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Quality of Mountain Pine Beetle Infested Fibre: Implications on the Production of Pulp and Paper Products

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ABSTRACT

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. There is a significant change in the chemical and moisture profiles of the wood chips produced from infested logs. As well, MPB killed timber contains blue stain in the sapwood and extensive checking which may lower its commercial value for use in lumber and pulp. .

To mitigate the impact of the MPB epidemic on the BC forest products sector, an understanding of the relationship between pulp processing and quality and time since infestation is required. In this project we investigated the effect of MPB infected wood on chemical pulp processing efficiency and the consequential fibre quality of grey stage, 3 year and 5 year since beetle attack. As the pulping and bleaching data are influenced by many factors including the geo-climatic conditions of the sampling sites, chip storage, number of test specimen etc.., the collected information showing trends of yield, and fibre properties is considered preliminary. Additional sampling and testing will be needed to confirm the findings. Our preliminary results showed that the MPB attacked wood had lower amounts of the 16 mm and 7 mm chip fractions in comparison to a typical SPF reference from the same mill, and the grey 5 year attack had a 80% higher fines content than the 3 year grey attack. There was little difference in kappa, yield and liquor consumption between the 3 and 5 year MPB grey attacked wood, likewise with tear strength, burst, and tensile strength. There appeared to be an improved bleaching response in MPB attacked pulp as compared to the SPF reference, but at the cost of slightly lower yield, and higher bleach filtrate COD and solids contents.

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INTRODUCTION

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). Significant changes in the chemical and moisture profiles of the wood chips produced from infested logs were observed. As well, MPB killed timber contains blue stain in the sapwood and extensive checking which may lower its commercial value for use in lumber and pulp.

To mitigate the impact of the MPB epidemic on the BC forest products sector, an understanding of the relationship between pulp processing and quality and time since infestation is required. The proposed research project will comprehensively investigate the effect of MPB infected wood on chemical pulp processing efficiency and the consequential fibre quality at various times since beetle attack in the grey stage. Using chemical and physical analyses the effect of MPB and time of attack on the pulping and bleaching of the MPB resource as well as non-process elements will be determined. Laboratory scale testing will be correlated to mill scale processing to investigate the relationship between performance and pulp recovery, and potential value-added streams since time of infestation. As a result, this project will enable the prediction of the limitation of time span of infestation within which some of the processing and pulp properties of wood can still be considered useful, as well as potentially discovering new value-added process streams.

Pulp mills will be able to adjust process conditions to optimize effective pulping of MPB fibre. Potential exists for product development as the pulp properties from this unique furnish are explored. This proposal integrates fundamental and practical research to develop strategies for the extraction of the highest value from MPB infested wood, while minimizing detrimental effects during processing.

METHODS and MATERIALS

Sample Selection

Two truckloads of three year old MPB grey attack stems from the Chedakuz area and two truckloads of five year old MPB grey attack stems from the Vantyne area were delivered to Plateau sawmill near Vanderhoof, B.C. Both areas had identical biogeoclimatic zone classification of SBS mc3 with site index of 13.

Chip Samples

The two truckloads of full-length stems were sawn into dimensional lumber. The two truckloads of 3 year attack were run first, followed by the 2 truckloads of 5 year attack. Chips (approximately 50 kg each) were collected directly off material from the chip/canter. For the Vanderhoof reference, chips were collected from the chip bin during processing of normal timber. A grab sample of 400g for chemical analysis was taken prior to screening.

Fibre Properties

Chip Size Distribution

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. There was very little bark present in all three conditions.

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.

Loose Chip Packing Density

Bulk density was determined according to a procedure as described in Pulp and Paper Technology Series[1]. Screened chip samples were introduced 1L at a time, whereupon the container was dropped from a height of 5cm. Chips were filled to a tared container at a 5L mark, and the weight recorded.

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 mill procedure. Fifty gram chip samples were placed into a 400 mL beaker containing 200 mL deionized water. The beaker was covered and sample boiled for 10 minutes. The liquid was decanted, cooled to room temperature and pH measured.

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 chips and pulp according to T222 om-98.

Carbohydrate Content

Carbohydrate content was determined on wood chip 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

Extractions

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

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[1] Pulp and Paper Technology Series No.5 Chip Quality Monograph Edited by Dr. J.V. Hutton 1979

duplicate at pH 11 into a 20 *u*L injection port with a 0.45 *u*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

Vanderhoof reference SPF, MPB 3 year Grey, and MPB 5 year grey 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. Optimization involved variations of H factor in the range of 1400 to 2000 and chemical charge in the range of 13% to 18% active alkali. The cooking cycle involved impregnation for 35 minutes to 115C, ramping to 168C and 120psi. Pulps were disintegrated, washed, and screened. Optimized pulps were combined for further analysis, including chemical composition, fibre and strength properties, and bleaching response.

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 by standard Tappi methods.

Pulp Bleaching

SPF and MPB grey attack pulps underwent D Ep D bleaching. Process conditions are shown in table 1.

Table 1. Bleaching Conditions.

Do	
Kappa Factor	0.17%
consistency (%)	3
time (min)	20
Temperature [oC]	50
pH initial	4
E_P	
H_2O_2	0.55%
NaOH	1.80%
consistency (%)	10%
Time [minutes]	90
Temperature [^{o}C]	82
pH initial	11
D1	
ClO2 (%)	1.30%
consistency (%)	10
time (min)	120
Temperature [oC]	68
pH initial	3

Bleaching response was monitored by brightness, Kappa, and chemical consumption. Dissolved solids and chemical oxygen demand (COD) of the bleach filtrates were measured (CPPA standard H.3) in order to evaluate impact on the mills effluent treatment system. To investigate impact on yield, alkali solubility (S18) of the bleached pulps was determined according to Tappi T235 cm-00.

RESULTS AND DISCUSSION

Fibre Properties

Chemical Composition

Table 2 shows the lignin and carbohydrate composition of the SPF and MPB attacked wood samples. The grey 5 year condition had a slightly lower lignin content than the 3 year, however the sugar analysis results were essentially the same.

Table 2. Extractive, lignin and carbohydrate composition of wood chips.

	Wood Chemical Composition						
Sample	Klason lignin, %	Acid soluble lignin, %	Arabinose, %	Galactose, %	Glucose, %	Xylose, %	Mannose, %
Vanderhoof SPF	26.4	0.51	1.52	3.13	50.55	5.88	12.51
Grey 3 Year Attack	26.3	0.52	1.80	2.86	50.30	6.02	13.73
Grey 5 Year Attack	24.7	0.52	1.67	3.02	50.66	6.05	12.54

Table 3 displays the extractives content and fibre properties of the wood chip samples. Moisture contents of the MPB grey attacked chips are lower in comparison to the SPF, by 20%. The grey 5 year attack fibre had a 23% higher caustic solubility than the grey 3 year attack fibre which indicates higher presence of decay with increasing time since beetle attack. The grey 3 year condition had a 32% higher amount of total extractives and 83% higher resin acid content than the 5 year attack. The higher extractives would offer improved protection from decay organisms. The grey attack chips had slightly lower pH and this may be due to the higher resin acid content. Grey attack chips had lower bulk density than the SPF.

Table 3. Extractives content and fibre properties of wood chip samples.

Chip Sample	pH	moisture content (%)	Bulk Density (g/cm3)	acetone extractives (w%)	resin acid (mg/kg)	Decay (% solubility)
Vanderhoof SPF	4.98	48%	0.1306	2.54%	1292	14.0
Grey 3 Year Attack	4.56	40%	0.1193	3.04%	1844	12.1
Grey 5 Year Attack	4.55	40%	0.1256	2.31%	1006	14.9

Chip Size Distribution

Table 4 and figure 1 show the chip size distribution of the SPF and MPB grey attacked wood. The 16 mm and 7 mm fractions are the most ideal for pulping. The MPB attacked wood had lower amounts of the 16 mm fraction in comparison to the SPF. The 7 mm fractions were not significantly different. The grey 5 year attack fibre had 125% more fines than the grey 3 year attack fibre.

Table 4. Percentage chips retained on a Linden Chip Classifier

	% Retained				
Chip Sample	**10 mm Bar**	**16mm Round**	**7mm Round**	**2mm Bar**	**Fines**
Vanderhoof SPF	12	60	22	2	5
Grey 3 Year Attack	25	50	18	2	4
Grey 5 Year Attack	14	53	21	2	9

