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EFFECTS OF BLEACH PLANT PROCESSING ON FIBER STRENGTH

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ABSTRACT

The increased use of medium-consistency high shear mixers in bleach plants has resulted in significant changes in fiber morphology as pulp is processed through a fiberline. Samples were collected after individual stages in two mills employing ECF bleaching and medium-consistency processing. Significant changes in fiber curl and kink were observed. Handsheet properties were also measured. Straightening of the fibers from laboratory PFI mill refining significantly increased the strength properties. Losses in viscosity were reflected by losses in fiber strength but the magnitude of the change in fiber strength was considerably less than the change in viscosity. A significant decrease in fiber strength across the fiberline was seen in one mill but was minimal in the other. This appears to be due to the presence of an oxygen stage and the process conditions used in the D_1 stage.

INTRODUCTION

More than fifty years ago, Hill, Edwards, and Beath in a classic paper described the effects of curling fibers by shearing a pulp suspension at high consistency.[1] They noted that curl had a range of unusual effects. It increased tear, decreased tensile, increased stretch both wet and dry, increased freeness, and increased bulk. They observed that curl could be induced deliberately, but often occurred incidentally, for example in the high consistency stages of bleach plants.

Little notice was taken of this latter observation until the work of DeGrace and Page.[2] They studied the properties of dried bleached kraft market pulps from 21 mills across Canada and the U.S.A. They found that physical properties of these pulps differed greatly, but surprisingly the major part of the differences did not come from differences in species. They came from differences in the degree of curl present in the fiber. Some pulps had straight fibers; others were curly. At the same time they observed that the curly fibers also often contained microcompressions that contributed to property differences.[3]

Curl was found to be characteristic of a mill. Fibers of subsequent samples from the same mills were curly, if the original samples were curly; they were straight, if the original samples were straight. In a study of one bleach plant it was found that the degree of curl increased monotonically during bleaching and was closely related to the energy imparted to the pulp in the medium consistency pumping and mixing stages. Mills differed in the amount of energy used and therefore in the amount of curl induced.

It was clear from this work that future progress would be stalled unless routine methods could be devised for the measurement of curl. This led to the development of image analysis procedures which were at first time consuming.[4,5] Today they have reached the point of automation, and curl measurement has become as routine as fiber length or freeness measurement.[6] As a result curl is becoming more widely recognized as an important fiber property and papers utilizing curl measurement are now common in the literature.

In addition to the direct effects of curl and microcompression, localized fiber deformations, such as kinks, are created by mechanical action, and these are susceptible to chemical attack. This was shown for acid sulphite pulps as long ago as 1940.[7] For kraft pulps, MacLeod showed that fiber deformations occurring during digester blowing were degraded by the cooking chemicals, causing fiber strength losses as high as 30%.[8]

The extent to which this mechanical change, followed by chemical attack, is important in bleach plant operations has been studied by several researchers. Allison and co-workers found that bleaching of pulps with selected chemicals after medium-consistency processing has a small additional detrimental effect on fiber strength compared to fibers that were bleached without the prior mechanical treatment.[9] Fiber strength loss from an oxygen delignification stage was shown to be primarily due to the medium-consistency mixing with only a small effect from the bleaching chemicals.[10] Bennington and Seth found no significant synergistic effect of fiber strength from mechanical and chemical treatments for chlorine, chlorine dioxide, and ozone stages.[11]

A number of researchers have characterized the nature and extent of fiber deformations when they have been imparted by the fluidization that is necessary for effective mixing of medium consistency pulp in modern high-shear mixers.[12,13,14]

Mohlin and others have used the zero-span tensile strength of rewetted sheets as an indicator of fiber deformation.[15,16] The rewetted zero-span tensile strength correlates strongly with the extent of fiber deformations. Fiber deformations from commercial processing can be either reversible or irreversible. Reversible damage can be determined as the recovery of zero-span tensile strength when fibers are straightened, for example by refining in the PFI mill. Typical mill refining, however, is of high intensity and short duration and not very complete in removing such reversible deformations.

