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The Effects of Recycling on a Never-dried Softwood Kraft Pulp Beaten to Different Initial Freeness Levels

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by

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Acknowledgments

A special thanks to Dr. David Peterson who served as my faculty advisor throughout this entire project. For his patience with me when I forgot about meeting times or was unable to turn in a weekly progress report.

A special thanks also goes to Tim Liverance who served as my partner on this project and provided me with the material for the mechanical pulp.

Abstract

The objective of this study is to compare two different pulps, a softwood kraft pulp with a groundwood pulp, to see if there is any difference in the behavior of their sheet properties as they are recycled. Neither pulp was dried before the experiment began. The pulps were each refined to three different freeness levels to determine the effect of initial freeness on recycled sheet properties. Tests for tear, tensile, zero-span tensile, opacity, brightness, scattering coefficient, absorption coefficient, and porosity were performed on the sheets in order to determine the effects of recycling on those sheet properties. A Kajaani fiber length analysis was performed after each run to determine if the fibers were being cut during recycling.

For the chemical pulp, the tensile strength was found to decrease with recycling. Tear increased and the fell as it was increased. Brightness, opacity, scattering coefficient, absorption coefficient, were relatively unaffected by recycling. The porosity increased as recycling increased.

The mechanical pulp behaved the same as the chemical pulp for tensile strength and porosity. The tear strength was unaffected by recycling, but the data for the tear strength may have been bad. The opacity and brightness fell with recycling. The scattering coefficient and absorption coefficient were unaffected by recycling.

Different pulping methods yield pulps that behave slightly different when they are recycled. It may be expedient to compare other pulping methods with the ones in this report following the same experimental design.

Introduction

Secondary fibers are very important to the papermaking industry for many reasons. Consumers are demanding more use of secondary fibers in order to cut down the use of trees to obtain virgin fibers. The government is also mandating that a percentage of secondary fiber be used in the paper that they utilize. A third reason is that they offer a good source of fibers for papermakers that do not have the equipment to make their own virgin pulp, or the funds to purchase that pulp from other sources.

Many studies have been done over the years to determine the effects of recycling on fibers. This is usually studied by observing the change in sheet properties as the number of times the fiber is used increases. There are almost as many different experimental designs as there are studies on the effects of recycling. This leads to differing opinions on how certain fiber sources behave as they are used again and again.

The reason for this study is to compare two different pulps, a softwood kraft pulp with a groundwood pulp, to see if there is any difference in their behavior of sheet properties as the number of times the fibers are reused increases. It is also important to note that both pulps had never been dried before the experiment, therefore, the experiment will begin with virgin fiber sources and follow them through several recycles. It is also important to note that the pulps were each refined to three different freeness levels to determine if initial freeness levels have any affect on recycled sheet properties. Once the required hand sheets were made, as will be described in the experimental portion of the report, tests for tear, tensile, zero-span tensile, opacity, brightness, scattering coefficient, absorption coefficient, and porosity were performed on the sheets in order to determine the effects of recycling on those sheet properties.

Theoretical and Background Discussion

Robert Mckee (1) refined a virgin pulp in a valley beater to a freeness of 325 ml CSF. He then made handsheets on a British Handsheet Mold. The sheets were tested for density, zero-span tensile, burst, fold, tensile and tear. The sheets were then reslushed and beaten back to 325 ml CSF. He found that density, zero-span tensile, burst, fold, tensile all decreased and tear increased as the number of recycles increased. He also beat a pulp to initial freeness levels of 600, 450, and 300 ml CSF. After one recycle, the pulp was beaten back to these same freeness levels. He found that tear, apparent density, porosity, bursting strength, and brightness fell with freeness, and tensile, TEA, Z-direction tensile and opacity rose with freeness.

Richard Horn (2) used simulated papermaking techniques with virgin never-dried, unbleached, northern, softwood, kraft pulp. He found that the tear strength increased through second recycle, it then decreased through the remaining recycle, but remained at a value above that of the original cycle. Tensile and burst strength decreased rapidly through the first few recycles, but then leveled of to a more constant rate of decline.

Childar and Howarth (3) beat a virgin pulp to an initial freeness of 37° SR and then made handsheets at approximately 65 g/m^2. The sheets were tested and then repulped back to 37° SR. They found that there was an acceleration deterioration of the tensile strength ratio and discovered an appearance of a minimum tear ratio. They also found that opacity did not vary with an increase in recycling. Zero-span tensile strength indicated a paper strength loss due to a loss in bonding ability.

Bovin, Hartler, and Teder (4) disintegrated six different pulps to two freeness levels. They closed the water system so that the fines were retained. The pulps were dried in a drying chamber at 60°C. The pulps were disintegrated dried and beaten 6 times, handsheets were made in the first third and sixth recycle before the pulp was dried. The chemical pulps showed an increase in tear strength, scattering coefficient and absorption coefficient increased, while breaking length, density, and air resistance decreased. For the mechanical pulps, all properties except for scattering coefficient remained the same. The scattering coefficient rose from 55 cm^2/g to 90 cm^2/g yielding a brightness decrease from 69% to 61%. They attributed the reaction of the mechanical pulp to recycling to the fact that lignin rich pulps are affected less by drying.

Howard and Bichard (5) disintegrated handsheets after soaking them overnight in deionized water for 25 minutes in a standard disintegrator. Five recycles were carried out by this method. They found that for the mechanical pulps, fiber strength did not change considerably. The tensile, burst, Scott bond, sheet density, and air resistance increased. They also found that scattering coefficient rose and tear strength remained fairly constant. They found that for the chemical pulps, the breaking length, burst, Scott bond, air resistance, and sheet density fell while the tear strength and scattering coefficient rose. They attributed the strength loss to the loss in bonding ability and stated that the loss of fines affected the magnitude but not the trends of recycling.

Howard (6) agrees that recycling causes a major reduction in breaking length, burst and fold with a lesser reduction in apparent density and stretch. He also agrees that recycling caused an increase in tear strength, stiffness, scattering coefficient, and air permeability. He also notes that the biggest change in properties occurs with the first recycle.

