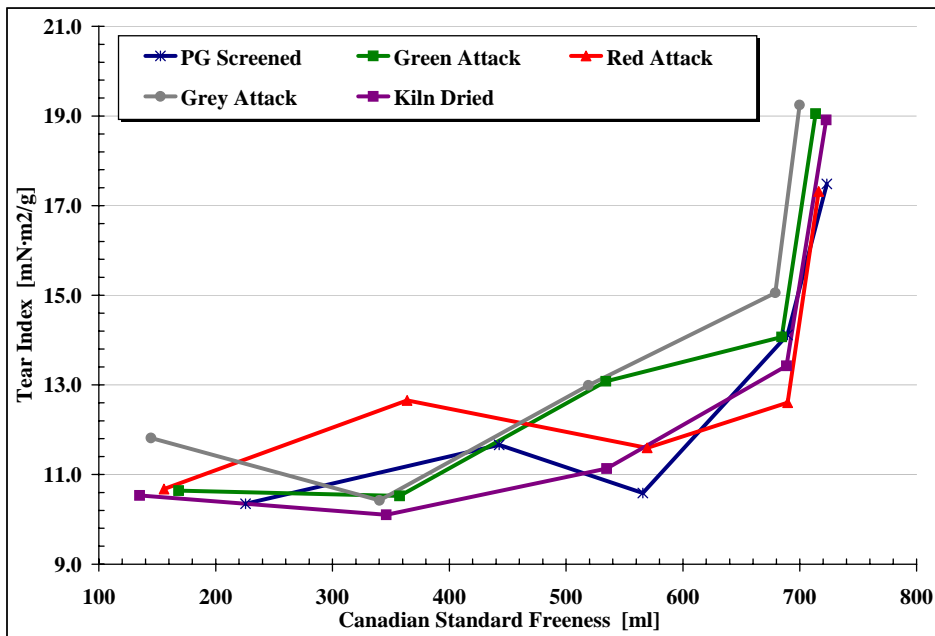


Figure 16. Tear vs CSF

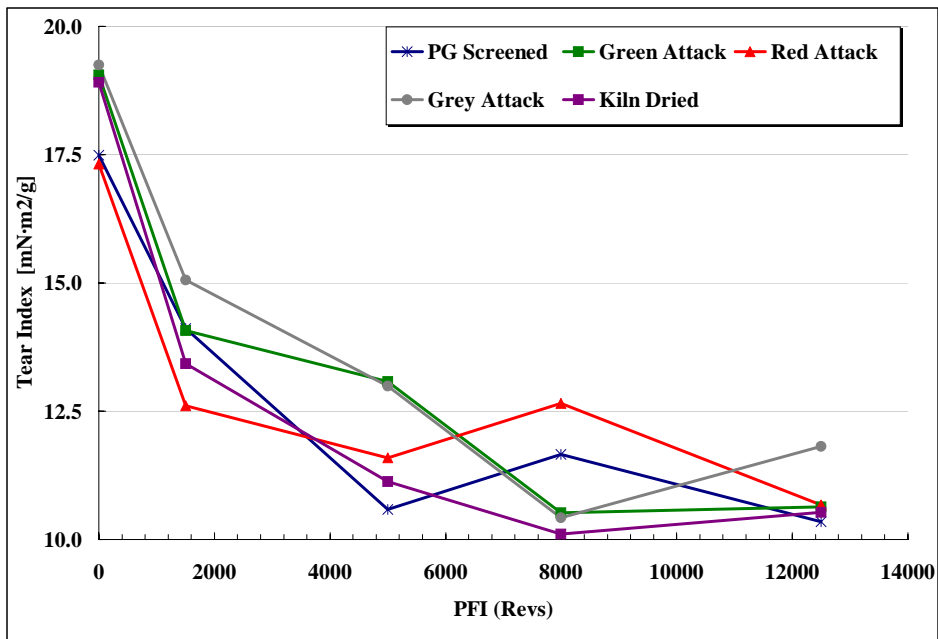


Figure 17. Tear vs Beating Energy

Figures 18 and 19 show that grey attack and kiln dried generally had the highest tensile. Red and green attack were similar to the SPF reference.

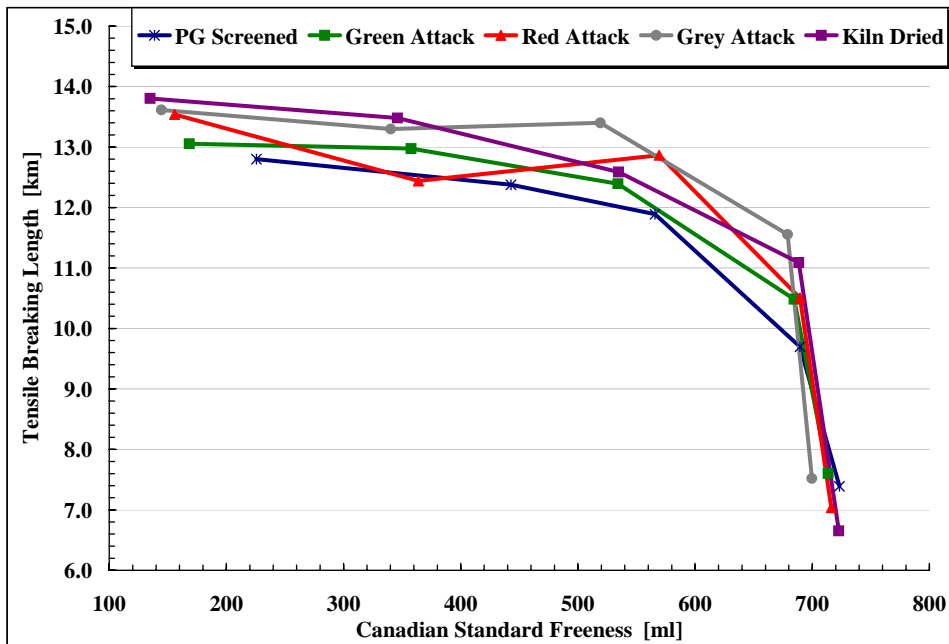


Figure 18. Tensile vs CSF

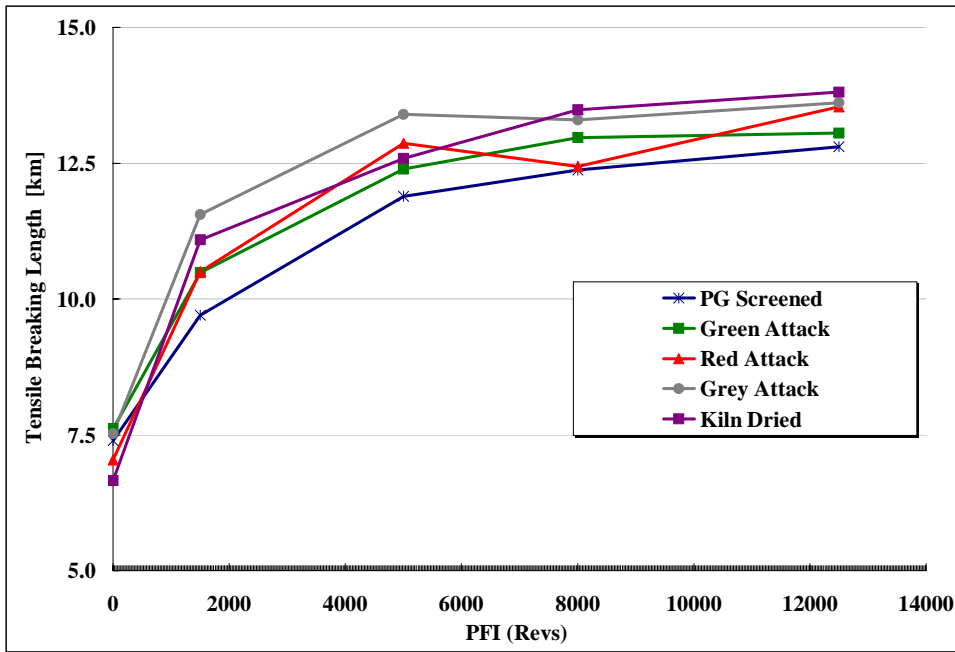


Figure 19. Tensile vs Beating Energy

Figures 20 and 21 show the burst results were very similar for all samples except for red attack at the higher refining energies, where the strength was lower.