Tikka and Sundquist recently reported on the significant fiber strength loss that was found to occur across the bleach plants of two modern fiberlines that are achieving in excess of 90% strength delivery from the digester discharge.[17] Reasons for the observed loss were not evident to the authors though they point to several possibilities.

Bleaching sequences have been changing rapidly in recent years, spurred by environmental concerns. It is important that the industry should remain aware of fiber modifications that are occurring during modified sequences. For this reason a study was made of the properties of pulps from two newly modified sequences. The experimental work described below is from two such sequences.

EXPERIMENTAL

Samples from two mill fiberlines were collected and fiber and handsheet properties were measured both before and after PFI mill refining for 3000 revolutions. Both mills produce bleached pulp from southern pine with EMCC™ digesters. The bleaching sequence for Mill A is OD(EOP)DnD and for Mill B it is D(EO)DP. Both are diffusion bleach plants with medium-consistency bleach stages.

Grab samples were collected in Mill A from a sampling valve in the continuous digester blow valve and from a sampling valve in the discharge chutes of the diffusion washer following each of the bleach plant stages. Grab samples were collected in Mill B from the discharge of the brownstock diffuser, decker discharge, bleach feed tank, and the discharge of each bleach stage diffusion washer.

Fiber length and curl were measured with a Fiber Quality Analyzer™ from OpTest Equipment Inc.
Additional testing was done according to the following methods.

Kappa number	TAPPI UM246
Viscosity	TAPPI T230
PFI mill refining	TAPPI T248
Handsheet Making	TAPPI T205
Handsheet Testing	TAPPI T220

RESULTS AND DISCUSSION

The complete fiber properties and handsheet results for Mill A and Mill B are shown in the Appendix.

The curl and fiber length results across the fiberline before and after PFI mill refining are shown in Figure 1 for Mill A and in Figure 2 for Mill B. After brownstock diffusion washing, there is already a significant amount of curl in the fibers at both mills. For Mill B there is an apparent decrease in curl through the screen room and decker. For both mills, curl increased significantly after the first medium-consistency bleach stage, the O stage for Mill A and the D_0 stage for Mill B. However, the amount of curl does not increase further in additional medium-consistency stages. PFI mill refining reduces the curl index to a relatively constant low value except for the D_1 stage of Mill B where some measurable curl still remained after 3000 revolutions.

There is a significant increase in apparent fiber length as measured by the FQA after refining in the PFI mill. Some of this may be real and attributable to the removal of microcompressions,[18] and some may be due to a tendency of the instrument to underestimate the length of curled fibers.[19] There is considerable variation in the measured fiber length across the bleach plant for both mills, with Mill A showing some overall loss in length from the blowline to the end of the bleach plant while Mill B shows very little overall loss in fiber length.

While additional medium-consistency processing does not noticeably increase the curl, additional mechanical effects on the fibers are taking place. Seth and others measured the effects of repeated medium-consistency fluidization on fibers and used the ratio of stretch to the tensile index to show that the occurrence of microcompressions in the fibers increases with additional processing even though the curl index only increased following the first stage.[13]

The stretch/tensile ratio across the fiberline is shown in Figure 3 for Mill A and in Figure 4 for Mill B. Mill A shows an increase through the (EOP) stage followed by a decrease while Mill B shows a steady increase through the bleach plant. The reduction in the ratio following PFI mill refining indicates that some removal of the microcompressions takes place.

The zero-span tensile strength across the fiberline is shown in Figure 5 for Mill A and in Figure 6 for Mill B. There is an increase in both the wet and dry zero-span tensile strength with PFI mill refining corresponding to the removal of the fiber curl. The viscosity results for each stage are shown in the Appendix and the change in viscosity reflects the changes in the zero-span tensile strength across the fiberline though the magnitude of the viscosity loss is higher.