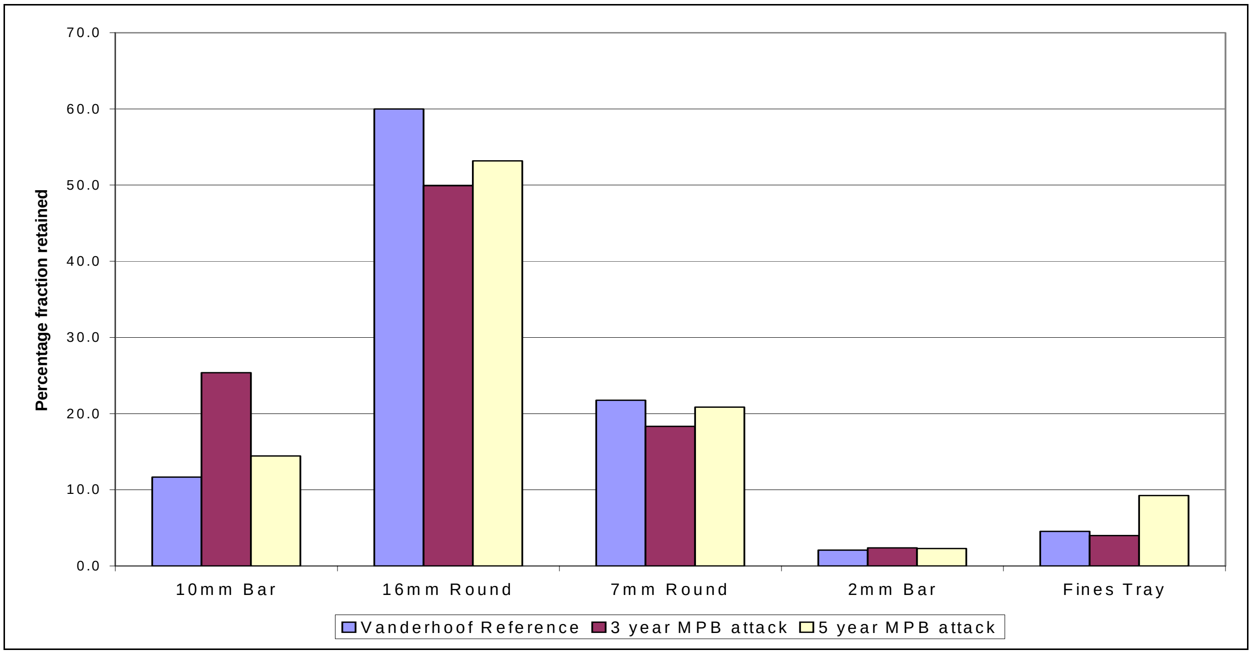

Figure 1. Chip size distribution of SPF reference and kiln dried and MPB attacked wood.

Pulping Optimization

Appendix A shows the H Factor and chemical charge conditions and results of Kappa, yield, rejects, and residual active alkali for the optimization pulping trials. Highlighted samples indicate which pulps experienced the optimum conditions and were mixed for subsequent property analysis. Figure 2 shows the optimization of chemical charge at constant H factor and shows that 16% active alkali is required to reach a 30 Kappa for the grey attack fibre.

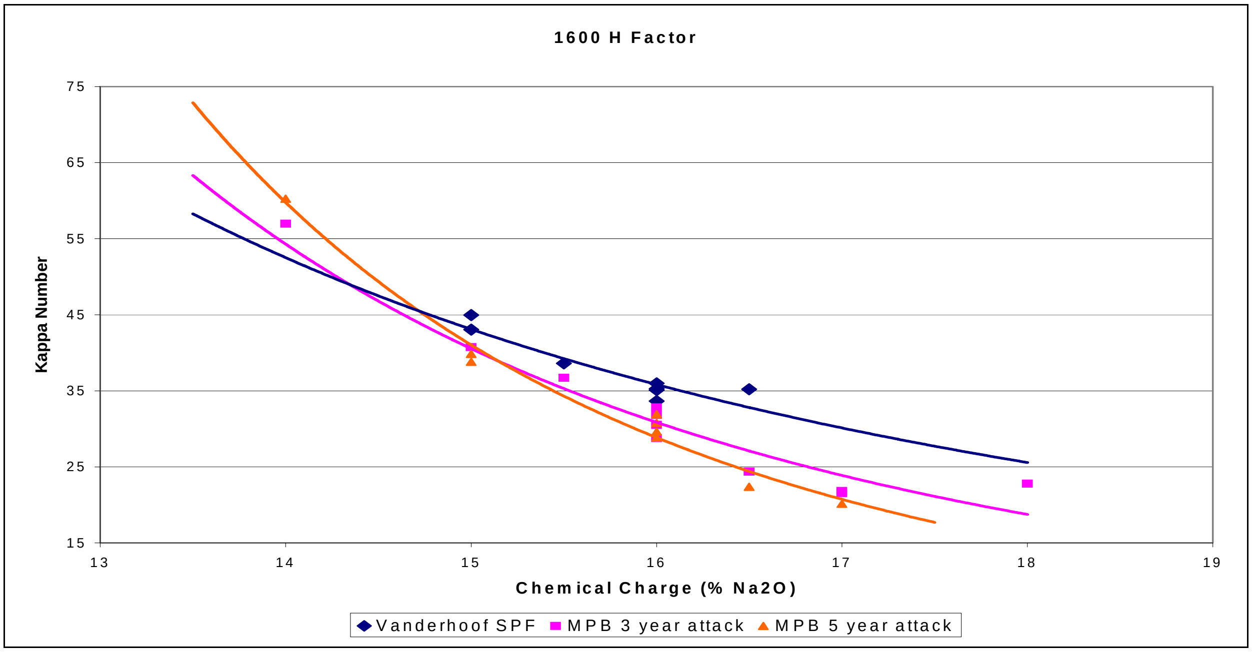

Figure 2. Kappa number vs. chemical charge at 1600 H factor.

Chemical Pulping Properties

Table 5 shows the pulping properties of the wood chip samples pulped under optimal conditions. The Kappa numbers of the MPB grey attacked wood fell within the target range of 30±2. The grey attack wood pulped to a higher yield than the Vanderhoof SPF and a digester feed SPF (figure 3).

Table 5. Pulping properties of SPF and MPB grey attacked wood.

sample	yield (%)	reject (%)	Kappa #
Vanderhoof SPF	45.7	0.23	36
Grey 3 Year Attack	46.4	0.11	31
Grey 5 Year Attack	45.7	0.26	30

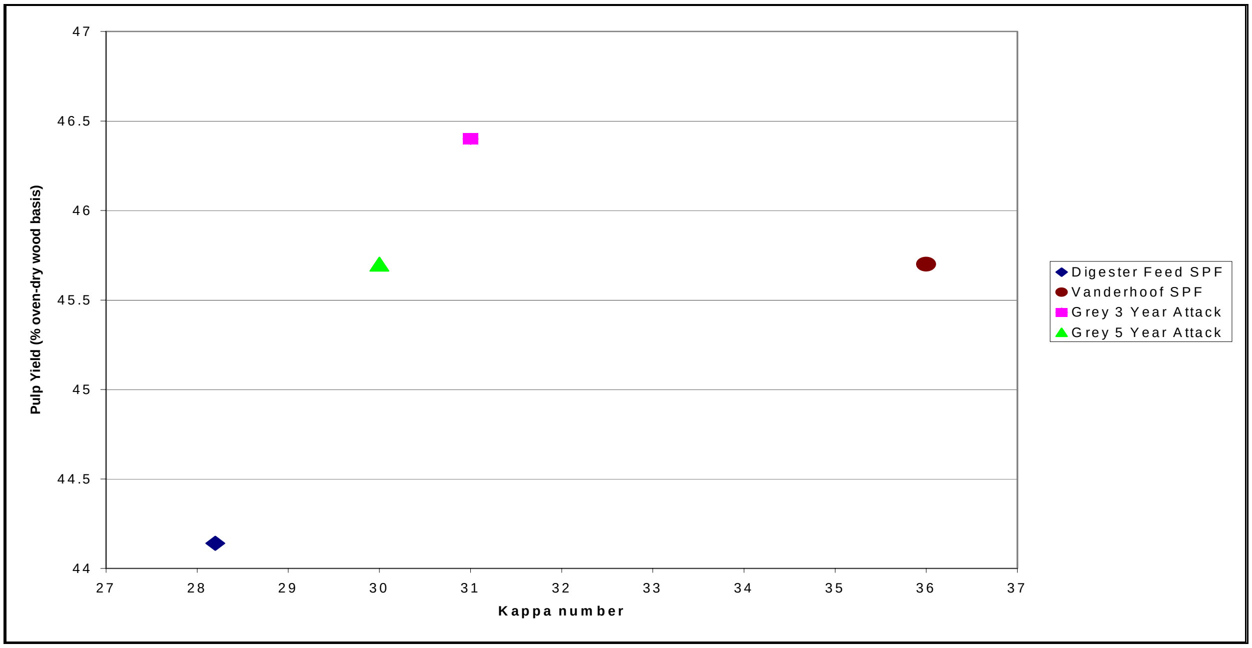

Figure 3. Pulp yield vs Kappa number for MPB grey attack and SPF pulp.

Table 6 shows the black liquor analysis results. The black liquor from the pulping of MPB grey attacked wood had a 6% higher solids content in comparison to the SPF. The MPB grey attacked wood had slightly higher residual alkali values. Resin acid was significantly higher in the MPB pulped black liquor. Relative to the SPF, dehydroabietic acid concentrations were 72% higher in 3 year grey attack and 22% higher in 5 year grey attack black liquors. This has implications for impact on a mill's effluent treatment capacity.

Table 6. Black liquor analysis from pulping of SPF and MPB grey attacked wood.

sample	black liquor density (g/cm^3)	black liquor solids (%)	Res Alkali (%)	Dehydroabietic acid (ppm)
Vanderhoof SPF	1.080	16.44	16.80	168.93
Grey 3 Year Attack	1.080	17.39	17.60	290.57
Grey 5 Year Attack	1.075	17.38	17.50	207.43

Chemical Composition of Kraft Pulp

Dehydroabietic acid was not detected in any of the pulp samples.

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 B, optical properties in

Appendix C, and strength properties in Appendix D. An SPF digester feed sample pulped at identical conditions and having Kappa of 28 is plotted, representing a typical pulp mill furnish.

Coarseness and Fibre Length

Figure 4 shows that the grey MPB attack fibre is less coarse than the Vanderhoof SPF. Coarseness of the grey 3 year attack and grey 5 year attack are lower by 8% and 12%.