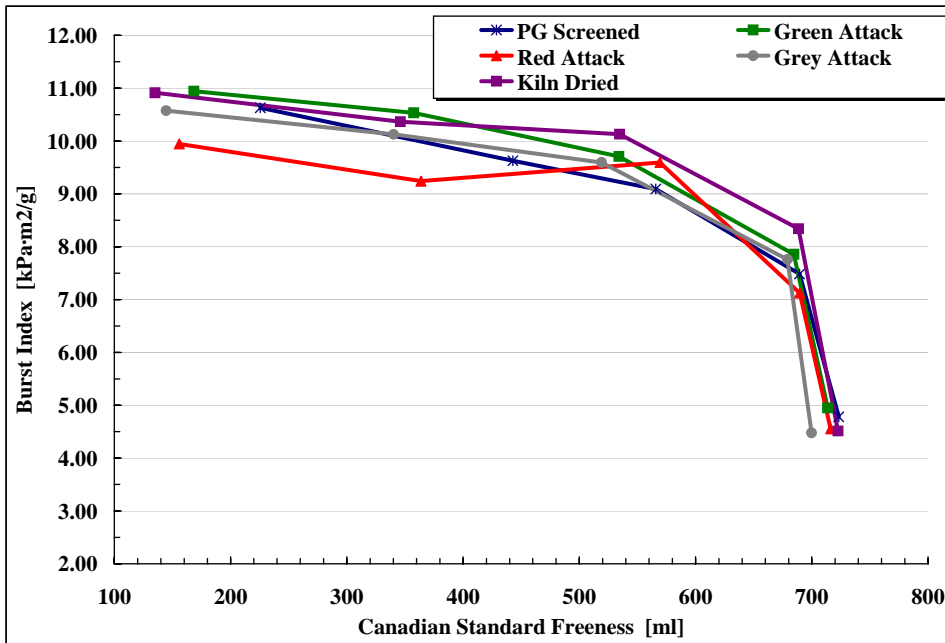


Figure 20. Burst vs CSF

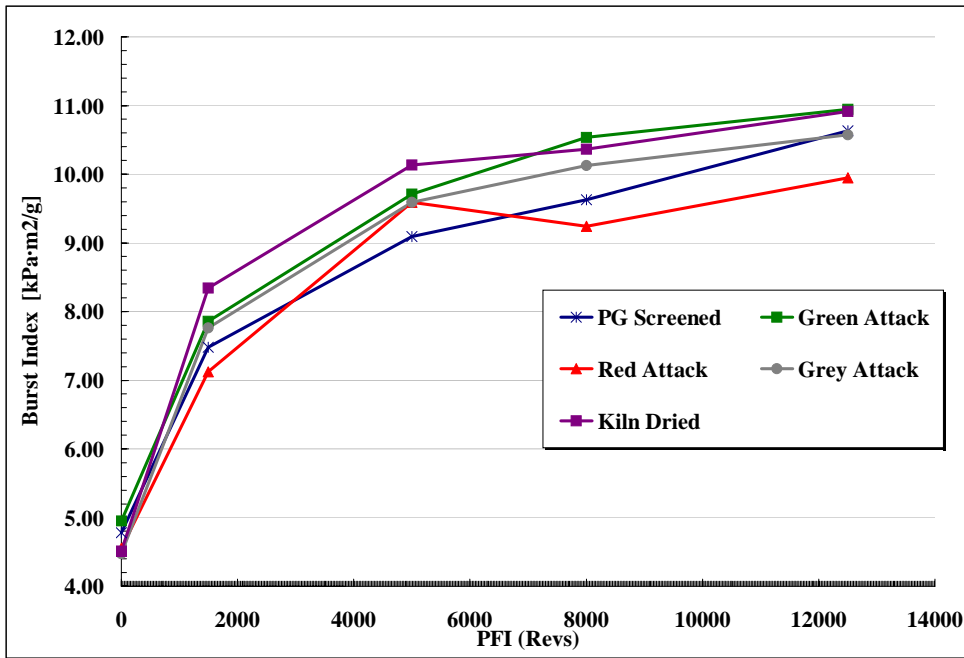


Figure 21. Burst vs Beating Energy

Figure 22 shows that the overall strength of the grey attack pulp was highest, 7% greater than the SPF digester feed reference. Green attack and kiln dried were similar and were about 4% higher than the SPF digester feed. Red attack was similar to the SPF reference.

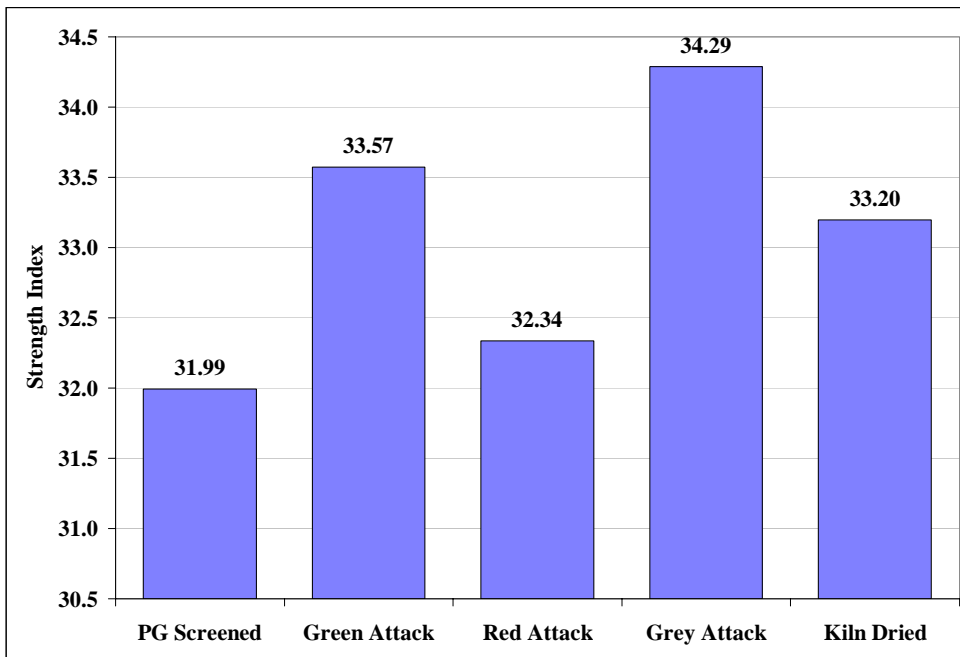


Figure 22. Strength Index for MPB attack and SPF pulp.

Physical Properties of Refiner Mechanical Pulp

Table 8 summarizes the Bauer McNett fibre length distributions and physical properties of refiner mechanical pulps. Appendix D displays the data for the physical properties, Appendix E the optical properties and Appendix F the strength properties.

Table 8. Physical properties of refiner mechanical pulp.