The loss in zero-span tensile strength from the dry to the wet state has been attributed to weakening or degradation of the fiber matrix by either chemical or mechanical means.[20] The magnitude of this loss can be an indicator of the extent of degradation. The ratio of the wet to dry zero-span tensile strength for each of the samples is shown in Table 1. Mill A shows a larger drop in the ratio especially across the D_1 stage indicating more extensive fiber damage. In this mill, caustic is added at the D_1 diffusion washer for a neutralization step prior to the D_2 stage. It may be hypothesized that hypochlorous acid formation during the attendant pH increase causes carbohydrate degradation. We have previously observed that viscosity loss in a D_1 stage can be avoided by decreasing the pH.[21]

For Mill B, there is some loss in zero-span tensile strength across the fiberline but not as much as Mill A.

Table I. Ratio of Rewet/Dry Zero-span tensile Strength for Mill Samples

Stage	Mill A	Mill A PFI refined	Stage	Mill B	Mill B PFI refined
Blowline	0.89	0.88	**Diffuser**	0.85	0.83
O_2 Pressure Diffuser	0.89	0.82	**Decker**	0.86	0.83
O_2 Hi-D	0.86	0.82	**Bleach Feed**	0.86	0.81
D_0	0.83	0.77	**D_0**	0.88	0.83
(EOP)		0.80	**(EO)**	0.83	0.78
D_1	0.76	0.72	**D_1**	0.82	0.77
D_2	0.76	0.72	**P**	0.83	0.80

The tear and tensile strengths for Mill A are shown in Figure 7 and in Figure 8 for Mill B. The loss across the fiberline for Mill A refined samples is 13.8% in tear and 8.6% in tensile. The magnitude of this loss is less than that observed for the loss in viscosity and zero-span tensile strength. For Mill B, there is minimal loss in the tear or tensile strength.