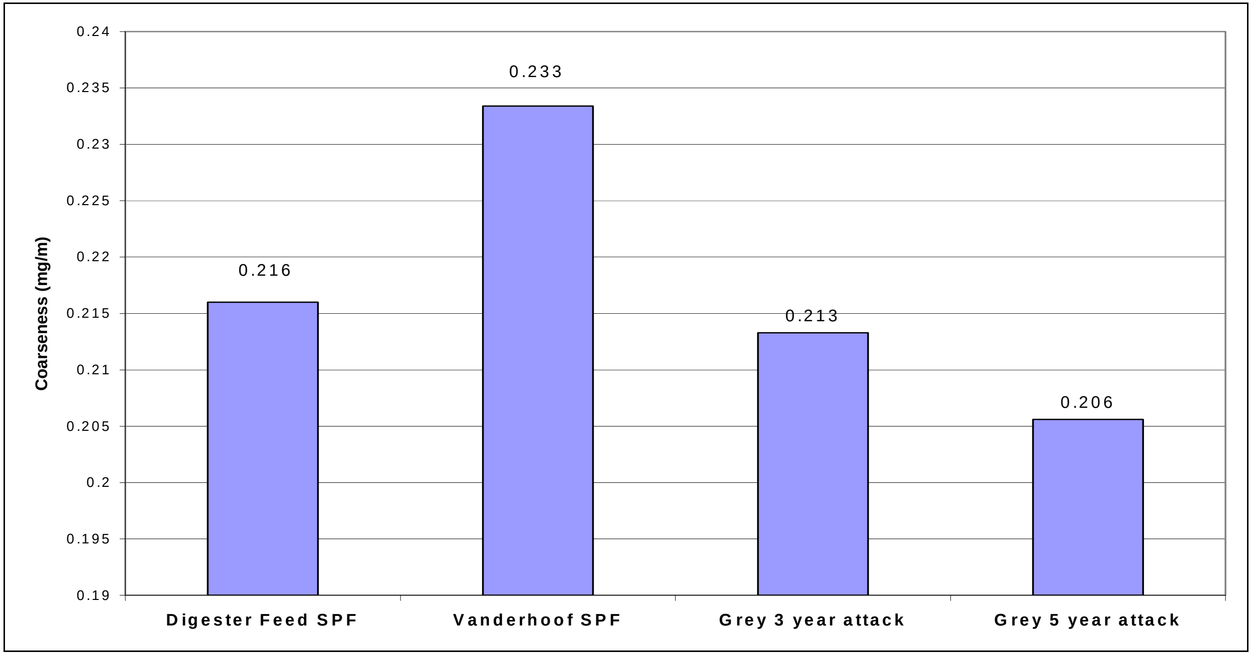

Figure 4. Coarseness of pulps.

Figure 5 shows that the fibre length of the grey attack wood is lower than that of the Vanderhoof SPF, by 7% for the 3 year and 3% for the 5 year.

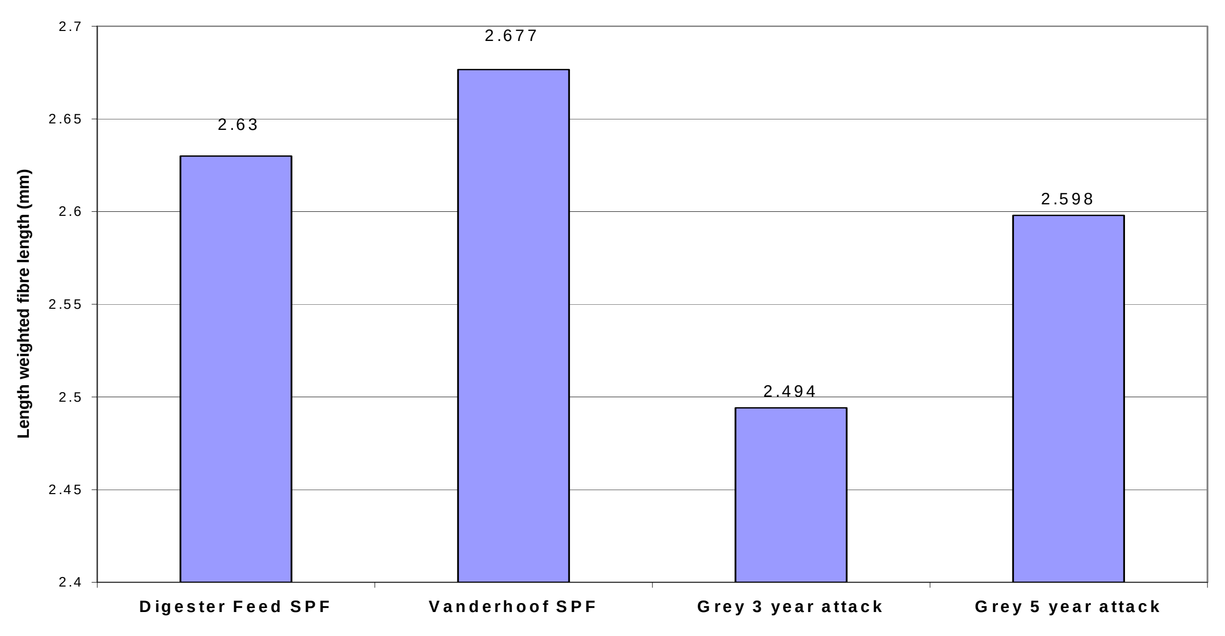

Figure 5. Length weighted fibre-length of pulps.

Canadian Standard Freeness

Figure 6 shows that there is no significant difference in the ease of refining between the Vanderhoof SPF and grey attack pulps. The Vanderhoof fibre was harder to refine than the Digester feed SPF.

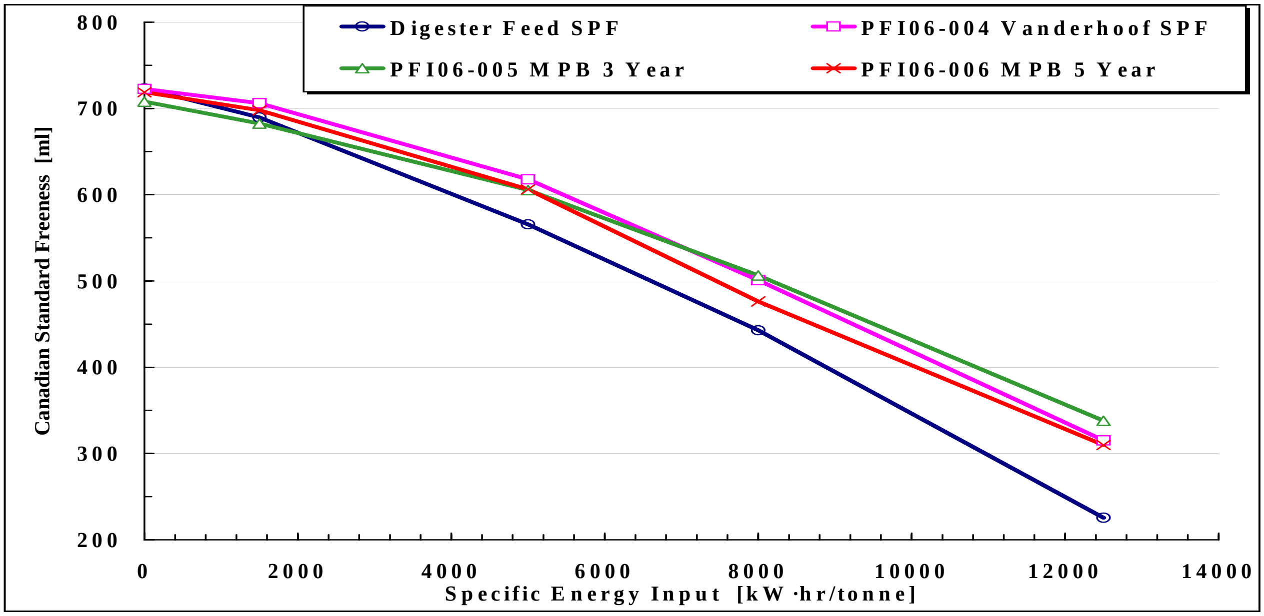

Figure 6. Canadian Standard Freeness vs refining energy.

Porosity

Figures 7 and 8 suggest that the MPB grey attack pulps form a less porous sheet in comparison to the SPF pulp.