Bobalek and Chaturvedi (7) lightly refined several pulp species. Handsheets were made and dispersed in water and then more handsheets were made. This process was repeated two more times. Freeness and fiber length changed little from cycle zero to cycle three indicating little refining action during dispersment. They found that Tappi opacity, scattering coefficient, and Parker Print surf did not change much. Tensile strength, Z-direction tensile strength and Scott bond all decreased with increased recycling while Zero-span tensile strength did not change much with recycling.

As the literature indicates, there are as many experimental designs for studying the effects of recycling as there are studies on the effects of recycling. In order to get a better understanding of what happens to a fiber and paper made from that fiber as it is used again and again, one basic experimental design must be agreed upon and then only slight variations made of that design in order to study all the different mechanisms that cause a fiber to change in properties as it is reused.

Experimental

A never-dried, bleached, softwood, kraft pulp was beaten to three different initial freeness levels using the laboratory Valley Beater. The freeness levels were 615 ml CSF, 430 ml CSF, and 200 ml CSF. The mechanical pulp had freenesses of 140, 90, and 60 ml CSF. Each freeness level, for the chemical pulp, started with about 300 grams of fiber on an oven dry basis. A large number of handsheets were made at each freeness level. Seven sheets were set aside for testing. The sheets weighed 2.5 g plus or minus four percent, or between 2.42 and 2.6 grams. Therefore, the basis weight of the sheets was 60 g/m^2. The sheets that were not chosen for testing were soaked in water overnight. The sheets were then broken up as much as possible by hand, then they were placed into the Valley Beater. The beater was then run for approximately five minutes under no load in order to re-slush the handsheets the rest of the way. Once the pulp was re-slushed, more handsheets were made, and seven set aside for testing. This was done at each of the three freeness levels.. The process was repeated until five sets of handsheets for each freeness level were obtained. The first set of handsheets at each freeness level represented paper that was made from virgin fiber. The following four sets of handsheets represented paper that had been recycled four times, with the second set of handsheets for each freeness level representing the first recycle level the third set the second recycle level and so on to the fourth recycle level. Tests for opacity, brightness, scattering and absorption coefficients, porosity, tensile strength, tear strength, and zero-span tensile strength were performed on the handsheets. The opacity, brightness, scattering coefficient, and absorption coefficient measurements were taken on the Brightmeter Micro S-4M. The tensile measurement was taken on an Inston machine, and the values converted to Tensile index. The tear measurements were taken on an Elmendorf Tearing Tester and the values converted to tear index. Porosity was measure using the Gurley-Hill S-P-S Tester, and the zero-span tensile readings were taken on a Pulmac machine. The fines to fiber ratio was determined for the fourth and fifth cycles. The fines were defined as fiber that passed through a 200 mesh screen. The fiber was defined as what was collected on top of the 200 mesh screen. A Kajaani fiber length analysis was run on several of the pulp samples after they were repulped to determine if there was a overall shortening in the average fiber length as the number of recycles was increased.

Results

Table 1:

Sheet Properties of Recycled Never-dried Softwood Kraft Pulp															
	Weight	SD	Brightness	SD	Opacity	Scattering	Absorption	Tensile	SD	Tear Index	SD	Zero-span	SD	Porosity	SD
						Coefficient	Coefficient	Index				Tensile			
	(g)		(%)		(%)	(m^2/kg)	(m^2/kg)	(Nm^2/g)		(mNm^2/g)		(psi)		(sec/100ml)	
a-0	2.48	0.05	61.69	1.95	75.39	26.25	2.44	72.13	6.9	9.77	0.3	34.6	3.4	40.3	15
a-1	2.51	0.08	71.18	1.93	74.37	30.57	0.87	40.37	3.4	16.1	1.7	32.44	1.8	5.02	0.2
a-2	2.49	0.06	67.94	2.66	73.77	28.38	1.25	37.43	3.4	15.6	1.4	30.48	2.4	3.64	0.3
a-3	2.46	0.04	62.00	2.56	75.02	29.67	1.30	32.23	1.9	21.9	1.0	30.48	2.6	2.74	0.3
a-4	2.55	0.03	67.91	1.03	73.49	29.76	0.81	26.08	1.3	13.1	0.9	34.04	2.5	0.98	0.1
b-0	2.52	0.06	66.72	1.11	68.61	24.52	0.81	65.5	6.5	11.6	0.3	36.78	1.0	7.3	0.9
b-1	2.55	0.07	70.49	3.18	74.27	30.40	0.89	36.79	2.7	17.4	3.5	32.28	0.7	2.06	0.3
b-2	2.50	0.08	68.72	1.94	71.00	26.62	0.89	28.42	3.2	21	2.1	29.08	2.7	1.4	0.3
b-3	2.50	0.05	62.10	5.45	82.34	34.63	2.61	29.06	2.9	16.4	2.0	31.48	1.2	1.1	0.1
b-4	2.55	0.03	64.95	1.61	77.98	31.56	1.78	31.74	1.1	2.55	1.4	31.52	1.1	2.2	0.4
g-0	2.52	0.06	70.02	1.52	73.27	28.23	1.13	46.73	5.7	14.7	0.7	33.36	1.9	1.18	0.2
g-1	2.52	0.07	73.66	1.80	77.26	33.83	1.03	23.94	2.4	19.8	2.5	30.88	2.9	0.54	0.2
g-2	2.51	0.06	67.05	1.52	82.48	36.50	2.23	17.36	2.9	16.9	2.1	30.56	1.5	-	-
g-3	2.46	0.06	68.95	2.69	73.66	29.38	0.95	14.04	4.1	14.1	0.4	27.6	2.5	-	-
g-4	2.51	0.06	69.60	1.24	71.75	27.77	0.80	16.61	1.9	18.3	0.5	31.12	2.5	-	-
a= Low freeness, b= Medium freeness, g= High freeness															

The data presented in the results will be put into graphical form for both the chemical and the mechanical pulp. The Chemical pulp will be dealt with more thoroughly than the mechanical pulp as it is the focus of this thesis. Comparisons will be made between the results for the chemical and the mechanical pulp.