# of Passes	PG Screened			Green Attack			Red Attack			Grey Attack		
	3	4	5	3	4	5	3	4	5	3	4	5
Unscreened CSF (ml)	175	117	84	144	109	70	178	144	50	144	105	75
Specific Energy (MJ/kg)	11.1	12.5	14.1	10.5	11.7	12.9	11.2	12.9	14.4	11	12.2	13.6
Screened CSF (ml)	179	123	83	155	114	71	149	115	58	159	109	61
Reject (% of pulp)	1.39%	0.70%	0.51%	1.24%	0.76%	0.48%	1.69%	0.95%	0.61%	1.64%	0.86%	0.64%
Density(g/cm ³)	0.312	0.356	0.349	0.311	0.351	0.347	0.330	0.321	0.349	0.310	0.339	0.384
Burst Index (kPa·m ² /g)	1.74	2.08	2.26	1.57	1.91	2.20	1.54	1.81	2.03	1.65	1.86	2.02
Tensile Index (N·m/g)	3.523	4.031	4.462	3.361	4.013	4.362	3.376	3.842	4.253	3.434	3.863	4.216
Stretch (%)	1.74	1.78	1.92	1.61	1.80	1.99	1.68	1.85	1.87	1.63	1.93	1.94
Tear Index (MN·m ² /g)	6.92	6.07	5.97	6.35	6.22	6.01	6.12	6.10	6.19	6.67	6.28	5.86
Brightness (%)	56.23	56.83	55.98	53.73	53.54	53.91	51.97	52.79	51.70	50.39	52.12	53.46
ISO Opacity	95.07	95.83	95.77	95.84	96.73	97.09	95.37	96.25	97.05	96.15	96.82	97.16
Scattering Coefficient (cm ² /g)	52.07	54.83	56.87	52.45	55.02	58.30	49.58	54.20	56.85	53.58	55.07	58.13
% Rejects	1.39%	0.70%	0.51%	1.24%	0.76%	0.48%	1.69%	0.95%	0.61%	1.64%	0.86%	0.64%
Bauer McNett												
R14	16%	12%	9%	15%	11%	9%	14%	10%	3%	13%	12%	8%
R28	32%	31%	30%	33%	32%	29%	32%	31%	35%	31%	31%	31%
R48	19%	19%	19%	20%	19%	20%	20%	19%	20%	18%	19%	19%
R100	10%	11%	11%	11%	11%	11%	11%	11%	11%	10%	11%	11%
R200	8%	7%	7%	8%	8%	9%	8%	8%	9%	7%	8%	8%
Fines	16%	19%	24%	13%	19%	23%	14%	21%	23%	20%	19%	22%

Bauer McNett Fibre Length

Generally, there were not large differences in Bauer McNett fibre fractions between the MPB attacked and SPF reference pulps. Figures 23 to 28 show the percentage fibre fractions vs freeness.

The long fibre R14 fraction data is plotted in Figure 23. The SPF reference pulp has the highest percentage of long fibre at all the freeness levels. The MPB attacked pulps show a decreasing trend for percentage of R14 fraction at the high freeness, with green (15%), red (14%) and grey (13%). At the low freeness level, SPF reference, green, and grey attack have similar percentage of R14 fraction (between 8% and 10%) while the red attack is significantly lower at 3%.

The R28 fraction contains the highest percentage of fibre for all the pulps. Figure 24 shows that at the high freeness, green attack has the highest percentage of R28 fibre fraction at 33%, followed by red attack and SPF reference at 32% and grey attack at 31%. At the low freeness, red attack has the highest R28 percentage at 35%, followed by grey at 31%, SPF reference at 30%, and green attack at 29%.

Fines data is shown in Figure 28. At the high freeness, the grey attack has significantly more fines than the SPF reference, green, and red attack.

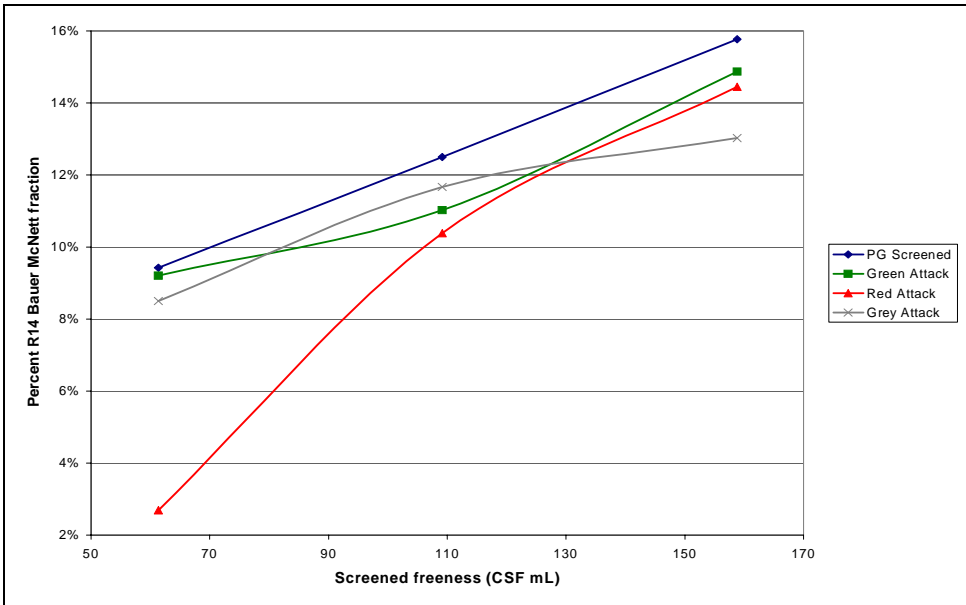


Figure 23. R14 Bauer McNett fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

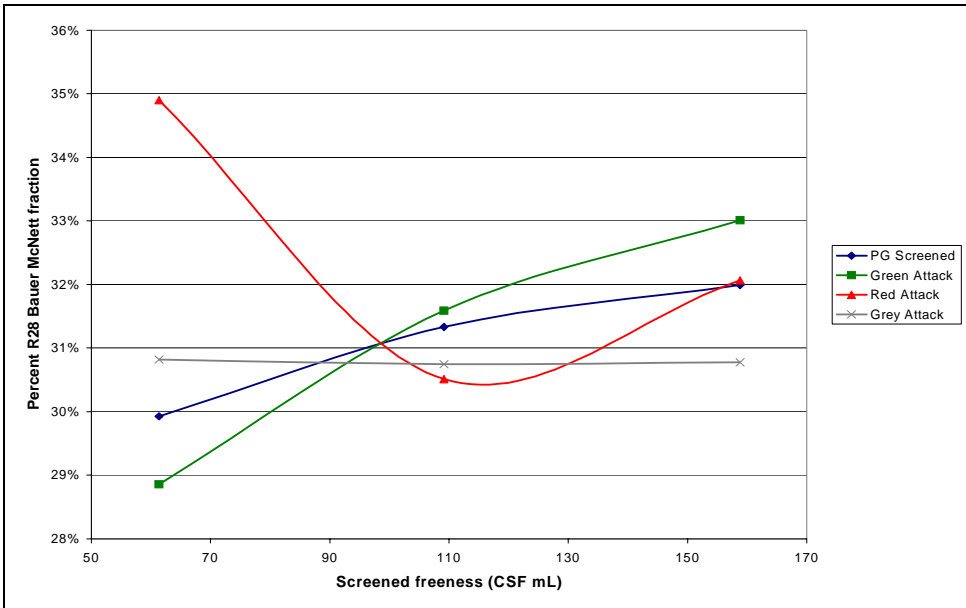


Figure 24. R28 Bauer McNett fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

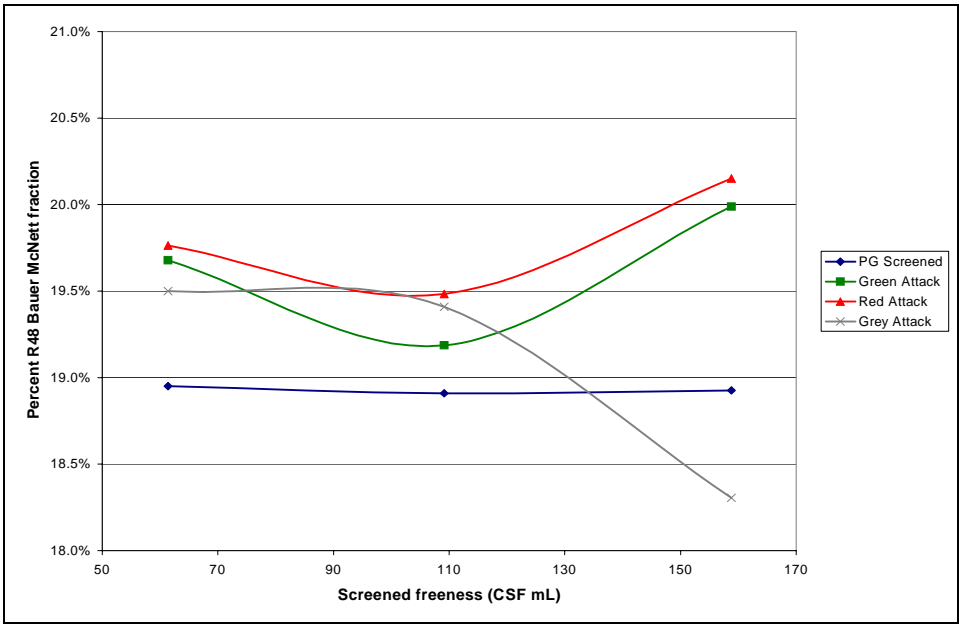


Figure 25. R48 Bauer McNett fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