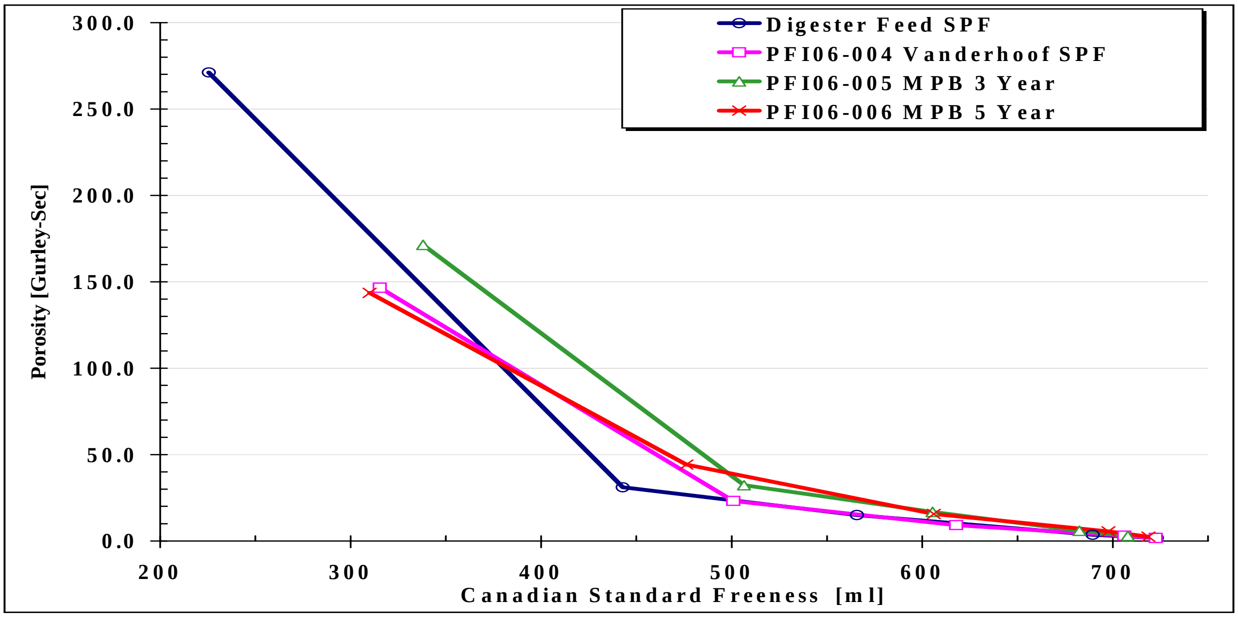

Figure 7. Porosity vs. Canadian Standard Freeness.

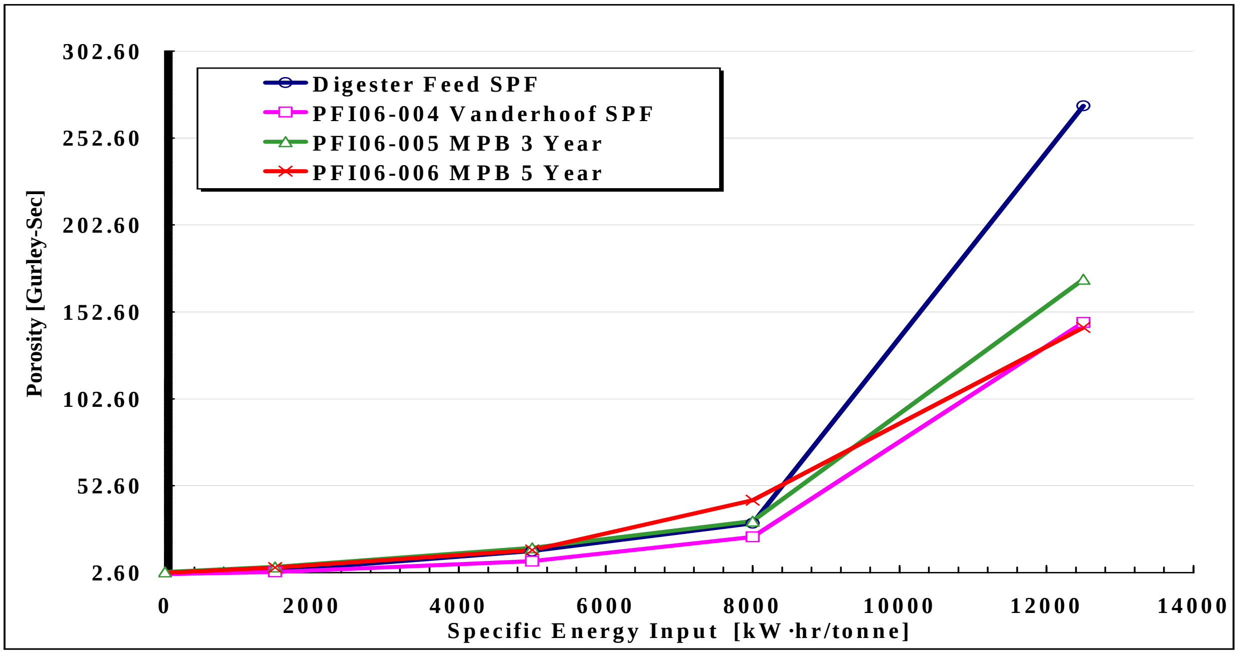

Figure 8. Porosity vs. Beating Energy

Density

Figures 9 and 10 show that the MPB grey attacked pulps formed denser sheets than the SPF samples.

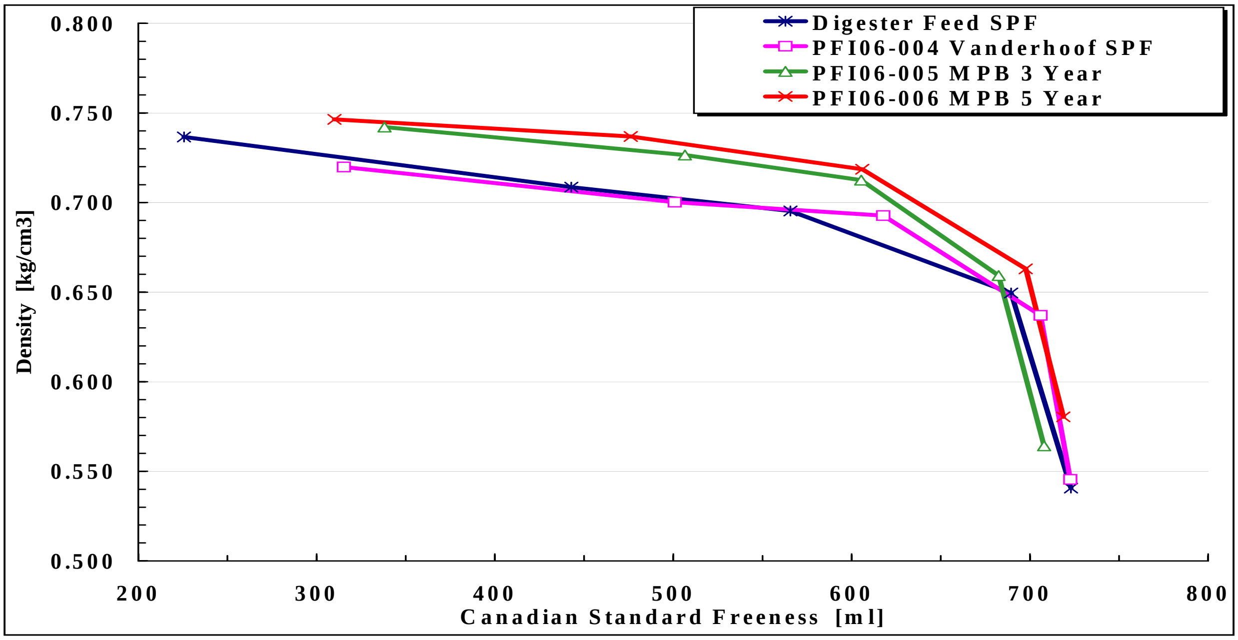

Figure 9. Density vs. Canadian Standard Freeness

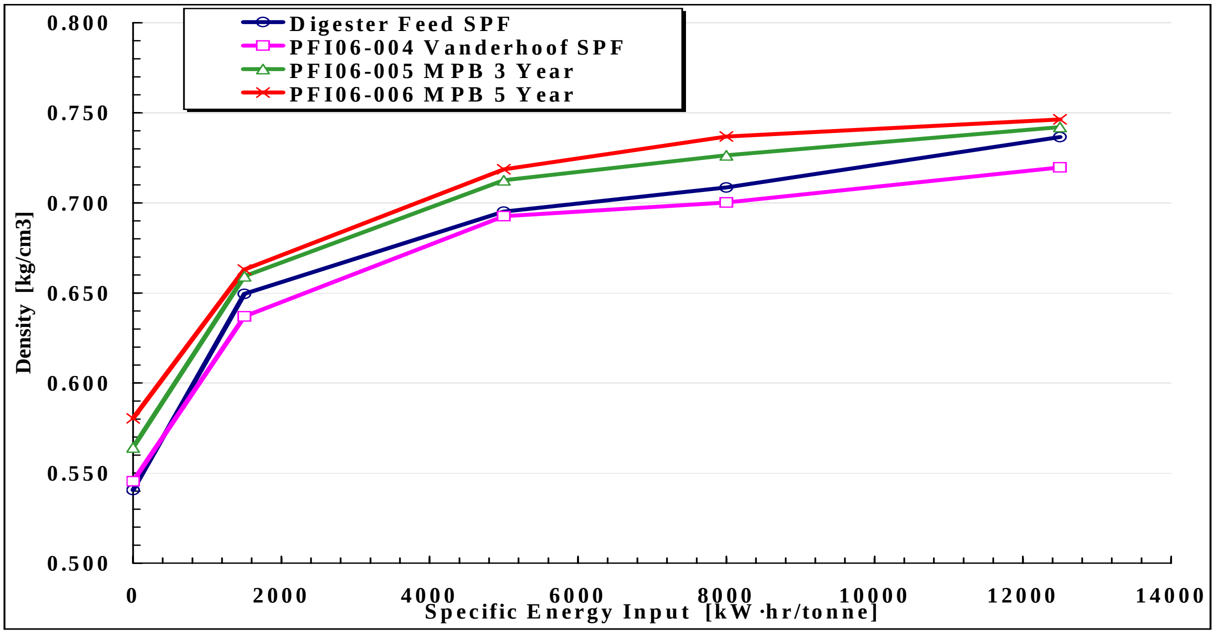

Figure 10. Density vs. Beating Energy

Tear, Tensile, and Burst Strengths

Figure 11 shows that the grey attack pulps have a lower tear at given tensile in comparison to the SPF.