Table 2:

Sheet Properties of a Never-dried Stone Ground Wood Pulp																
	Weight	SD	Opacity	SD	Brightness	SD	Scattering	Absorption	Tensile	SD	Tear	SD	Zero-span	SD	Porosity	SD
							Coefficient	Coefficient			Index		Tensile			
	(g)		(%)		(%)		(m^2/kg)	(m^2/kg)	(Nm^2/g)		(mNm^2/g)		(psi)		(sec/100ml)	
a-0	2.53	0.07	69.18	0.63	50.53	0.2	46.11	5.20	20.8	3.4	3.96	1.1	20.80	1.36	8.58	1.9
a-1	2.48	0.05	67.07	0.46	48.03	0.8	41.90	5.37	20.4	1.7	3.87	0.6	20.88	0.86	5.28	0.5
a-2	2.51	0.07	66.06	0.63	46.40	0.9	55.06	7.88	18.0	3.0	4.69	0.9	24.28	1.35	5.06	0.2
a-3	2.48	0.06	65.79	0.41	44.67	1.0	52.08	7.77	18.4	1.3	5.1	0.3	24.22	1.19	4.22	0.5
a-4	2.46	0.02	62.55	0.55	43.04	1.8	39.87	6.16	15.7	2.1	3.9	0.3	21.80	0.55	4.52	0.8
b-0	2.52	0.06	66.83	0.7	48.20	0.3	62.09	7.84	33.7	1.4	3.63	1.0	22.72	1.06	24.44	2.1
b-1	2.47	0.07	66.36	0.9	46.57	0.5	51.72	7.31	24.2	2.4	3.35	0.3	21.92	0.81	9.22	1.9
b-2	2.48	0.03	65.65	0.58	44.55	0.9	55.33	8.23	20.3	2.7	3.69	0.5	22.36	1.45	7.92	1.0
b-3	2.52	0.04	65.39	0.58	43.17	0.6	55.77	8.71	18.6	1.7	5.02	0.6	23.68	2.27	6.2	0.5
b-4	2.49	0.06	64.99	0.44	42.98	0.8	55.60	9.05	13.8	2.4	3.85	0.3	20.88	0.94	4.42	0.7
g-0	2.5	0.09	65.11	1.06	47.11	2.10	40.36	5.15	28.5	6.3	4.01	0.6	21.80	0.47	21.24	2.4
g-1	2.47	0.06	64.15	0.58	42.65	1	55.63	6.03	25.6	3.0	4.41	0.6	21.96	0.65	12.02	2.6
g-2	2.48	0.03	64.37	0.75	43.14	0.3	53.32	8.71	21.4	2.3	3.34	0.3	21.44	1.25	7.54	0.9
g-3	2.49	0.05	63.19	0.34	41.53	0.50	59.10	10.86	20.6	0.6	6.3	1.8	21.84	1.37	6.62	0.7
g-4	2.46	0.02	62.55	0.55	41.23	0.9	56.75	9.98	17.0	0.8	3.72	0.0	22.80	1.01	6.22	0.5

a= High freeness b= Medium freeness
g= Low freeness

Table 3:

Kajaani Fiber Length Analysis for a Never-dried Softwood Kraft Pulp						
	a		b		g	
Cycle Number	Weighted Average	Arithmetic Average	Weighted Average	Arithmetic Average	Weighted Average	Arithmetic Average
0	1.18	0.51	1.59	0.81	1.41	0.61
1	1.1	0.53	1.32	0.62	1.31	0.61
3	1.28	0.62	1.32	0.64	1.29	0.65
4	---	---	0.99	0.47	1.23	0.62

Discussion of Results

Chemical Pulp:

The brightness for the chemical pulp (Figure 1) rose for all three freeness levels then fell for the next two cycles, except for the high freeness which fell for the second cycle then rose slightly for the third cycle. The brightness for each of the freenesses recovered slightly for the final cycle. The biggest difference in brightness between the three freeness levels occurred in the first set of handsheets, or cycle 0. This still only represented a difference in brightness of under 10%. The initial brightness of the fiber is dependent on the initial freeness level. The higher the freeness, the higher the initial brightness. This may also hold for the rest of the cycles if the standard deviations presented in table 1 are considered. The high freeness pulp maintained a higher brightness throughout the recycling process except for the 2nd cycle where it fell slightly below the other two freeness levels. However, by considering the standard deviation the value for the high freeness level could be higher in this cycle as well.

The opacity values for the chemical pulp (Figure 2) do not appear to vary much with recycling. There is only a slight change in opacity and there was no appearance of any specific trends for opacity as the number of recycles was increased. The initial freeness level also did not appear to have any significant effect because the opacity for the low freeness was initially between the values for the high and medium freeness. There were also no trends that appeared for opacity with respect to initial freeness levels as the cycles increased. The trend lines for each of the freeness proceeded to cross back and forth over each other as the number of recycles was increased yielding no specific trends.

Figure 1:

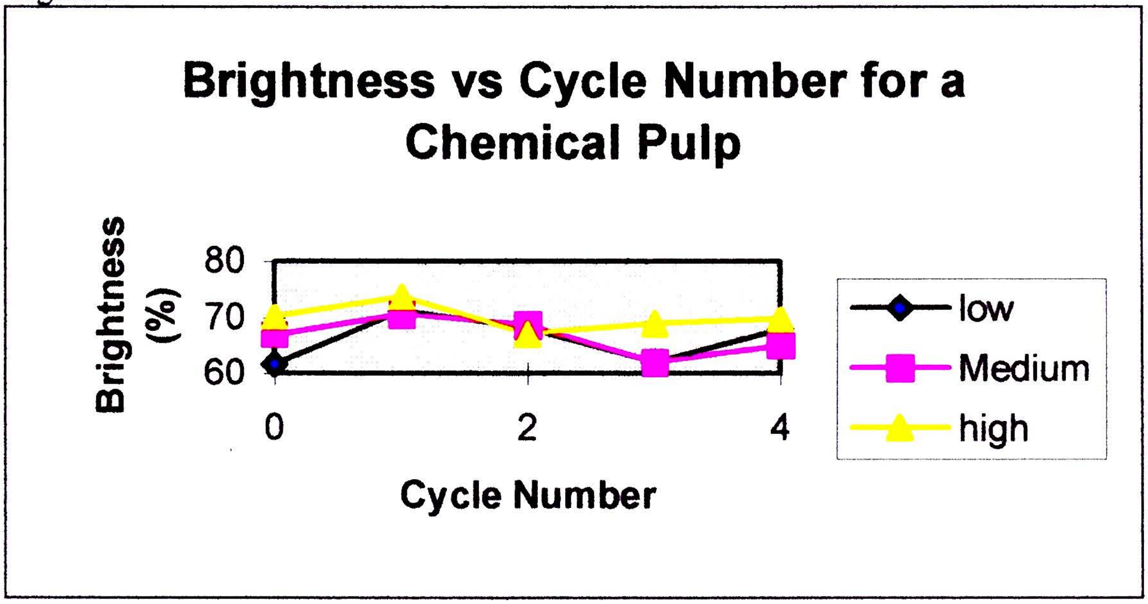


Figure 2:

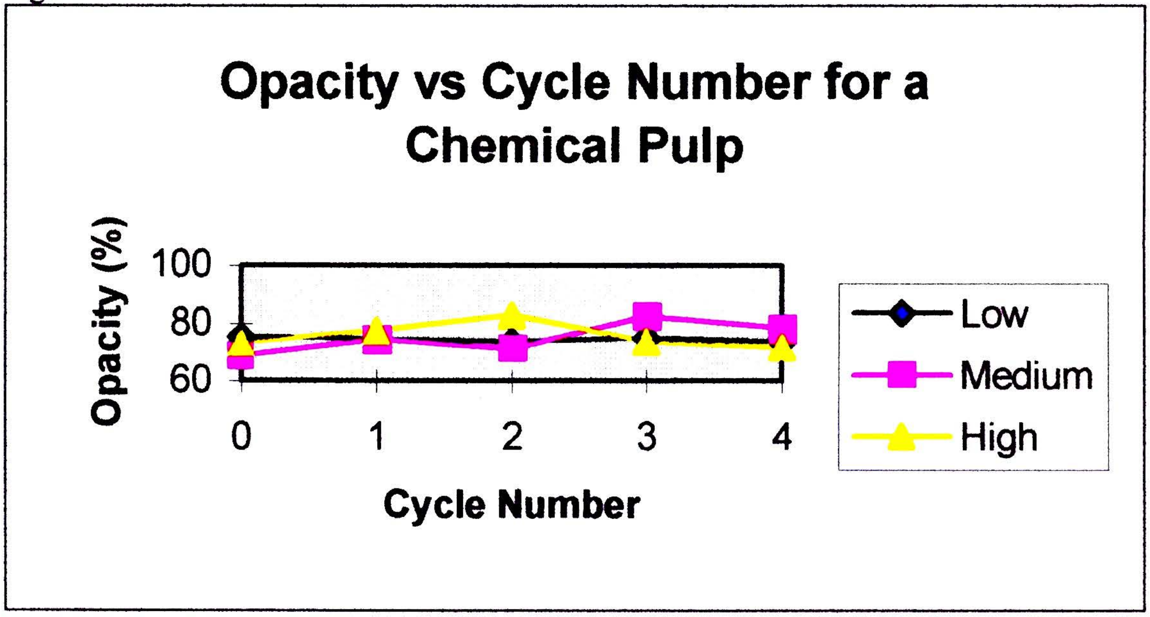
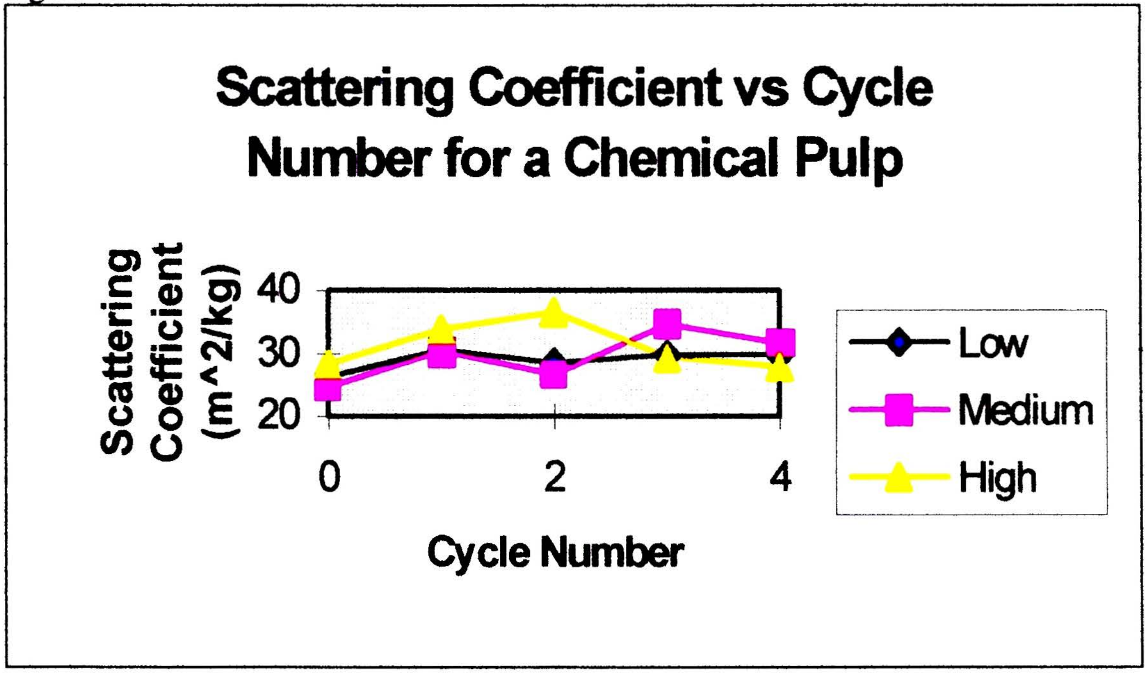