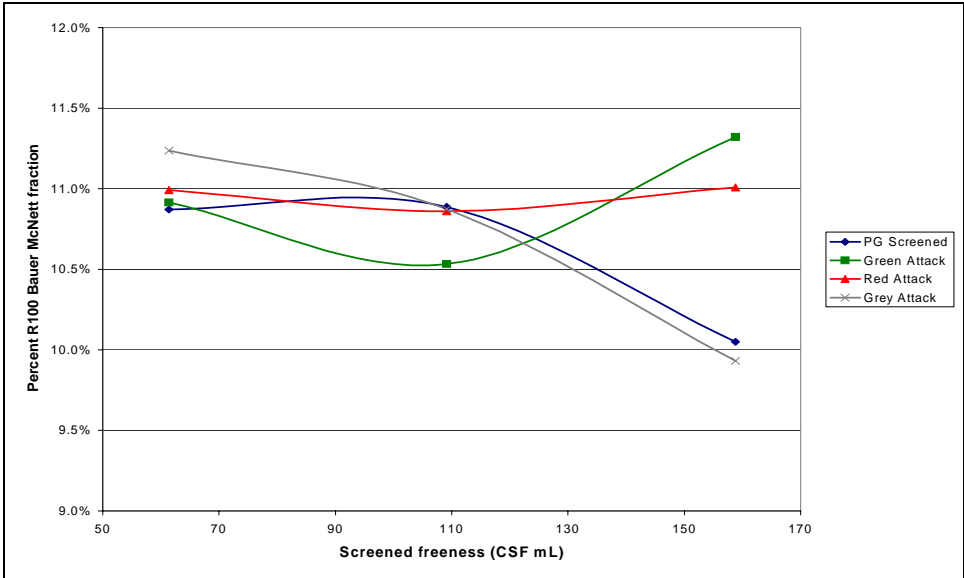


Figure 26. R100 Bauer McNett fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

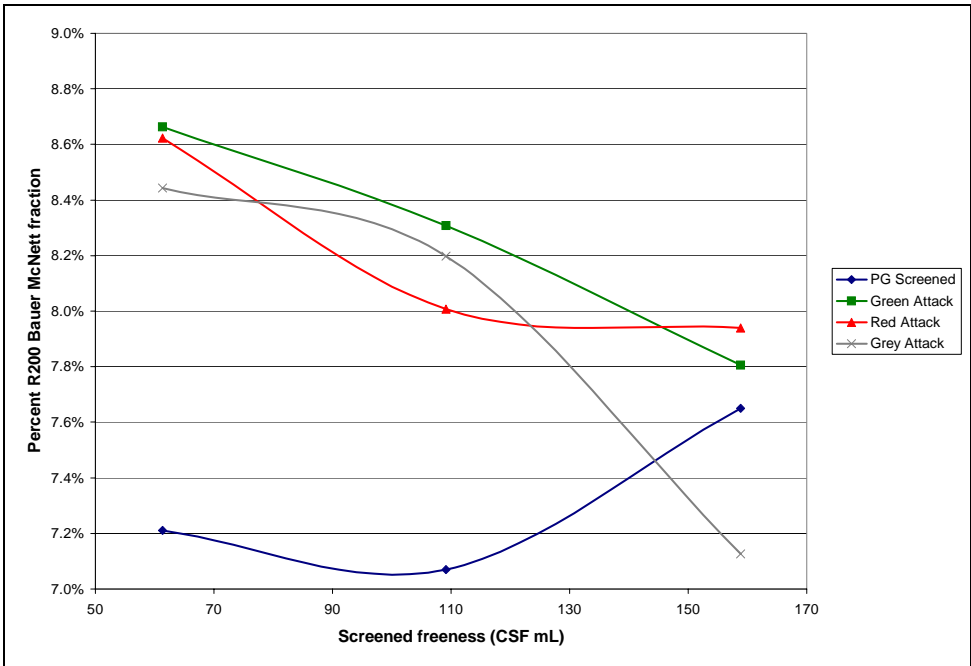


Figure 27. R200 Bauer McNett fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

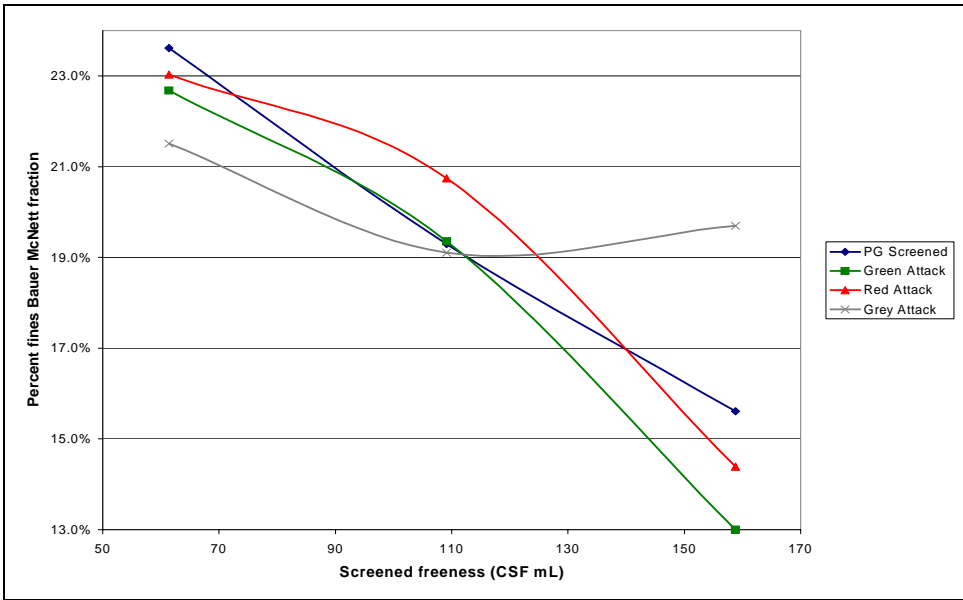


Figure 28. Bauer McNett fines fraction vs. Canadian Standard Freeness for SPF and MPB attacked refiner mechanical pulps.

Canadian Standard Freeness

Figure 29 shows that the green-attack sample required significantly less energy to a given freeness than those from the other three wood samples.

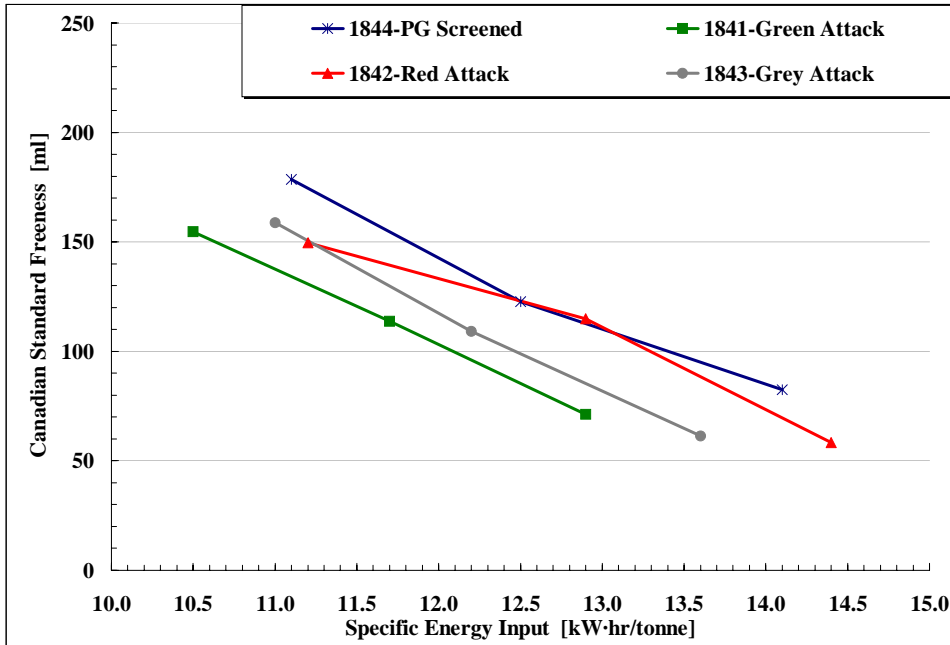


Figure 29. Canadian Standard Freeness vs refining energy for refiner mechanical pulp.