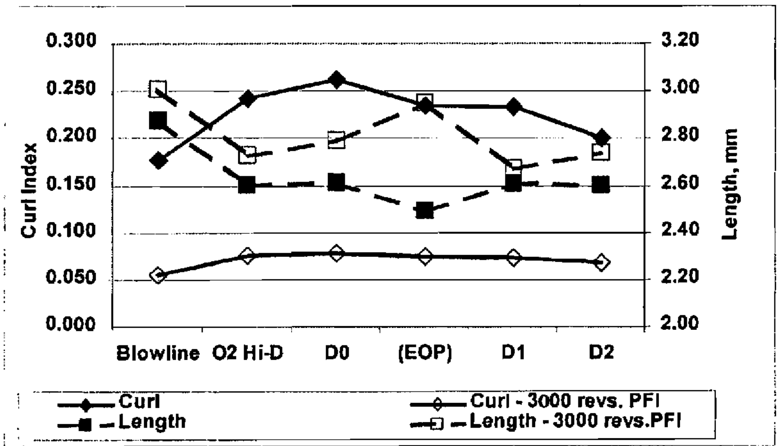

Figure 1. Curl and Fiber Length for Mill A

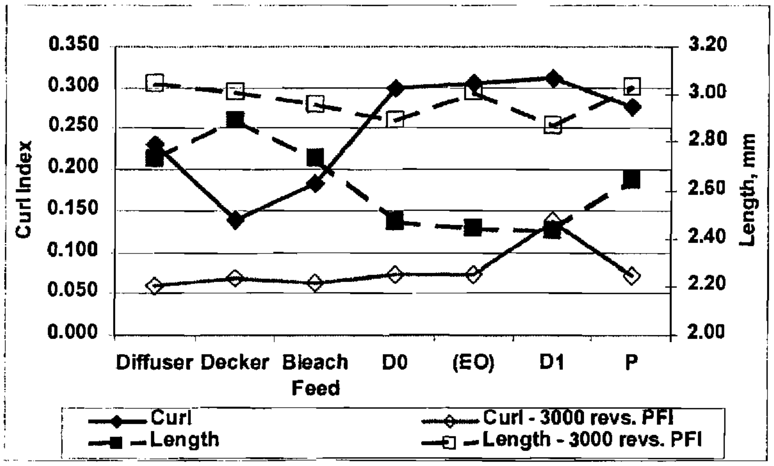

Figure 2. Curl and Fiber Length for Mill B

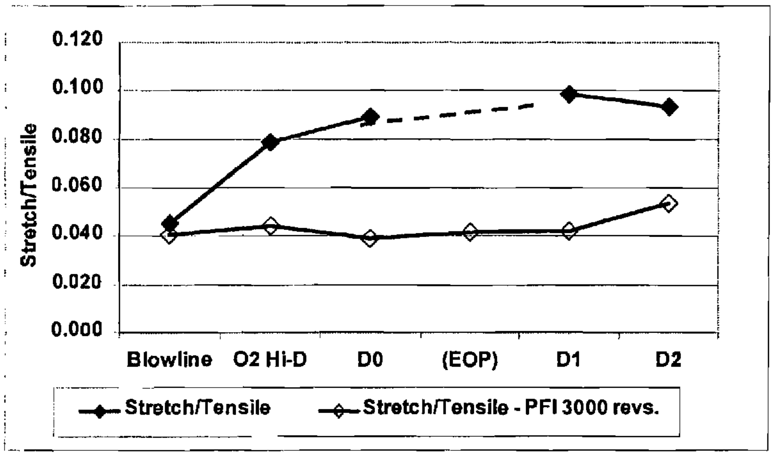

Figure 3. Stretch/Tensile Ratio for Mill A

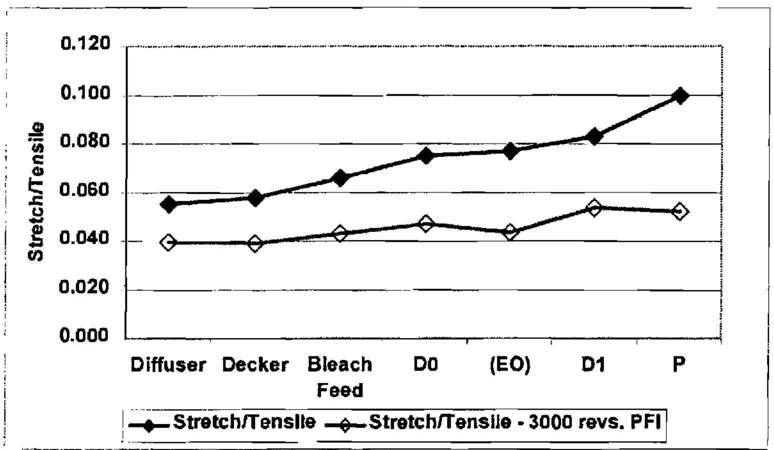

Figure 4. Stretch/Tensile Ratio for Mill B

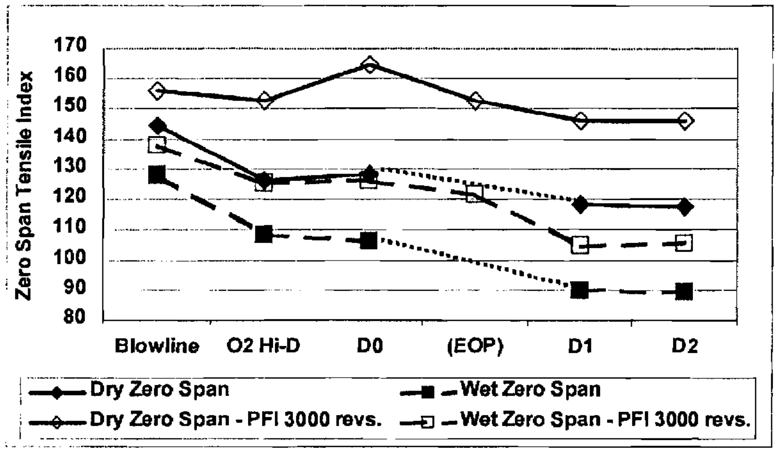

Figure 5. Dry and Wet Zero-span Tensile Index for Mill A

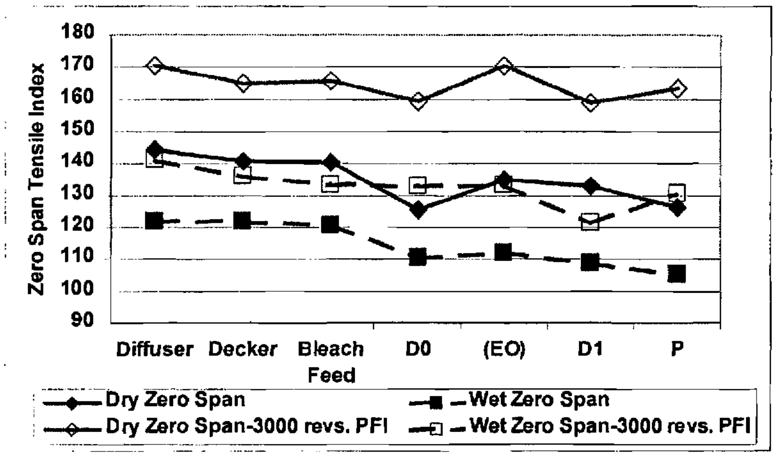

Figure 6. Dry and Wet Zero-span Tensile Index for Mill B

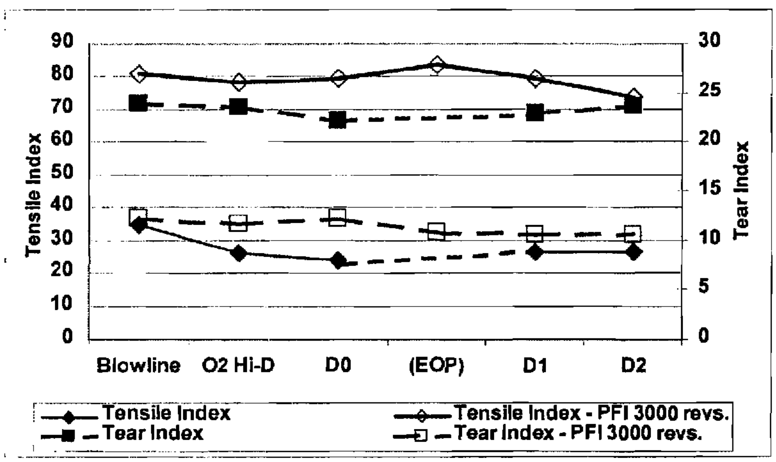