Figure 3 shows the change in scattering coefficient as the cycle number was increased. The scattering coefficient appears to have increased with increased recycling. The increase, however, appears to be only slight. Because scattering coefficient is related

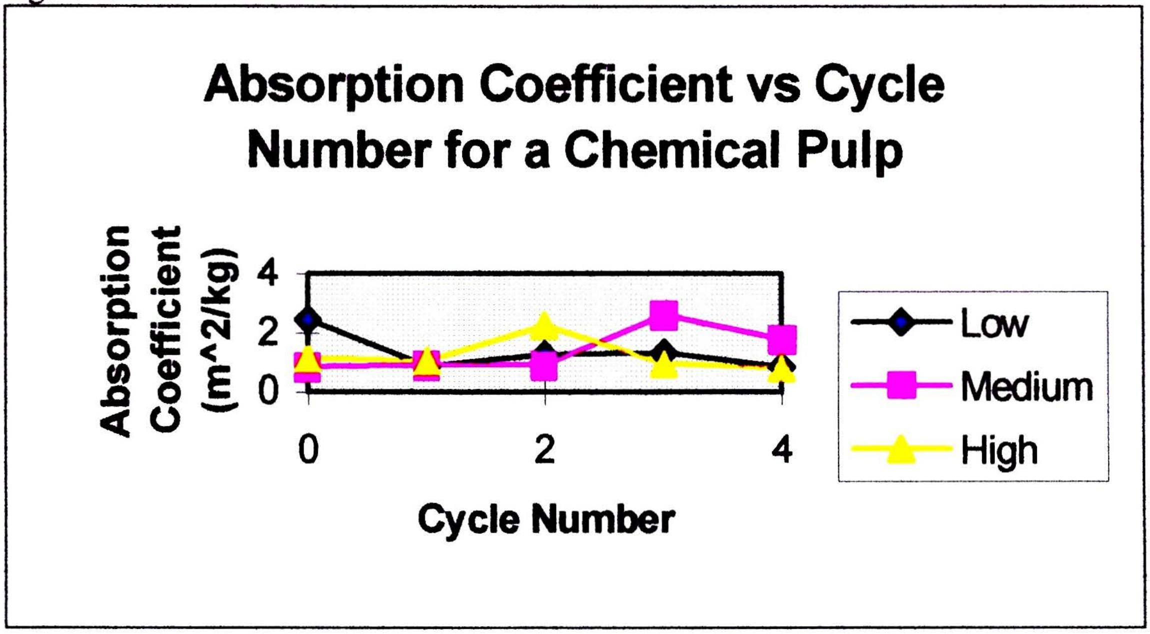
Figure 3:



to opacity, it should behave similarly to opacity. Figure 3 indicates that the initial freeness level did not have much effect on the scattering coefficient much like opacity, and that recycling did not have much affect on scattering coefficient, also like the opacity. The slight rise can be attributed to the fact that the scattering of light depends on the number of air to fiber interfaces. Light gets scattered as it passes through one of these interfaces. As the fibers are recycled, a more open sheet is formed, creating more air to fiber interfaces, and less fiber to fiber interfaces, which are not conducive to light scattering.

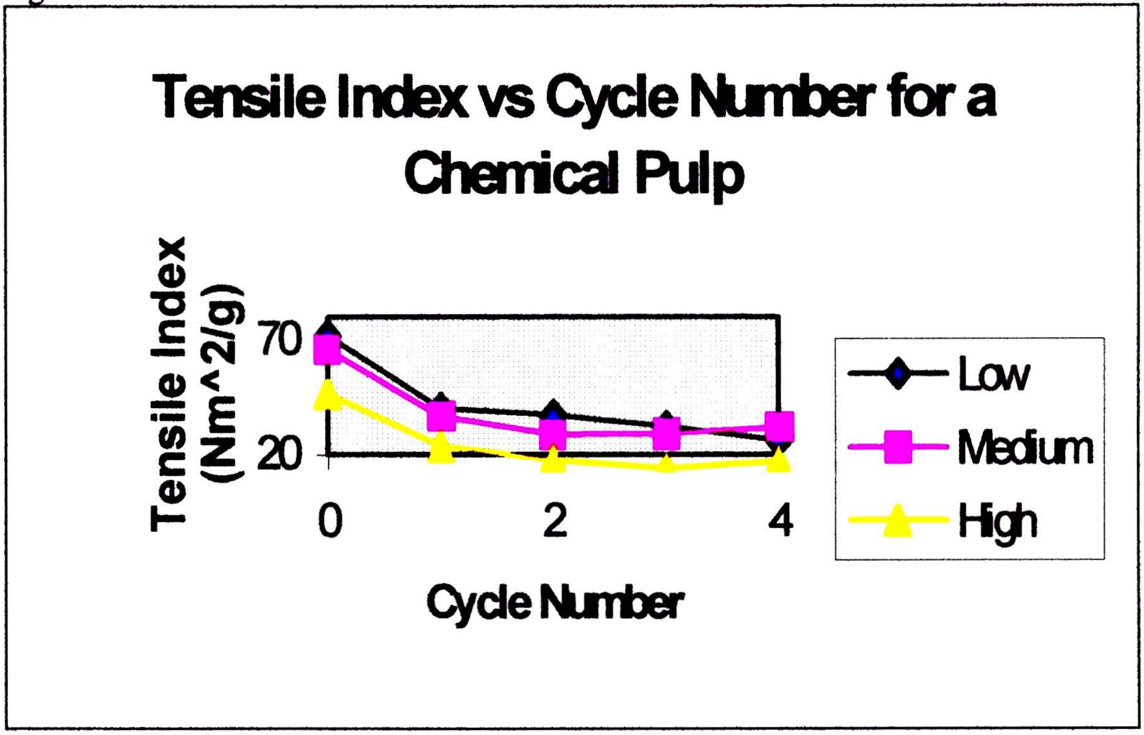
The absorption coefficient is essentially the opposite of the scattering coefficient in terms of what it describes. Instead of describing the amount of light scattered by the sheet, it describes the amount of light that is absorbed by the sheet. Absorption coefficient is also related to the opacity of a sheet. Figure four shows that the absorption coefficient did not change much with recycling. It also did not appear to be affected significantly by the initial freeness level of the pulp.