Porosity

Figure 30 shows that the MPB attacked pulps have improved porosity at given freeness in comparison to the SPF reference.

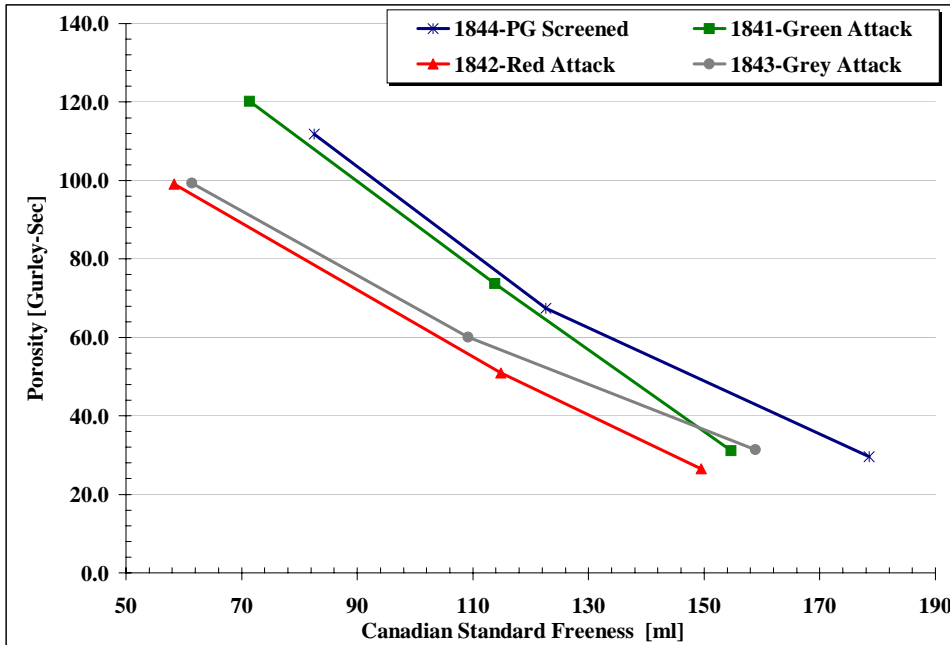


Figure 30. Porosity vs. Canadian Standard Freeness for refiner mechanical pulp.

Density

Figure 31 shows that the MPB pulps have lower density and therefore higher bulk than the SPF reference at the higher freeness levels.

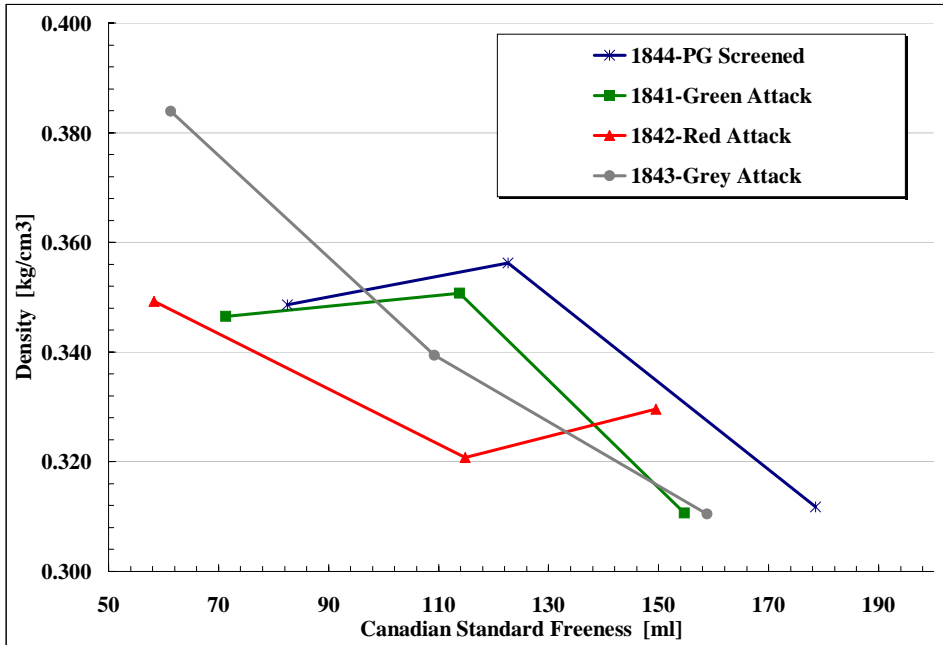


Figure 31. Density vs. Canadian Standard Freeness for refiner mechanical pulp.

Tear, Tensile and Burst Strengths

Figure 32 shows that at the higher tensile, there is little difference in tear strength between the pulps. At the lower tensile, the MPB attacked pulps have lower tear strength than the SPF pulp.

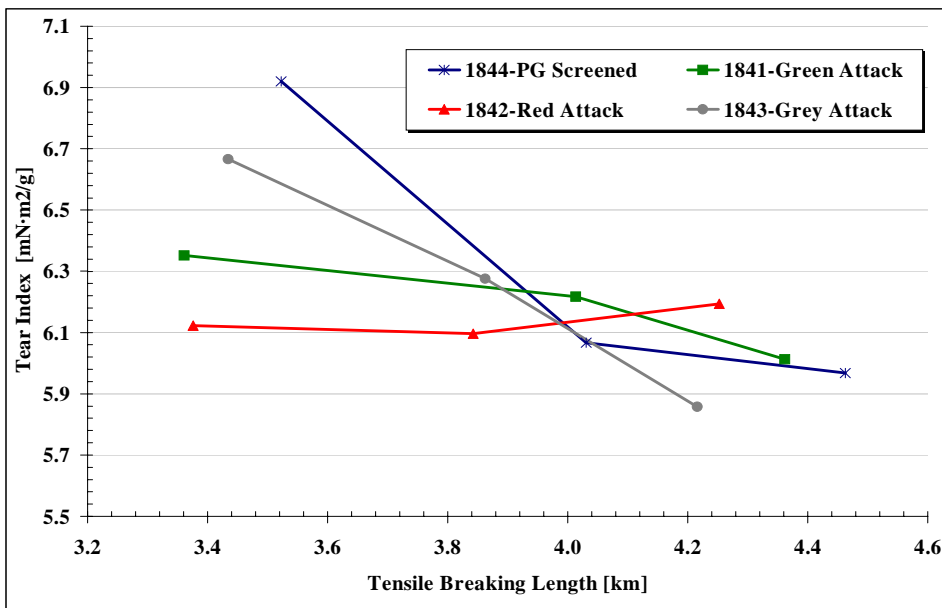


Figure 32. Tear vs. tensile relationship for refiner mechanical pulp.

Figure 33 shows little difference in tear strength among the MPB and SPF pulps. At the higher freeness, the grey attack MPB pulp exhibits slightly higher tear strength.