Figure 7. Tensile and Tear Index for Mill A

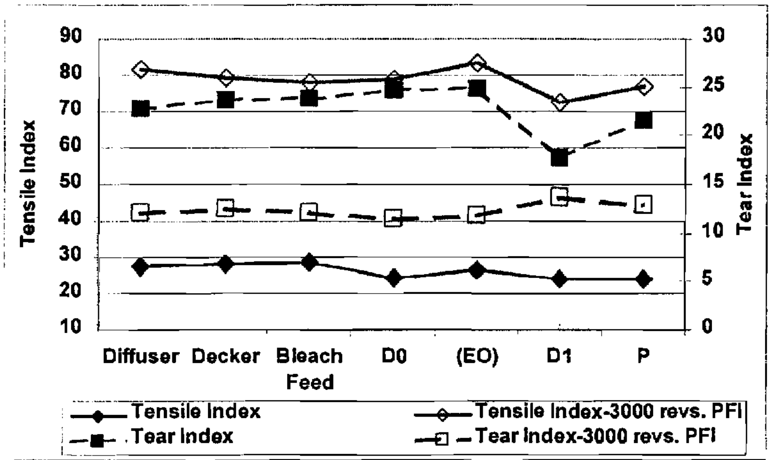

Figure 8. Tensile and Tear Index for Mill B

CONCLUSIONS

Previous work has shown that in the high consistency stages of pumping and bleaching fibers are curled and microcompressed, resulting in significant changes in sheet properties. In addition localized regions are damaged leaving them susceptible in these regions to chemical degradation. This work was carried out to determine the extent to which similar phenomena are observed in modern bleach plants.