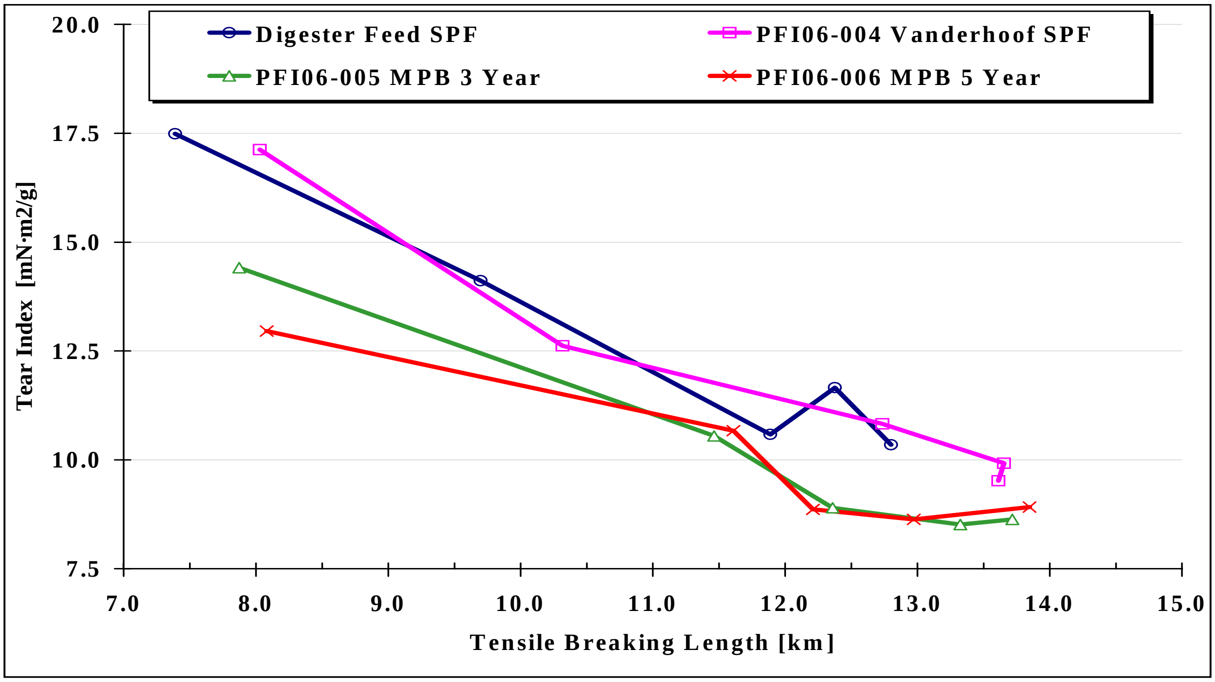

Figure 11. Tear vs tensile relationship

Figures 12 and 13 show that grey attack pulps have lower tear strength in comparison to the SPF.

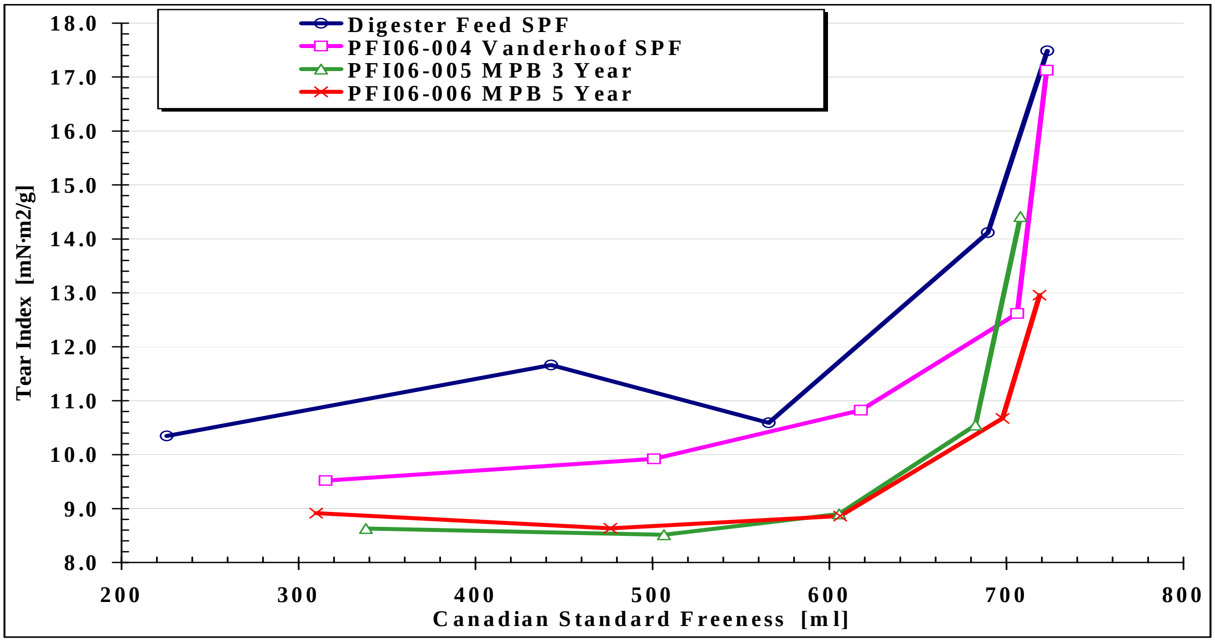

Figure 12. Tear vs CSF

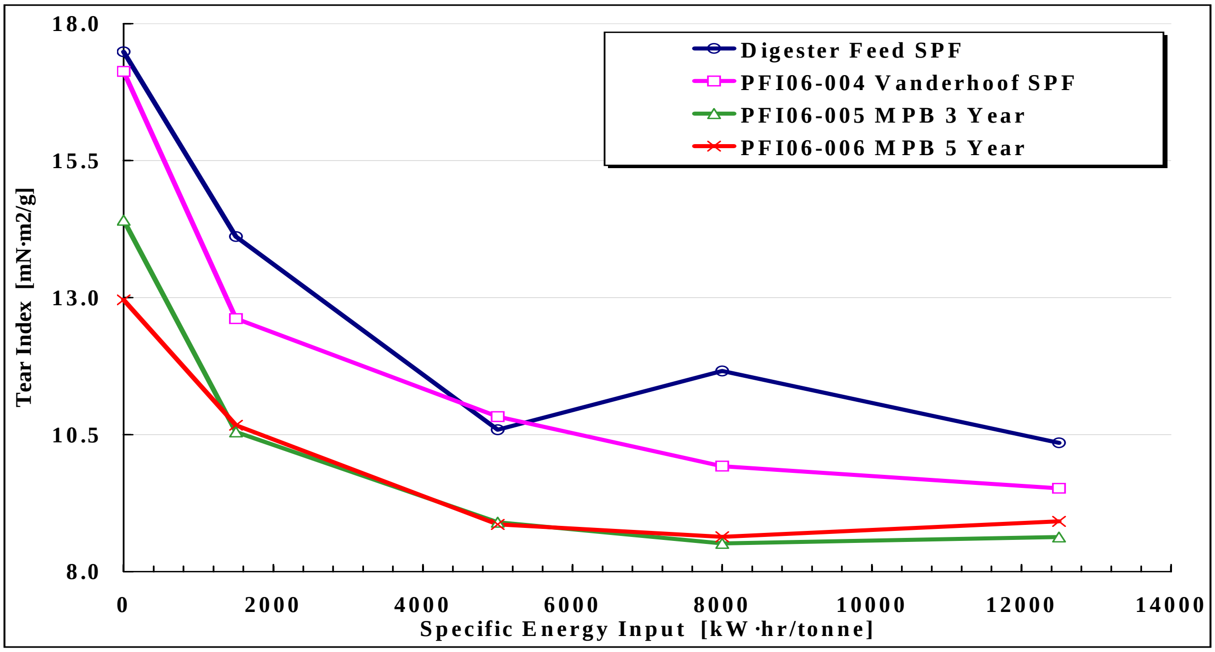

Figure 13. Tear vs Beating Energy

Figures 14 and 15 show that the tensile of the grey attack pulps was similar to that of the Vanderhoof SPF reference. The Vanderhoof fibre had higher tensile than the Digester Feed SPF.