Figure 4:



The tensile index fell for all three freeness levels for the chemical pulp (figure5). The greatest change in the tensile index occurred in the first cycle. This can be attributed to the fact that the most fines created by refining the pulps to their initial freeness levels were lost between cycle 0 and the first cycle. These fines, which normally improve the tensile strength of paper by increasing the bonding area available in the sheet, when lost lead to a large decrease in the tensile strength of paper. The fines to fiber ratios remained about the same for the 3rd and 4th cycle indicating that the refining method used was generating a similar amount of fines in each recycling run. Therefore the loss in tensile index from the 1st to the 4th cycle can be attributed to the loss in bonding potential

Figure 5:



caused by drying. As a fiber is dried over and over again it becomes more and more crystalline, thus reducing its ability to bond with other fibers, causing a reduction in the tensile strength of paper made from those fibers. The effect of initial freeness level was that the low freeness had a higher tensile strength than the medium freeness level over all the cycles and the high freeness level had a lower strength yet. The fiber must then maintain some of the bonding ability created by refining throughout its life when no more significant work is done on the fiber by refining it before reusing it. Otherwise, the tensile strength would have fallen to a similar value as the number of recycles was increased.

The Tear index (Figure 6) rose from cycle 0 to cycle 2. It then fell in the next two cycle for the medium freeness pulp. For the low freeness pulp it basically rose through the 4th cycle. For the high freeness it rose through the 1st cycle, fell only slightly for the next two cycles, and recovered significantly in the final cycle. The data that was collected indicates that recycling has a positive effect on the tear index for a chemical pulp. Horn (2) in his article attributed this positive effect of recycling on the tearing strength of paper to the fact that as hornification caused by drying a fiber occurs, the fiber becomes less likely to rupture and more likely to pull out of a sheet due to a reduction in the bonding potential. He gets this theory from a theory on tearing strength proposed by Van den Akker (8). This makes sense because tearing strength, which is less dependent on bonding ability than tensile strength, may in fact be able to improve as the bonding ability is reduced. The effect of initial freeness level on the tear index is most significant in cycle 0. It basically determined at what value tear index would be initially. The higher the freeness the higher the initial freeness. This may be due to the fact that the tear value may be linked, in some cases, to the average fiber length. A low freeness would have a lower overall average fiber length and therefore a lower tear strength.

The three different freeness levels behaved the same in terms of the zero-span tensile (Figure 7). Therefore, initial freeness level does not have much effect on the zero-span tensile strength. They all fell from cycle 0 to cycle 2 then rose slightly through cycle four. However, the total change in zero-span tensile strength is only slight through all of the cycles. The final cycle has a value about that, or only slightly less than that, of the initial value. This indicates that recycling does not have a significant effect on the strength of the individual fiber. And since zero-span tensile strength is ultimately a test of the individual fiber strength, it would therefore, not change much. Any significant variance in the zero-span tensile strength can, more likely than not, be attributed to testing error.

Figure 6:

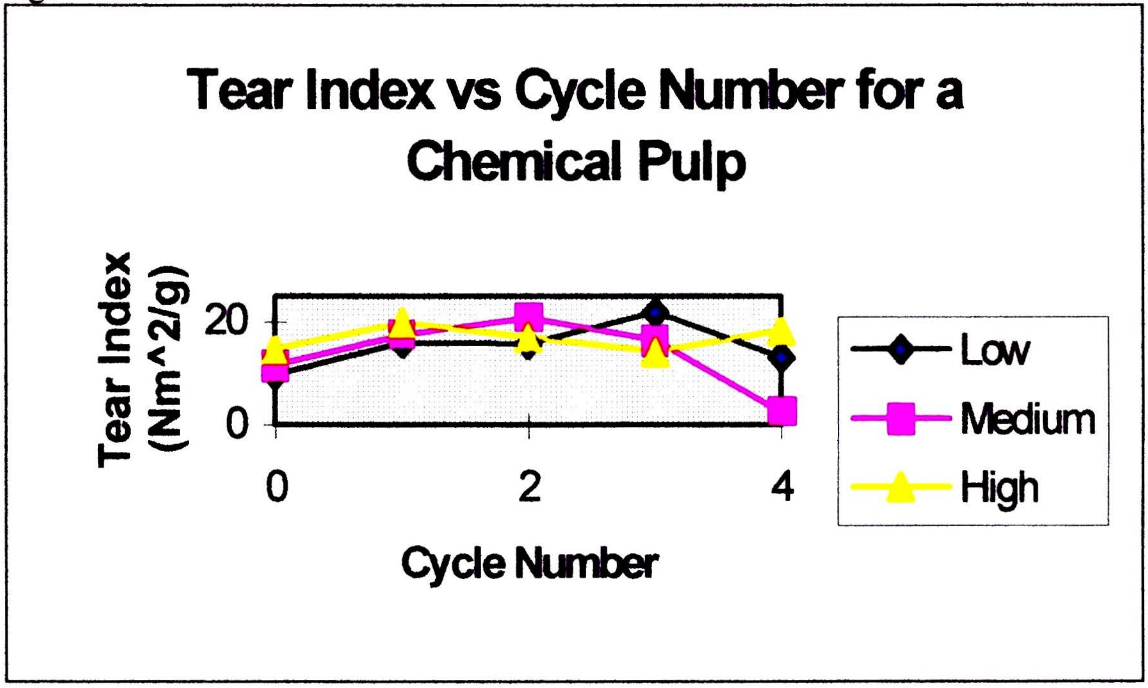
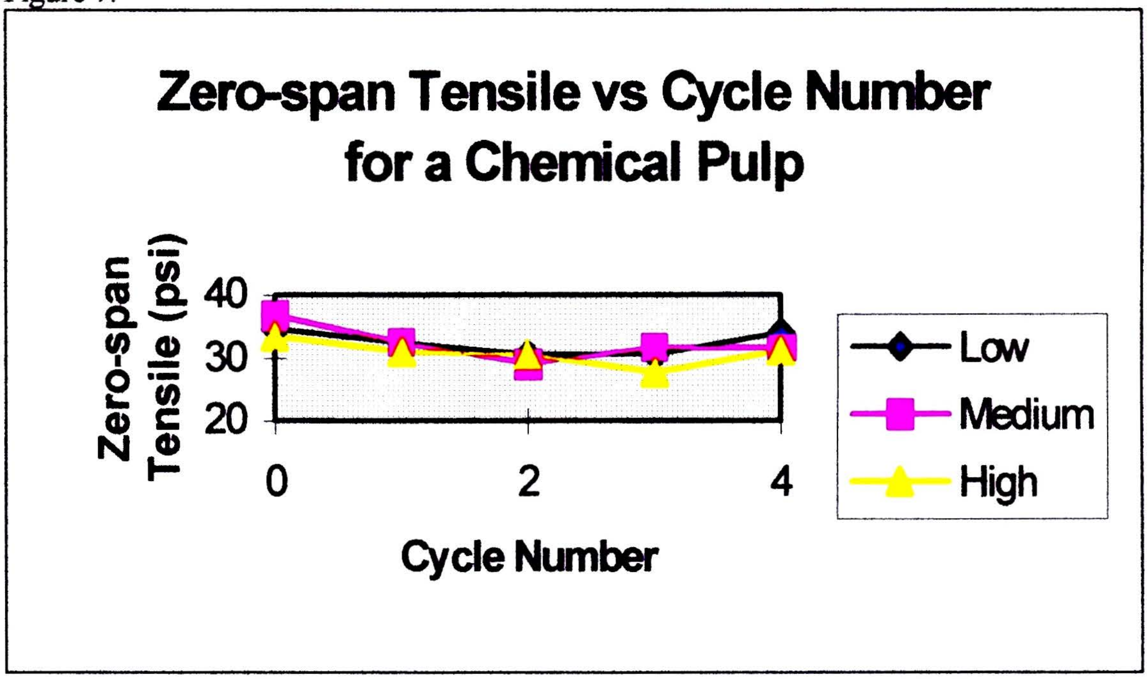
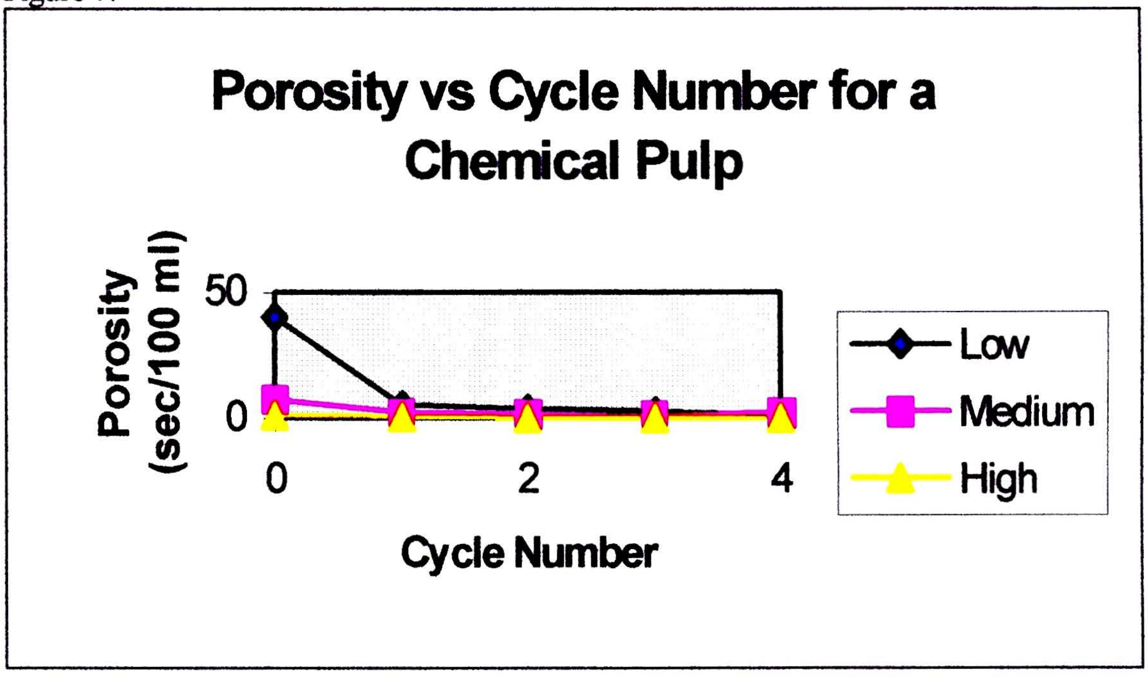


Figure 7:



The average porosity of the sheets (Figure 7) increased as the number of cycles was increased for each of the three freeness levels. The greatest increase in porosity was again seen between cycle 0 and cycle 1, with the most significant change occurring in the low freeness level. This again can be attributed to the fact that fines created in the beating stage are almost completely washed out in the first recycle. The low freeness would have the greatest amount of fines initially and therefore would incur the greatest change as those fines were removed. As the fines are removed, the sheet becomes more open or more porous. As this occurs, the time required for a constant volume of air to pass through the sheet goes down. The effect of initial freeness level is seen in the magnitude of change from one cycle to the next. The low freeness level changes the greatest, followed by the medium, then the high freeness.