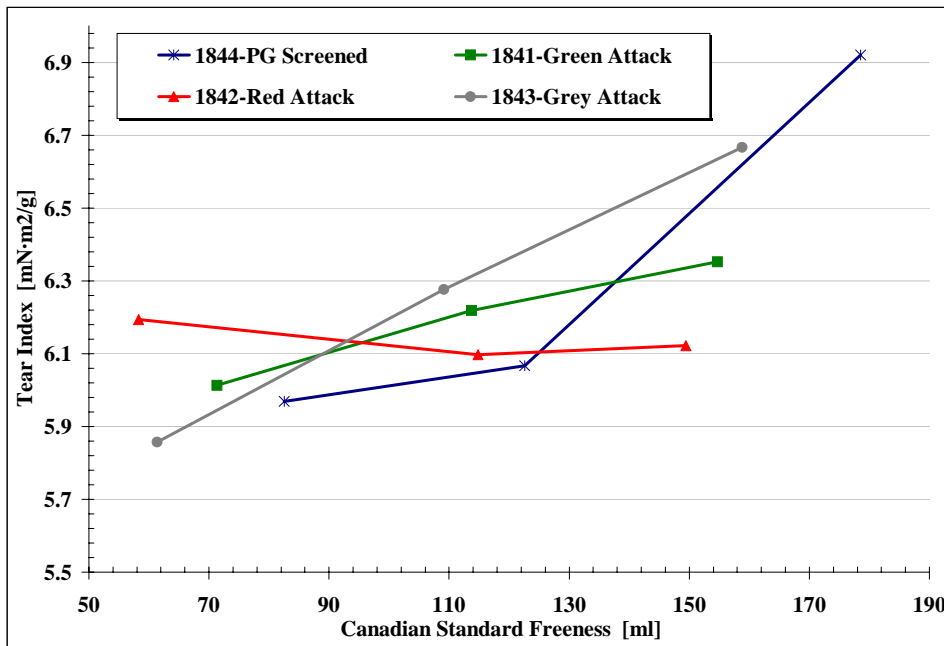


Figure 33. Tear vs Canadian Standard Freeness for refiner mechanical pulp.

Figure 34 and 35 show that the MPB pulps have lower tensile and burst than the SPF pulp.

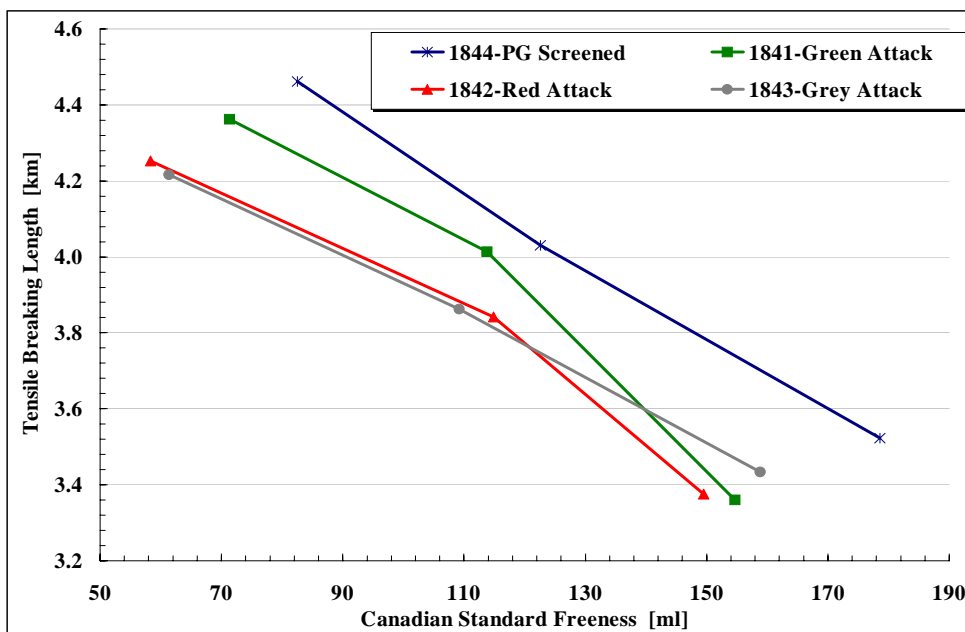


Figure 34. Tensile vs Canadian Standard Freeness for refiner mechanical pulp.

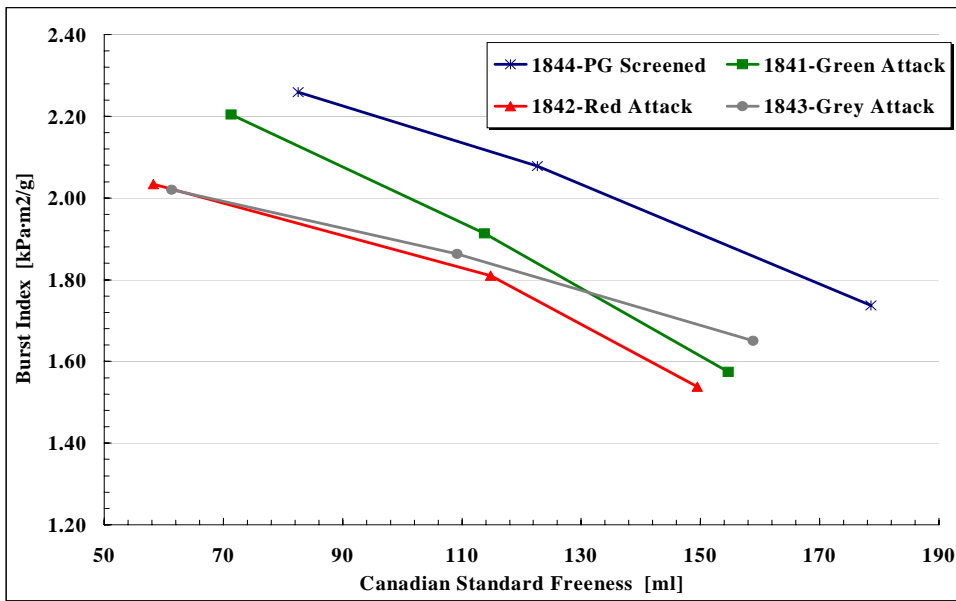


Figure 35. Burst vs. Canadian Standard Freeness for refiner mechanical pulp.

Figure 36 shows that the overall strength of the SPF refiner mechanical pulp was the highest. Green and grey MPB attack strengths were 3% lower and red attack strength was 5% lower.

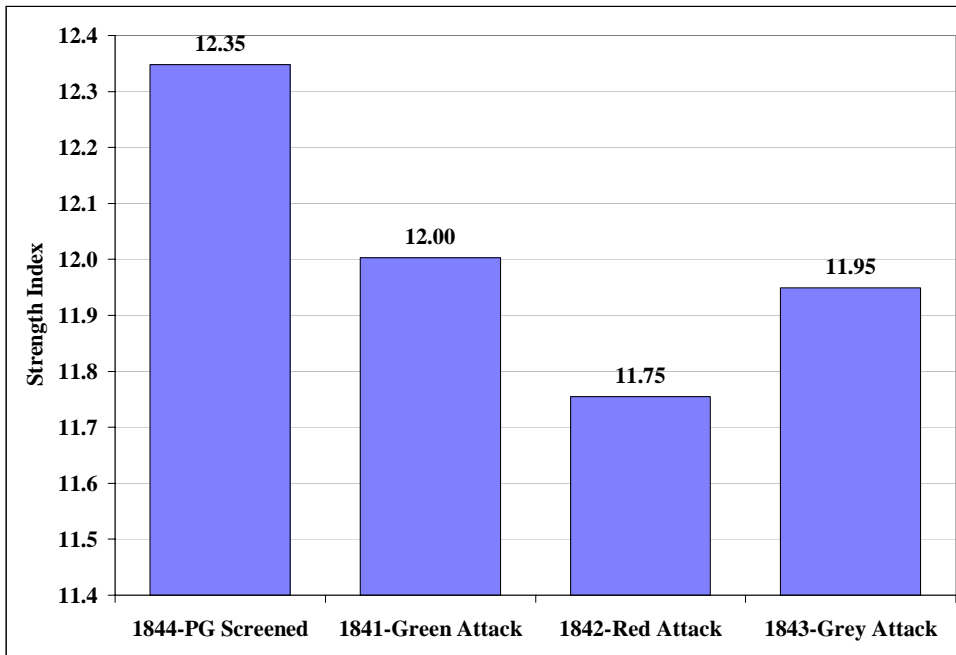


Figure 36. Strength index for MPB attack and SPF refiner mechanical pulp.