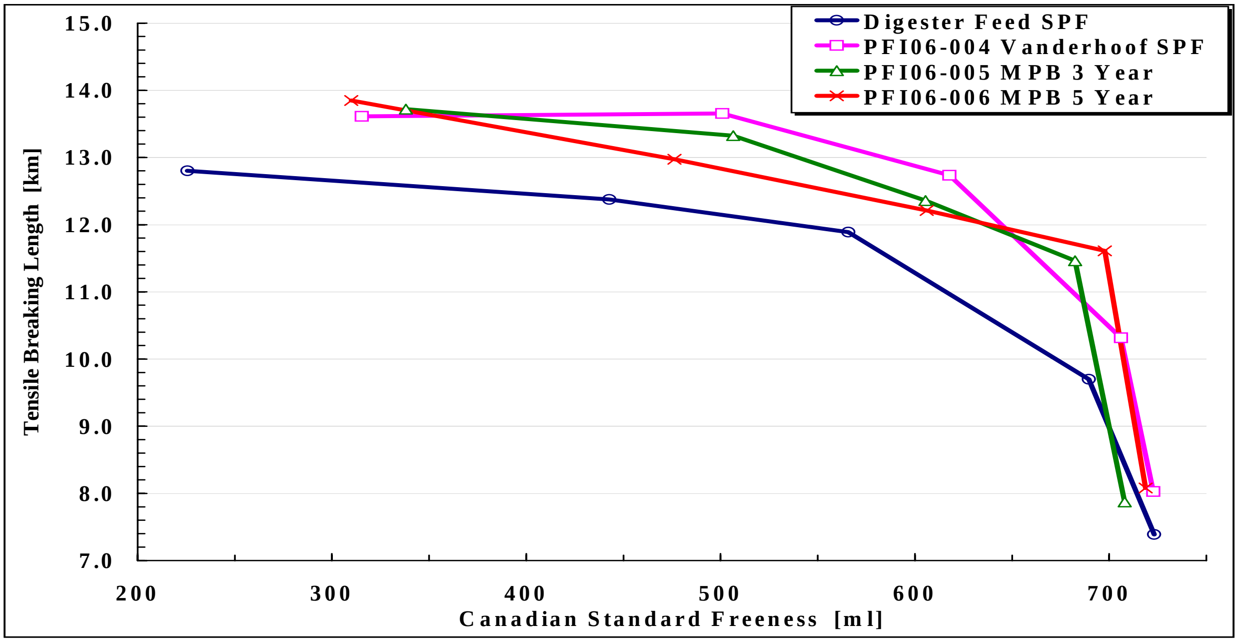

Figure 14. Tensile vs CSF

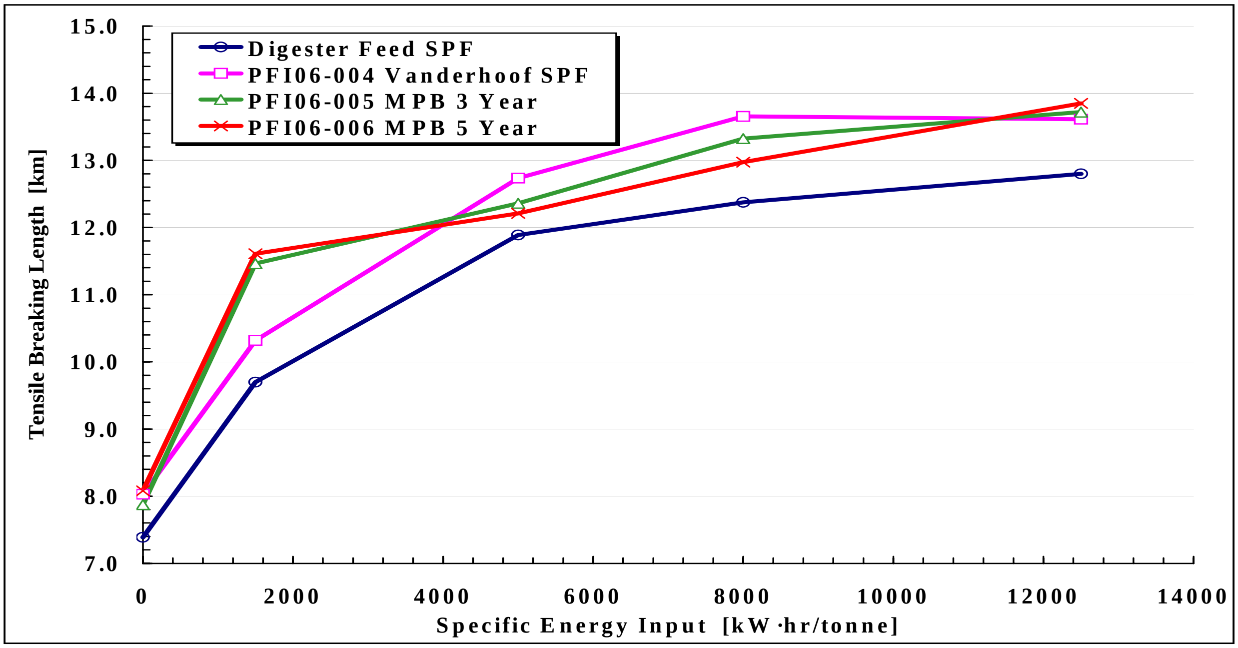

Figure 15. Tensile vs Beating Energy

Figures 16 and 17 show that grey attack pulps have higher burst in comparison to the SPF.

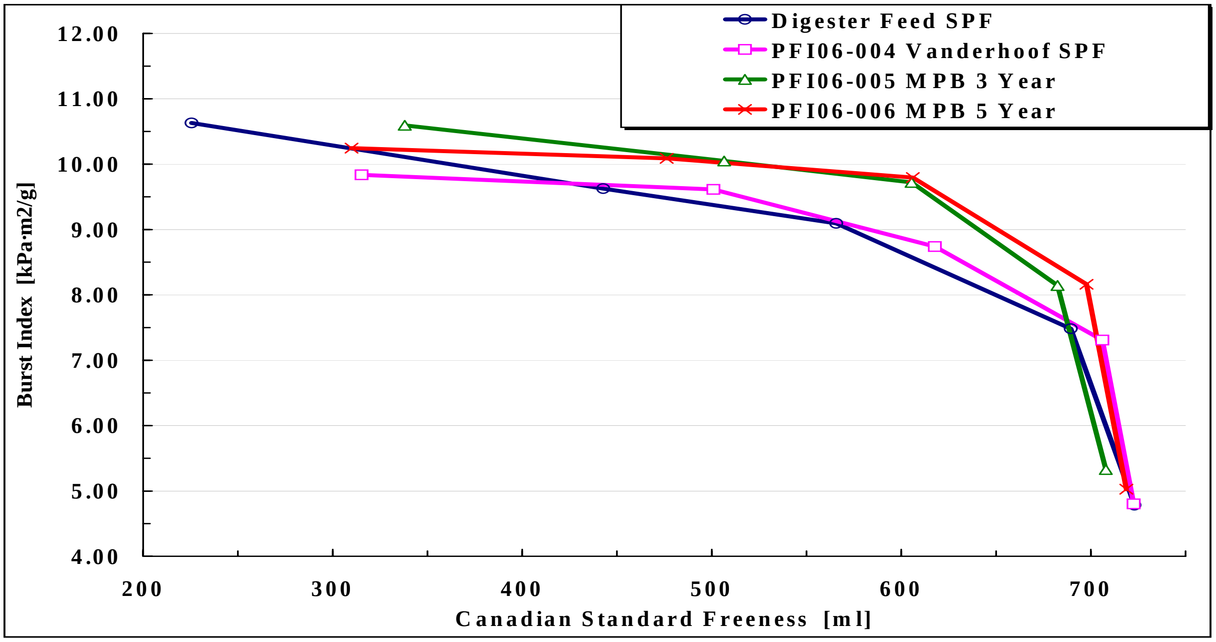

Figure 16. Burst vs CSF

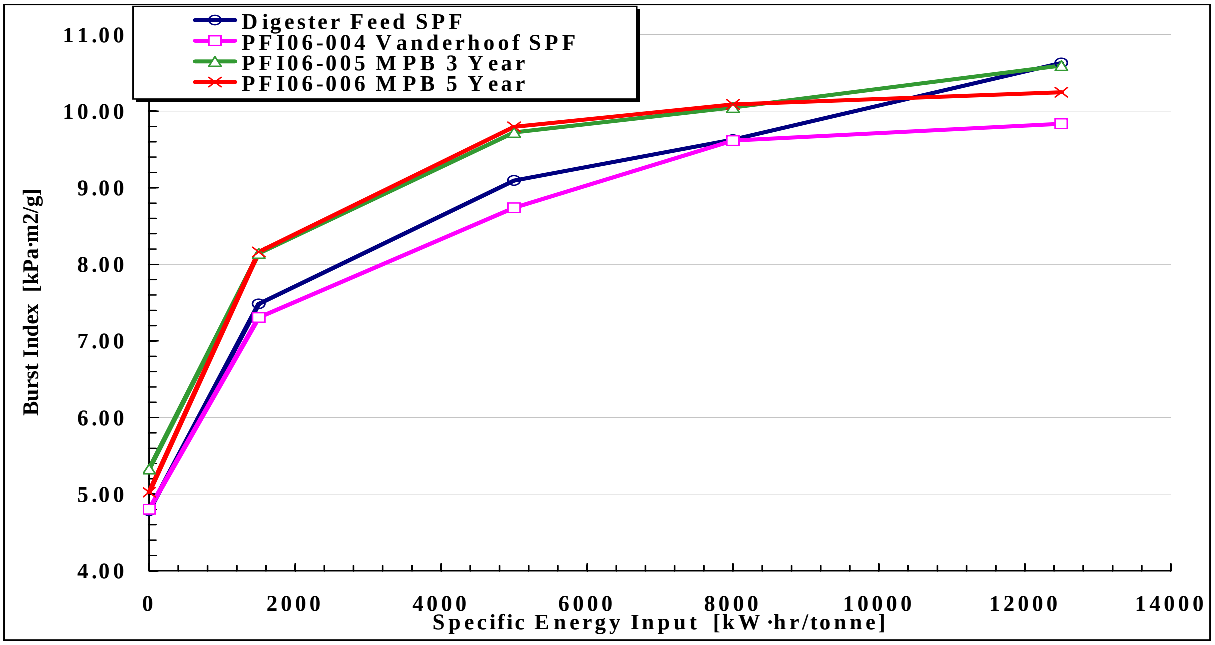

Figure 17. Burst vs Beating Energy

Figure 18 shows that the overall strength of the grey attack pulp was lower than that of the SPF by approximately 3%.