A mill with a medium-consistency OD(EOP)DnD sequence showed a measurable loss in strength across the bleach plant, particularly after the D_1 stage. A medium-consistency D(EO)DP sequence did not show any appreciable strength loss. For both mills, the loss in measured viscosity was considerably greater than any strength loss.

Mill processing equipment designed to minimize fiber damage could provide a significant improvement in mill fiber quality.

ACKNOWLEDGMENTS

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APPENDIX

Table A.1 Fiber and Sheet Properties for Mill A

Stage		Blowline	Pressure Diffuser	O_2 Hi-D	D_0	(EOP)	D_1	D_2
Kappa No.		21.7	10.6	10.7		1.3		
Viscosity		31.7	23.3	23.4	21.9	18.4	11.4	13.3
FQA Fiber Properties								
% Fines, length weighted		1.33	1.28	1.61	1.37	2.20	1.56	1.91
Length, mm length weighted		2.88	2.73	2.60	2.61	2.49	2.61	2.60
Curl, length weighted		0.178	0.269	0.242	0.262	0.235	0.233	0.201
Kink Index		1.12	2.00	2.00	2.11	2.00	2.12	1.89
Basis Weight	g/m^2	63.96	67.14	67.63	68.31		66.82	66.11
Caliper	mm	142.2	141.4	134.5	143.0		137.6	135.7
Density	g/cm^3	0.450	0.475	0.503	0.478		0.487	0.494
Dry Zero-span tensile	Nm/g	144.3	129.3	126.2	128.4		118.5	117.6
Wet Zero-span tensile	Nm/g	127.7	114.6	108.5	106.6		90.0	89.7
Tensile Index	Nm/g	34.98	28.30	26.08	23.70		26.41	26.33
Stretch	%	1.58	2.06	2.05	2.12		2.61	2.46
Specific Modulus	Nm/g	5245	4182	3766	3459		3709	3660
TEA Index	mJ/g	333	447	416	362		564	494
Tear Index	$mN.m^2/g$	23.99	22.34	23.54	22.21		22.95	23.64
Scattering Coefficient	m^2/kg	21.8	21.2	20.6	24.0		23.8	23.1
Absorption Coefficient	m^2/kg	5.14	3.16	3.21	0.410		0.079	0.080

Table A.2 Fiber and Sheet Properties for Mill A after 3000 PFI MILLRevolutions

Stage		Blowline	Pressure Diffuser	O_2 Hi-D	D_0	(EOP)	D_1	D_2
WRV, g H_2O/g		2.47	2.48	2.37	2.39	2.45	2.35	2.39
FQA Fiber Properties								
% Fines, length weighted		1.10	1.10	1.60	1.35	1.02	1.25	1.35
Length, mm length weighted		3.01	2.99	2.73	2.79	2.95	2.67	2.74
Curl, length weighted		0.056	0.070	0.076	0.078	0.075	0.074	0.068
Kink Index, length-weighted		0.60	0.75	0.96	0.96	0.89	0.94	0.87
CSF		424	397	400	397	383	321	343
Basis Weight	g/m^2	67.64	70.09	65.19	65.63	66.38	67.62	66.11
Caliper	mm	117.6	123.0	111.5	109.7	109.8	108.0	111.0
Density	g/cm^3	0.575	0.576	0.585	0.598	0.604	0.627	0.596
Dry Zero-span Tensile	Nm/g	156.1	154.6	152.9	164.8	152.6	146.0	146.0
Wet Zero-span Tensile	Nm/g	137.6	127.4	125.4	126.1	121.6	104.7	105.7
Tensile Index	Nm/g	80.85	80.94	78.19	79.52	83.74	79.55	73.82
Specific Modulus	Nm/g	7182	7078	6623	6325		6593	6289
Strain	%	3.30	3.50	3.47	3.11	3.49	3.38	3.97
TEA Index	mJ/g	1676	1881	1777	1973	1917	1845	1872
Tear Index	$mN.m^2/g$	12.29	12.16	11.75	12.27	10.81	10.56	10.60
Scattering Coefficient	m^2/kg	13.1	13.2	13.1	14.2	13.9	13.4	14.4
Absorption Coefficient	m^2/kg	5.36	3.15	2.89	0.341	0.191	0.107	0.100