CONCLUSIONS

1. Moisture contents of the MPB attacked and SPF kiln dried fibre are lower in comparison to the SPF reference, by 18% for green stage, approximately 40% for red and grey stages and 80% for kiln dried.
2. Total acetone extractive contents in the MPB attacked woods is lower than in the reference SPF, however, the particularly toxic resin acid composition is higher. Kiln dried SPF (higher heartwood composition) has both higher total extractives and resin acid content in comparison to digester feed SPF. Dehydroabietic acid was not detectable in the Kraft pulps. The resin acid was present in the black liquor, at increasing concentrations with increasing time since beetle attack.
3. No significant difference in decay of the MPB attack wood samples relative to the SPF digester feed ($\pm 3\%$) was observed. Decay in the kiln dried SPF was higher by 14%, which may be due to higher heartwood content and presence of heartrot.
4. There was no significant difference among the lignin and carbohydrate contents of the wood and pulp samples.
5. The MPB attacked and kiln dried woods had lower amounts of the 16 mm fraction in comparison to the digester feed reference. Green attack was lower by 5%, red attack by 3%, grey attack by 10%, and kiln dried by 44%. The 7 mm fractions were 24% lower for green and red attack, not significantly different in grey attack, and 67% higher for kiln dried.
6. Water re-absorption rates were highest for grey attack chips, followed in descending order by red attack, kiln dried SPF, green attack, and SPF digester feed. This has positive implications for improved white liquor impregnation in MPB attacked fibre.
7. The MPB attacked wood appeared to be slightly harder to cook, with similar Kappa, higher viscosity, and higher yield results at higher liquor consumption. The kiln dried wood was significantly harder to cook and reject levels were high.
8. The coarseness of the chemical pulp fibre increases with increasing time since beetle attack. Red attack chemical pulps had the longest fibre length and grey attack chemical pulps had the shortest fibre length.
9. Beetle infected and kiln dried chemical pulps refined easier. At higher refining energies, the beetle attacked and drier pulps showed poorer drainage characteristics.
10. A more porous sheet is formed from the MPB attacked chemical and refiner pulps compared to the digester feed pulp. The kiln dried chemical pulp forms a less porous sheet.
11. MPB attacked chemical and refiner pulps and kiln dried SPF formed lower density sheets than the digester feed sample. The red attack condition however showed higher density at the higher refining energy. Grey attack chemical pulp formed the lowest density sheet.
12. Chemical Pulp Strengths: Grey attack has the highest tear at given tensile. Grey attack and kiln dried show the highest tensile strength development. Burst results were generally similar among the samples.
13. Chemical pulp strength index results suggest that grey attack pulp was strongest, 7% greater than the SPF digester feed reference. Green attack and kiln dried were similar and were about 4% higher than the SPF digester feed. Red attack strength was similar to the SPF reference.

14. Refiner mechanical pulp strengths: The MPB attack pulps have lower tensile and burst and similar tear strengths. Green and grey MPB attack strength index were 3% lower and red attack strength index was 5% lower.
15. The Bauer Mcnett fibre distributions of refiner mechanical pulps indicate that there is a decreasing trend in long fibre fraction with increasing time since beetle attack. The grey attack had significantly greater fines than the SPF, green and red attack conditions.

APPENDIX A – CHEMICAL PULP PHYSICAL PROPERTIES

GREEN ATTACK

PHYSICAL TESTS						
REVS	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[Revs]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
0	714	0.116	1.95	0.513	1.7	2983
1500	685	0.096	1.60	0.625	3.3	2866
5000	534	0.087	1.45	0.689	14.6	2966
8000	358	0.085	1.41	0.711	69.4	3039
12500	168	0.081	1.37	0.728	551.8	3016

RED ATTACK

PHYSICAL TESTS						
REVS	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[Revs]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
0	716	0.115	1.88	0.531	1.2	2830
1500	690	0.099	1.57	0.638	2.6	2852
5000	569	0.087	1.46	0.686	10.0	2891
8000	364	0.085	1.34	0.745	56.6	3032
12500	156	0.081	1.30	0.768	560.5	3045

GREY ATTACK

PHYSICAL TESTS						
REVS	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[Revs]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
0	700	0.114	1.91	0.525	1.5	2886
1500	679	0.096	1.61	0.621	3.0	2848
5000	519	0.087	1.46	0.685	15.0	2930
8000	340	0.085	1.42	0.705	79.5	3017
12500	145	0.083	1.40	0.715	644.5	2999

PG SPF REFERENCE

PHYSICAL TESTS						
REVS	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[Revs]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
0	723	0.109	1.85	0.541	1.7	3006
1500	689	0.092	1.54	0.650	3.6	2945
5000	566	0.087	1.44	0.695	15.0	3060
8000	443	0.084	1.41	0.709	31.0	3042
12500	226	0.083	1.36	0.737	271.2	3043

KILN DRY SPF

PHYSICAL TESTS						
REVS	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[Revs]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
0	723	0.115	1.91	0.524	1.5	3006
1500	689	0.096	1.61	0.622	3.5	2885
5000	535	0.086	1.45	0.691	21.1	2947
8000	346	0.083	1.39	0.718	145.0	2493
12500	135	0.079	1.34	0.748	1370.3	3028

APPENDIX B – CHEMICAL PULP OPTICAL PROPERTIES

GREEN ATTACK

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
0	23.5	43.8	98.9	27.5	18.39
1500	20.4	47.6	97.6	20.1	16.32
5000	18.0	50.3	95.9	15.1	14.87
8000	17.7	50.4	94.9	13.8	13.94
12500	17.6	49.8	94.7	13.7	14.18

OPTICAL TESTS					
REVS	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[Revs]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
0	63.9	6.8	15.1	16.6	65.8
1500	61.1	7.5	15.0	17.5	64.8
5000	58.5	7.9	16.2	18.0	63.9
8000	58.1	7.9	16.1	17.9	63.9
12500	57.7	7.8	15.8	17.6	63.6

RED ATTACK

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
0	22.9	43.9	98.8	25.6	17.84
1500	20.0	48.3	97.6	18.8	15.58
5000	17.7	51.1	96.0	15.2	16.11
8000	17.0	52.0	95.4	13.3	14.00
12500	17.0	50.7	94.9	12.7	13.78

OPTICAL TESTS					
REVS	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[Revs]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
0	63.4	6.6	15.2	16.5	66.5
1500	60.8	7.4	16.2	17.8	65.5
5000	58.3	7.8	16.5	18.3	64.8
8000	57.3	7.8	16.4	18.2	64.7
12500	57.1	7.7	16.1	17.8	64.4

GREY ATTACK

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
0	22.5	43.6	99.0	26.3	19.39
1500	19.6	47.8	97.8	19.4	17.24
5000	17.4	50.3	95.9	14.6	15.45
8000	17.1	50.4	96.0	14.3	15.71
12500	17.2	49.5	95.0	13.4	14.63

OPTICAL TESTS					
REVS	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[Revs]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
0	62.6	7.0	14.6	16.2	64.4
1500	60.0	7.9	15.4	17.3	62.8
5000	57.5	8.3	15.7	17.7	62.2
8000	56.9	8.3	15.5	17.6	61.9
12500	57.0	8.1	15.3	17.3	62.2

PG SPF REFERENCE

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
0	23.8	43.3	98.6	26.3	17.46
1500	20.8	46.9	97.6	20.0	16.27
5000	18.4	49.7	95.3	14.6	14.18
8000	18.0	50.1	94.7	13.9	13.89
12500	17.5	49.5	93.7	12.4	13.00

OPTICAL TESTS					
REVS	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[Revs]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
0	64.0	7.4	14.6	16.4	63.4
1500	61.2	8.0	15.3	17.2	62.5
5000	58.6	8.4	15.7	17.8	61.8
8000	58.2	8.4	15.7	17.8	61.8
12500	57.4	8.3	15.3	17.4	61.5

KILN DRY SPF

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
0	22.3	46.0	99.0	26.8	19.20
1500	19.0	50.0	97.3	18.4	16.58
5000	16.6	52.5	95.7	14.0	15.45
8000	16.1	52.6	95.7	13.5	15.46
12500	15.7	52.2	94.7	12.2	15.00