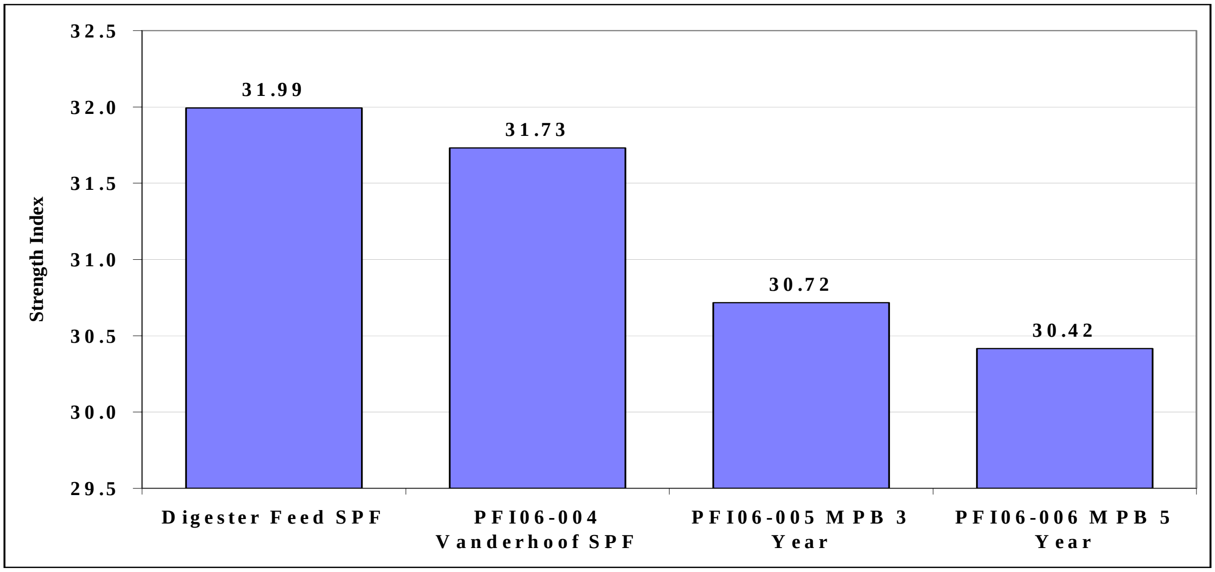

Figure 18. Strength Index for MPB attack and SPF pulp.

Pulp Bleaching

Bleaching conditions and results are shown in Appendix E. Table 7 summarizes the pulp response to chlorine dioxide. The grey attack pulps bleached to higher final brightness than the Vanderhoof SPF. Brightness of the 3 year grey and 5 year grey were 5% and 9% higher, respectively, than that of the Vanderhoof SPF. This suggests improved bleaching response with increasing time since beetle attack. The digester feed SPF, in which the fibre is from a variety of sawmills, showed the best response to bleaching with a 20% higher final brightness than the Vanderhoof SPF.

Alkali solubility results which are 5% and 1% higher for bleached 3 year and 5 year attack pulps in comparison to the Vanderhoof SPF suggest that there may be impact on yield.

Table 7. Bleaching response of pulp.

Pulp	Vanderhoof SPF	Digester Feed SPF	MPB Grey 3yr	MPB Grey 5yr
Brightness	22.87	--	25.36	25.40
Kappa	36	28	31	30
Do Ep				
Brightness	44.42	52.34	47.94	48.75
Kappa	10.6	6.6	8.2	8.0
D1				
Brightness	64.08	77.19	67.28	69.65
Kappa	3.5	1.8	2.7	2.5
Alkali solubility (S18)	16.12	--	16.91	16.32

Bleach filtrate results are shown in table 8. Bleach filtrates from the grey 5 year attack had on average 8% higher COD than filtrates from grey 3 year. Filtrate COD was significantly higher in the grey MPB attack than in the SPF. Total filtrate dissolved solids were 6% higher in the 5 year attack than in 3 year attack.

Table 8. Bleach filtrate analysis.

Pulp	**Vanderhoof SPF**	**Digester Feed SPF**	**MPB Grey 3yr**	**MPB Grey 5yr**
Do				
Residual ClO2 (% of initial)	0.51	0.91	0.56	0.64
filtrate COD (mg/L)	491	475	475	518
filtrate dissolved solids (%)	0.16	0.12	0.12	0.12
E_P				
Residual H_2O_2 (% of initial)	10.78	6.98	8.56	6.34
filtrate COD (mg/L)	3278	5034	5476	5938
filtrate dissolved solids (%)	42.0	37.6	41.5	43.9
D1				
Residual ClO2 (% of initial)	0.22	0.28	0.37	0.15
filtrate COD (mg/L)	1748	1089	1472	1579
filtrate dissolved solids (%)	0.43	0.48	0.43	0.40
Total				
Total filtrate COD (mg/L)	5517	6598	7423	8035
total filtrate dissolved solids (%)	42.60	38.19	42.01	44.44

CONCLUSIONS

1. Moisture contents of the MPB grey attacked chips are lower in comparison to the SPF reference, by 20%.
2. Total acetone extractive contents and dehydroabietic acid in the MPB attacked chips is higher in the 3 year attack and lower in the 5 year attack in comparison to the reference SPF.
3. Decay in the MPB attacked chips is lower in the 3 year attack and higher in the 5 year attack in comparison to the reference SPF.
4. Lignin and carbohydrate contents of the wood samples were comparable to the SPF.
5. The MPB attacked wood had lower amounts of the 16 mm chip fraction in comparison to the SPF reference. Grey 3 year attack was lower by 17% and grey 5 year attack by 12%. The 7 mm fractions were 18% lower for grey 3 year attack and not significantly different in grey 5 year attack in comparison to SPF reference. There was no significant difference in the fines content between the grey 3 year attack and the SPF reference. Fines content of the grey 5 year attack was 80% higher than the SPF.
6. The MPB attacked chips had lower bulk density than the SPF.

7. The MPB grey attacked wood appeared to be easier to cook in comparison to the Vanderhoof SPF fibre. Kappa, yield and liquor consumption results indicate that there was little difference between the 3 and 5 year. The 3 year did have a slight increase in yield at the same kappa, both of which were higher than the SPF.

8. The black liquor from the pulping of MPB grey attacked wood had a 6% higher solids content in comparison to the SPF.

9. Resin acid was significantly higher in the MPB pulped black liquor. Relative to the SPF, dehydroabietic acid concentrations were 72% higher in 3 year grey attack and 22% higher in 5 year grey attack black liquors. This has implications for impact on a mill's effluent treatment capacity.

10. Grey MPB attack fibre is less coarse than the Vanderhoof SPF. Coarseness of the grey 3 year attack and grey 5 year attack are lower by 8% and 12%, respectively.

11. Grey MPB attack has shorter fibre length than the Vanderhoof SPF. Grey 3 year attack and grey 5 year attack are lower by 7% and 3%, respectively.

12. The grey MPB attack and Vanderhoof SPF fibre refined similarly, but were harder to refine to a given freeness than a digester feed SPF.

13. The grey MPB attack pulps formed a less porous and denser sheet than the SPF pulps.

14. The grey attack pulps have a lower tear at given tensile in comparison to the SPF.

15. In comparison to the SPF, the grey attack pulps have lower tear strength, higher burst, and similar tensile. The overall strength of the grey attack pulp was lower than that of the SPF by approximately 3%.

16. No significant difference was seen in the physical properties between 3 year and 5 year attack conditions.

17. There was improved bleaching response seen in MPB attacked pulp, but at the cost of slightly lower yield.

18. MPB grey attacked bleach filtrates had higher COD and solids, than that of the SPF.

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- Jennifer Braun (Post Doctorate) UBC
- Batia Bar-Nir (Post Doctorate) UBC
- Magdalena Mazur (Undergraduate co-op student) UBC

APPENDIX A – PULPING OPTIMIZATION

VANDERHOOF SPF

Sample	H Factor	Chemical Charge %	Kappa	%Yeild	% Rejects
Ref B1	1600	15	43	42.8%	0.11%
Ref B2	1800	14	57	44.8%	0.42%
Ref E	1600	16	34	N/A	N/A
Ref F	1600	15	45	N/A	N/A
Ref G1	1600	16	36	46.8%	0.34%
Ref G2	1600	16	35	43.1%	0.08%
Ref G3	1600	16	35	47.2%	0.26%
Ref H	1600	15.5	39	48.0%	0.29%
Ref I1	1600	16.5	35	50.6%	0.03%
Ref J	1500	16	32	47.7%	0.04%

Grey MPB Three Year

Sample	H Factor	Chemical Charge %	Kappa	%Yeild	% Rejects
3yr B2	1600	14	57	47.5%	2.56%
3yr B3	1900	16	32	44.1%	0.28%
3yr B4	1750	15	45	47.3%	0.82%
3yr C1	2000	16	34	46.4%	0.36%
3yr D1	1600	18	23	41.9%	0.01%
3yr D2	1600	17	22	43.2%	0.16%
3yr E1	1600	17	22	43.0%	0.05%
3yr E2	1600	16.5	24	45.6%	0.03%
3yr F1	1600	16	32	N/A	N/A
3yr F2	1600	16	29	N/A	N/A
3yr G	1600	15	41	45.5%	0.40%
3yr H1	1600	16	31	44.7%	0.07%
3yr H2	1600	16	33	48.1%	0.16%
3yr I	1600	15.5	37	46.8%	0.75%
3yr K	1400	16	31	44.1%	0.23%
3yr L	1500	16	31	46.9%	0.07%