Table A.3 Fiber and Sheet Properties for Mill B

Stage		Diffuser	Decker	Bleach Feed	D_0	(EO)	D	P
Kappa No.				21.7	11.2	2.67		
Viscosity		31	25.7	31	19.5	24.8	25	21
FQA Fiber Properties								
% Fines, length weighted		1.32	1.21	1.79	1.69	1.69	1.96	1.52
Length, mm length weighted		2.74	2.89	2.74	2.47	2.45	2.43	2.65
Curl, length weighted		0.231	0.140	0.183	0.300	0.306	0.312	0.277
Kink Index, length-weighted		1.67	1.27	1.68	2.31	2.30	2.37	2.21
Basis Weight	g/m^2	66.63	66.80	68.20	66.21	65.07	66.22	64.53
Caliper	mm	148.1	148.5	143.9	141.0	128.2	132.3	130.7
Density	g/cm^3	0.450	0.450	0.474	0.470	0.508	0.501	0.494
Dry Zero-span Tensile	Nm/g	144.3	141.1	140.5	125.4	135.0	132.9	126.4
Wet Zero-span Tensile	Nm/g	122.1	121.9	120.9	110.5	112.3	108.8	105.4
Tensile Index	Nm/g	27.54	28.19	28.53	24.43	26.53	24.28	24.22
Stretch	%	1.52	1.63	1.87	1.83	2.04	2.02	2.41
TEA Index	mJ/g	264	313	398	337	426	380	506
Specific Modulus	Nm/g	4159	4049	4214	3338	3873	3183	3443
Tear Index	$mN.m^2/g$	22.80	23.63	23.82	24.64	24.85	17.73	21.64
Scattering Coefficient	m^2/kg	21.2	21.8	19.9	22.4	22.1	23.9	24.7
Absorption Coefficient	m^2/kg	8.48	9.33	9.42	5.18	0.929	0.103	0.056

Table A.4 Fiber and Sheet Properties for Mill B after 3000 PFI MILLRevolutions

Stage		Diffuser	Decker	Bleach Feed	D_0	(EO)	D	P
WRV, g H_2O/g		2.59	2.98	2.78	2.47	2.18	2.32	2.42
FQA Fiber Properties								
% Fines, length weighted		0.97	0.93	1.07	1.03	0.93	0.87	0.93
Length, mm length weighted		3.05	3.01	2.96	2.89	3.01	2.87	3.03
Curl, length weighted		0.059	0.069	0.063	0.073	0.073	0.138	0.072
Kink Index, length-weighted		0.58	0.74	0.73	0.88	0.77	1.42	0.85
CSF		489	484	500	500	387	564	418
Basis Weight	g/m^2	66.54	68.30	67.11	66.16	66.53	66.33	65.81
Caliper	mm	104.0	104.6	105.8	104.2	101.7	104.6	111.7
Density	g/cm^3	0.640	0.653	0.634	0.636	0.656	0.635	0.589
Dry Zero-span Tensile	Nm/g	170.5	164.9	165.6	159.6	170.4	159.0	163.3
Wet Zero-span Tensile	Nm/g	141.3	136.2	133.3	133.1	133.3	121.6	130.8
Tensile Index	Nm/g	81.61	79.33	77.85	78.94	83.40	72.47	76.74
Stretch	%	3.24	3.11	3.37	3.73	3.63	3.89	3.99
TEA Index	mJ/g	1661	1621	1762	1757	1997	1924	1952
Specific Modulus	Nm/g	7039	7265	6656	6924	7004	6261	5905
Tear Index	$mN.m^2/g$	12.16	12.53	12.20	11.46	11.88	13.71	12.93
Scattering Coefficient	m^2/kg	11.2	11.7	11.8	12.8	12.6	13.5	15.0
Absorption Coefficient	m^2/kg	7.70	8.20	8.44	4.68	0.874	0.116	0.116