OPTICAL TESTS					
REVS	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[Revs]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
0	63.0	7.4	15.6	17.3	64.5
1500	59.6	8.1	16.2	18.1	63.3
5000	56.8	8.6	16.3	18.4	62.3
8000	56.1	8.5	16.2	18.3	62.4
12500	55.4	8.5	15.8	18.0	61.8

APPENDIX C – CHEMICAL PULP STRENGTH PROPERTIES

GREEN ATTACK

STRENGTH TESTS							
REVS	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[Revs]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
0	19.05	4.95	7.60	1.86	9.48	919	74.59
1500	14.07	7.86	10.48	2.44	10.61	1633	102.86
5000	13.08	9.71	12.39	2.85	11.29	2240	121.55
8000	10.52	10.53	12.97	2.95	11.54	2431	127.30
12500	10.64	10.95	13.05	2.77	12.04	2307	128.07

RED ATTACK

STRENGTH TESTS							
REVS	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[Revs]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
0	17.31	4.55	7.04	1.97	8.75	898	69.02
1500	12.60	7.12	10.50	2.66	10.30	1788	103.05
5000	11.60	9.59	12.86	2.96	11.28	2396	126.20
8000	12.65	9.24	12.44	3.08	10.83	2424	122.05
12500	10.68	9.95	13.54	2.94	11.79	2516	132.80

GREY ATTACK

STRENGTH TESTS							
REVS	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[Revs]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
0	19.25	4.48	7.52	2.13	9.23	1059	73.77
1500	15.05	7.76	11.55	2.63	11.12	1925	113.36
5000	12.99	9.59	13.40	2.93	11.64	2459	131.47
8000	10.42	10.13	13.30	2.87	11.86	2414	130.44
12500	11.82	10.58	13.61	2.93	11.83	2515	133.54

PG SPF REFERENCE

STRENGTH TESTS							
REVS	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[Revs]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
0	17.49	4.78	7.39	2.21	8.86	1076	72.48
1500	14.11	7.48	9.70	2.40	10.11	1495	95.13
5000	10.59	9.09	11.89	2.98	10.72	2246	116.64
8000	11.66	9.63	12.38	2.89	11.16	2278	121.40
12500	10.35	10.63	12.80	2.84	11.52	2314	126.00

KILN DRY SPF

STRENGTH TESTS							
REVS	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[Revs]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
0	18.91	4.51	6.65	2.03	8.29	890	64.82
1500	13.42	8.34	11.09	2.69	10.37	1890	108.79
5000	11.13	10.13	12.59	3.01	10.89	2387	123.45
8000	10.10	10.37	13.48	3.03	11.39	2569	132.24
12500	10.53	10.91	13.81	3.01	11.85	2634	135.40

APPENDIX D- REFINER MECHANICAL PULP PHYSICAL PROPERTIES

GREEN ATTACK

PHYSICAL TESTS						
SPECIFIC EN. INPUT	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[kW.hr/te]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
11	155	0.194	3.22	0.311	31.1	3232
12	114	0.172	2.85	0.351	73.7	3232
13	71	0.175	2.89	0.347	120.2	3232

RED ATTACK

PHYSICAL TESTS						
SPECIFIC EN. INPUT	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[kW.hr/te]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
11	149	0.182	3.03	0.330	26.5	3232
13	115	0.185	3.12	0.321	51.0	3232
14	58	0.172	2.86	0.349	99.0	3232

GREY ATTACK

PHYSICAL TESTS						
SPECIFIC EN. INPUT	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[kW.hr/te]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
11	159	0.191	3.22	0.310	31.4	3232
12	109	0.179	2.95	0.339	60.0	3232
14	61	0.158	2.60	0.384	99.4	3232

PG SPF REFERENCE

PHYSICAL TESTS						
SPECIFIC EN. INPUT	CSF	CALIPER	BULK	DENSITY	AIR RESISTANCE	SMOOTHNESS
[kW.hr/te]	[ml]	[mm]	[cm ³ /g]	[g/cm ³]	[Gurley-Sec]	[SCCM]
11	179	0.197	3.21	0.312	29.5	3232
13	123	0.176	2.81	0.356	67.4	3232
14	83	0.172	2.87	0.349	111.8	3232

APPENDIX E- REFINER MECHANICAL PULP OPTICAL PROPERTIES

GREEN ATTACK

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
11	53.7	27.6	95.8	52.5	4.34
12	53.5	27.6	96.7	55.0	4.95
13	53.9	27.1	97.1	58.3	5.06

OPTICAL TESTS					
SPECIFIC EN. INPUT	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[kW.hr/te]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
11	85.3	1.5	13.5	13.5	83.8
12	85.2	1.5	13.4	13.5	83.7
13	85.3	1.4	13.2	13.2	83.8

RED ATTACK

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
11	52.0	29.2	95.4	49.6	4.32
13	52.8	28.5	96.3	54.2	4.68
14	51.7	28.5	97.1	56.8	5.17

OPTICAL TESTS

SPECIFIC EN. INPUT	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[kW.hr/te]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
11	84.7	1.8	14.1	14.2	82.9
13	85.0	1.7	13.8	13.9	83.2
14	84.3	1.8	13.7	13.8	82.6

GREY ATTACK**OPTICAL TESTS**

SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
11	50.4	28.8	96.2	53.6	4.65
12	52.1	28.4	96.8	55.1	4.99
14	53.5	27.8	97.2	58.1	5.10

OPTICAL TESTS

SPECIFIC EN. INPUT	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[kW.hr/te]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
11	83.5	1.6	13.8	13.9	83.3
12	84.5	1.6	13.7	13.8	83.4
14	85.2	1.5	13.5	13.6	83.5

PG SPF REFERENCE

OPTICAL TESTS					
SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m ² /kg]	[m ² /kg]
11	56.2	28.0	95.1	52.1	3.54
13	56.8	26.8	95.8	54.8	3.68
14	56.0	27.5	95.8	56.9	3.85

OPTICAL TESTS					
SPECIFIC EN. INPUT	L* (Lightness)	a* (red - green axis)	b* (yellow - blue axis)	C* (chroma)	h* (hue angle)
[kW.hr/te]	[CIE]	[CIE]	[CIE]	[CIE]	[CIE]
11	86.9	1.3	14.0	14.2	84.7
13	87.0	1.1	13.4	13.4	85.4
14	86.6	1.2	13.7	13.7	84.9

APPENDIX F- REFINER MECHANICAL PULP STRENGTH PROPERTIES

GREEN ATTACK

STRENGTH TESTS							
SPECIFIC EN. INPUT	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[kW.hr/te]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
11	6.35	1.57	3.36	1.61	4.33	342	32.97
12	6.22	1.91	4.01	1.80	4.86	465	39.37
13	6.01	2.20	4.36	1.99	4.98	561	42.79

RED ATTACK

STRENGTH TESTS							
SPECIFIC EN. INPUT	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[kW.hr/te]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
11	6.12	1.54	3.38	1.68	4.33	364	33.12
13	6.10	1.81	3.84	1.85	4.71	461	37.69
14	6.19	2.03	4.25	1.87	5.01	513	41.72

GREY ATTACK

STRENGTH TESTS							
SPECIFIC EN. INPUT	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[kW.hr/te]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
11	6.67	1.65	3.43	1.63	4.47	358	33.69
12	6.28	1.86	3.86	1.93	4.63	485	37.90
14	5.86	2.02	4.22	1.94	4.84	528	41.36

PG SPF REFERENCE

STRENGTH TESTS							
SPECIFIC EN. INPUT	TEAR INDEX	BURST INDEX	BREAKING LENGTH	STRETCH	STIFFNESS (Modulus of Elasticity)	T.E.A.	STRENGTH
[kW.hr/te]	[mN·m ² /g]	[kPa·m ² /g]	[km]	[%]	[MN·m/kg]	[J/kg]	[kNm/kg]
11	6.92	1.74	3.52	1.74	4.41	390	34.56
13	6.07	2.08	4.03	1.78	4.86	461	39.54
14	5.97	2.26	4.46	1.92	5.14	552	43.78