Grey MPB Five Year

Sample	H Factor	Chemical Charge %	Kappa	%Yeild	% Rejects
5yr B2	1600	14	60	49.9%	6.55%
5yr B3	1400	14	59	46.4%	6.78%
5yr B4	1500	13	N/A	N/A	N/A
5yr B5	1500	15	48	45.0%	0.55%
5yr C2	1900	16	37	39.8%	0.35%
5yr D1	1600	17	20	42.6%	0.01%
5yr D2	1500	18	19	43.2%	0.02%
5yr E2	1600	16.5	22	43.4%	0.01%
5yr F1	1600	16	29	N/A	N/A
5yr G1	1600	15	39	72.2%	0.34%
5yr G2	1600	15	40	45.2%	0.23%
5yr H1	1600	16	30	46.4%	0.34%
5yr H2	1600	16	31	45.2%	0.29%
5yr I1	1600	16	32	45.4%	0.14%
5yr K	1500	16	30	45.5%	0.11%
5yr L	1400	16	30	47.7%	0.22%

APPENDIX B – PHYSICAL PROPERTIES

GREY 3 YEAR ATTACK

PHYSICAL TESTS

SPECIFIC EN. INPUT [kW.hr/te]	CSF [ml]	CALIPER [mm]	BULK [cm^3/g]	DENSITY [g/cm^3]	AIR RESISTANCE [Gurley-Sec]	SMOOTHNESS [SCCM]
0	708	0.108	1.77	0.564	2.9	2813
1500	682	0.090	1.52	0.659	5.9	2713
5000	605	0.084	1.40	0.713	16.8	2914
8000	507	0.082	1.38	0.726	32.2	2919
12500	338	0.080	1.35	0.742	171.3	2901

GREY 5 YEAR ATTACK

PHYSICAL TESTS						
REVS	**CSF**	**CALIPER**	**BULK**	**DENSITY**	**AIR RESISTANCE**	**SMOOTHNESS**
[Revs]	[ml]	[mm]	[cm^3/g]	[g/cm^3]	[Gurley-Sec]	[SCCM]
0	719	0.105	1.72	0.580	2.5	2750
1500	698	0.090	1.51	0.663	5.5	2813
5000	606	0.085	1.39	0.719	15.6	2909
8000	476	0.082	1.36	0.737	44.2	2966
12500	310	0.080	1.34	0.746	143.6	2930

VANDERHOOF 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	0.108	1.83	0.546	1.8	3027
1500	706	0.095	1.57	0.637	3.0	2938
5000	618	0.089	1.44	0.693	9.2	2989
8000	501	0.086	1.43	0.700	23.2	3023
12500	315	0.083	1.39	0.720	146.6	3079

DIGESTER FEED 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	0.109	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

APPENDIX C – OPTICAL PROPERTIES

GREY 3 YEAR 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	43.9	99.1	28.2	18.60
1500	20.8	48.3	98.2	22.8	17.50
5000	19.2	51.2	96.4	17.2	14.79
8000	18.3	52.0	94.7	14.7	13.55
12500	17.8	52.0	94.5	14.0	13.53

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]
0	64.1	6.2	15.6	16.7	68.4
1500	61.9	7.0	16.7	18.1	67.2
5000	60.4	7.6	17.3	18.9	66.4
8000	59.4	7.7	17.3	19.0	66.1
12500	58.7	7.7	17.1	18.8	65.9

GREY 5 YEAR ATTACK

OPTICAL TESTS

SPECIFIC EN. INPUT	BRIGHTNESS	YELLOWNESS	OPACITY	SCATTERING COEFF.	ABSORPTION COEFF.
[kW.hr/te]	[ISO]		[%]	[m^2/kg]	[m^2/kg]
0	23.2	44.9	99.0	25.6	17.22
1500	20.6	49.4	97.1	19.7	15.20
5000	18.6	52.2	95.5	15.4	13.77
8000	17.9	52.7	94.5	13.9	13.21
12500	17.2	53.0	93.7	13.3	12.80

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	6.6	15.8	17.1	67.3
1500	61.8	7.5	16.8	18.5	65.9
5000	59.8	8.0	17.3	19.1	65.1
8000	58.9	8.1	17.2	19.1	64.8
12500	58.1	7.9	17.2	19.0	65.3

VANDERHOOF SPF

OPTICAL TESTS

SPECIFIC EN. INPUT [kW.hr/te]	BRIGHTNESS [ISO]	YELLOWNESS	OPACITY [%]	SCATTERING COEFF. [m^2/kg]	ABSORPTION COEFF. [m^2/kg]
0	21.0	47.7	98.6	23.9	18.64
1500	18.6	51.2	97.6	18.4	16.82
5000	16.7	54.1	96.6	15.0	15.74
8000	16.1	54.7	95.9	14.0	15.61
12500	15.9	54.4	95.0	12.9	14.80

OPTICAL TESTS

REVS [Revs]	L* (Lightness) [CIE]	a* (red - green axis) [CIE]	b* (yellow - blue axis) [CIE]	C* (chroma) [CIE]	h* (hue angle) [CIE]
0	61.8	7.3	16.1	17.7	65.5
1500	59.5	8.0	16.8	18.6	64.5
5000	54.5	8.5	17.3	19.3	63.8
8000	56.6	8.6	17.2	19.3	63.4
12500	56.2	8.4	17.1	19.0	63.7

DIGESTER FEED SPF

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

APPENDIX D – STRENGTH PROPERTIES

GREY 3 YEAR 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]
0	14.41	5.33	7.87	2.21	9.18	1165	77.24
1500	10.55	8.14	11.46	2.76	10.61	2011	112.48
5000	8.90	9.72	12.36	3.19	10.66	2506	121.28
8000	8.51	10.05	13.32	3.05	11.49	2580	130.71
12500	8.63	10.59	13.72	3.10	11.73	2694	134.57

GREY 5 YEAR 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	12.96	5.03	8.08	2.25	9.16	1190	79.27
1500	10.67	8.16	11.61	2.94	10.54	2178	113.88
5000	8.86	9.79	12.21	3.00	10.88	2334	119.79
8000	8.63	10.09	12.97	3.16	10.94	2594	127.26
12500	8.92	10.25	13.85	3.01	12.00	2638	135.87

VANDERHOOF 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	17.13	4.80	8.03	2.11	9.44	1106	78.77
1500	12.62	7.31	10.32	2.69	10.07	1785	101.21
5000	10.83	8.74	12.74	2.96	11.31	2397	124.94
8000	9.92	9.61	13.65	2.97	11.86	2566	133.95
12500	9.52	9.84	13.61	3.18	11.71	2754	133.53

DIGESTER FEED 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	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

APPENDIX E – Do Ep D1 BLEACHING

Pulp	**Vanderhoof SPF**	**Digester Feed SPF**	**MPB Grey 3yr**	**MPB Grey 5yr**
Kappa	**36**	**28**	**31**	**30**
Brightness	**22.87**	**--**	**25.36**	**25.40**
Do				
ClO2 (%)	2.33%	1.81%	2.00%	1.94%
Kappa Factor	0.17%	0.17%	0.17%	0.17%
consistency (%)	3	3	3	3
time (min)	20	20	20	20
Temperature [oC]	50	50	50	50
pH initial	4.25	4.56	3.88	3.89
Final pH	2.30	2.52	2.25	2.10
Residual ClO2 (% of initial)	0.51	0.91	0.56	0.64
filtrate COD (mg/L)	490.7	475.4	475.4	517.5
filtrate dissolved solids (%)	0.16	0.12	0.12	0.12
E_P				
H_2O_2	0.55%	0.55%	0.55%	0.55%
NaOH	1.80%	1.80%	1.80%	1.80%
consistency (%)	10%	10%	10%	10%
Time [minutes]	90	90	90	90
Temperature [^oC]	82	82	82	82
pH initial	11.13	11.42	11.31	11.54
End Process pH	8.80	10.02	9.43	9.88
Residual H_2O_2 (% of initial)	10.78	6.98	8.56	6.34
filtrate COD (mg/L)	3278	5034	5476	5938
filtrate dissolved solids (%)	42.01	37.58	41.46	43.92
Brightness	**44.42**	**52.34**	**47.94**	**48.75**
Kappa	**10.6**	**6.6**	**8.2**	**8.0**
D1				
ClO2 (%)	1.30%	1.30%	1.30%	1.30%
consistency (%)	10	10	10	10
time (min)	120	120	120	120
Temperature [oC]	68	68	68	68
pH initial	3.22	3.04	3.37	3.54
Final pH	2.01	2.02	2.02	1.95
Residual ClO2 (% of initial)	0.22	0.28	0.37	0.15
filtrate COD (mg/L)	1748	1089	1472	1579
filtrate dissolved solids (%)	0.43	0.48	0.43	0.40
Brightness	**64.08**	**77.19**	**67.28**	**69.65**
Kappa	**3.5**	**1.8**	**2.7**	**2.5**
Alkali solubility S18 (%)	16.12	--	16.91	16.32