Figure 7:

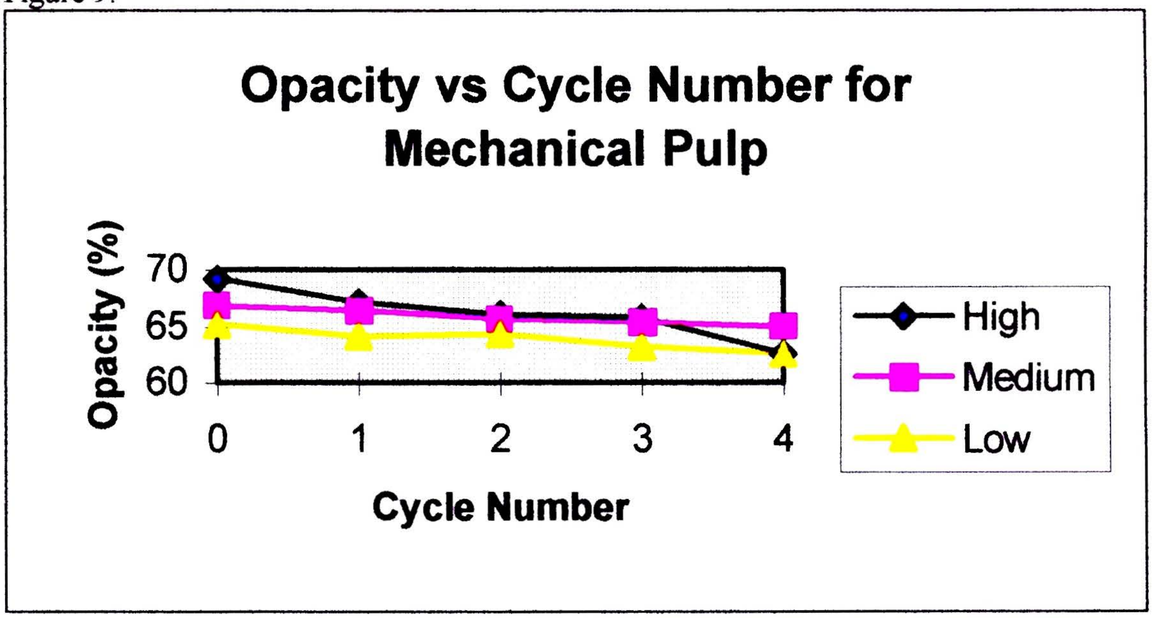


The Kajaani Fiber length analysis showed that there was some shortening of the fiber as the number of recycles was increased (Table 3). This may be due to two mechanisms. It may be caused by the repulping in the valley beater, even though the beater was run under no load conditions for each recycle after the initial freeness levels were reached. It may also be caused by the fiber becoming more and more brittle as it is subjected to drying. It also showed some gain in fiber length for some of the freeness levels as the cycle number increased. This phenomenon is most likely cause by a error in sampling. Even though care was taken to get a representative sample of fibers for measurement, it is difficult to determine whether or not these fibers represent the whole or not. At least until the fibers have been analyzed. This may have been avoided if a larger number of fibers were analyzed for each run.

Mechanical Pulp:

The remainder of this report will be for the purpose of making a comparison between a chemical and mechanical pulp. It will not be discussed in detail because the mechanical pulp will be the focus of another thesis by Tim Liverance.

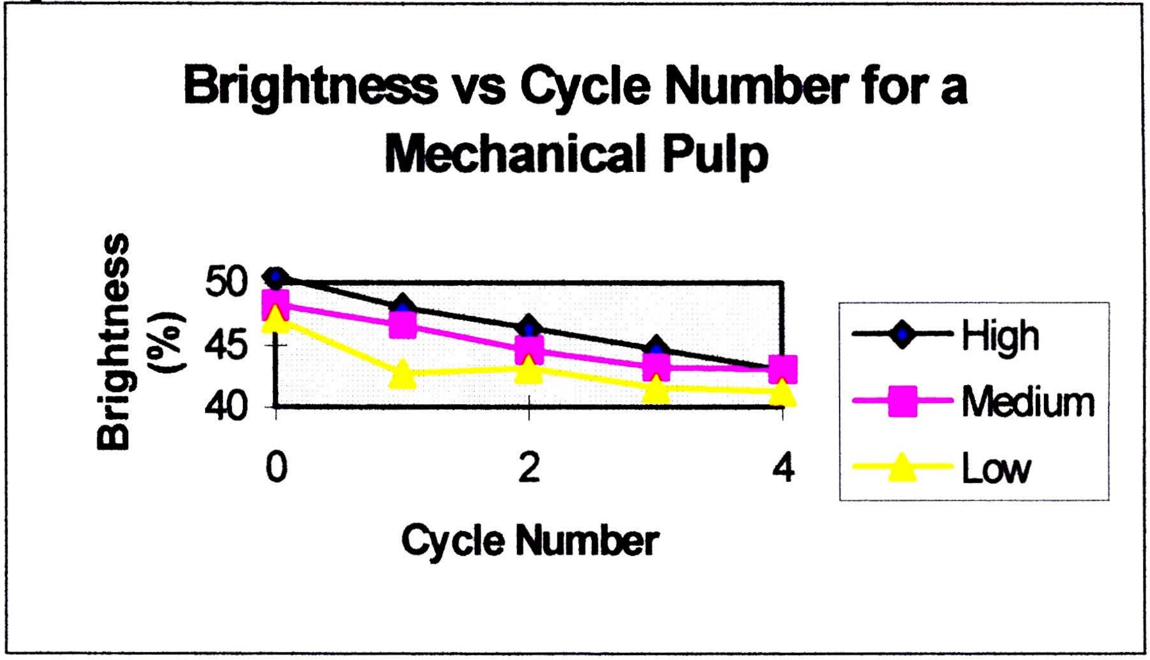
Figure 9:



The opacity for the mechanical pulp (Figure 9) appears to fall as the number of recycles was increased, where as for the chemical pulp there did not appear to be a definite relationship between cycle number and opacity. There is, however, only a change of less than 10%.

The brightness for the mechanical pulp (Figure 10) also appears to fall as the number of recycles is increased. The change in brightness also represents a change of less than 10% for each of the freeness levels. It does, however, appear to drop off and also gives an indication that the brightness was dependent on the initial freeness level. The brightness of the high freeness level remained above that of the Medium freeness level which remained above that of the low freeness level for each of the cycles in the recycling process.

Figure 10:



Like the chemical pulp the scattering coefficient for the mechanical pulp (Figure 11) did not show much of a relationship between the scattering coefficient and the number of recycles. The freeness level did not appear to have any significant effect on the scattering coefficient. This is similar to the results found for the chemical pulp.

Figure 11:

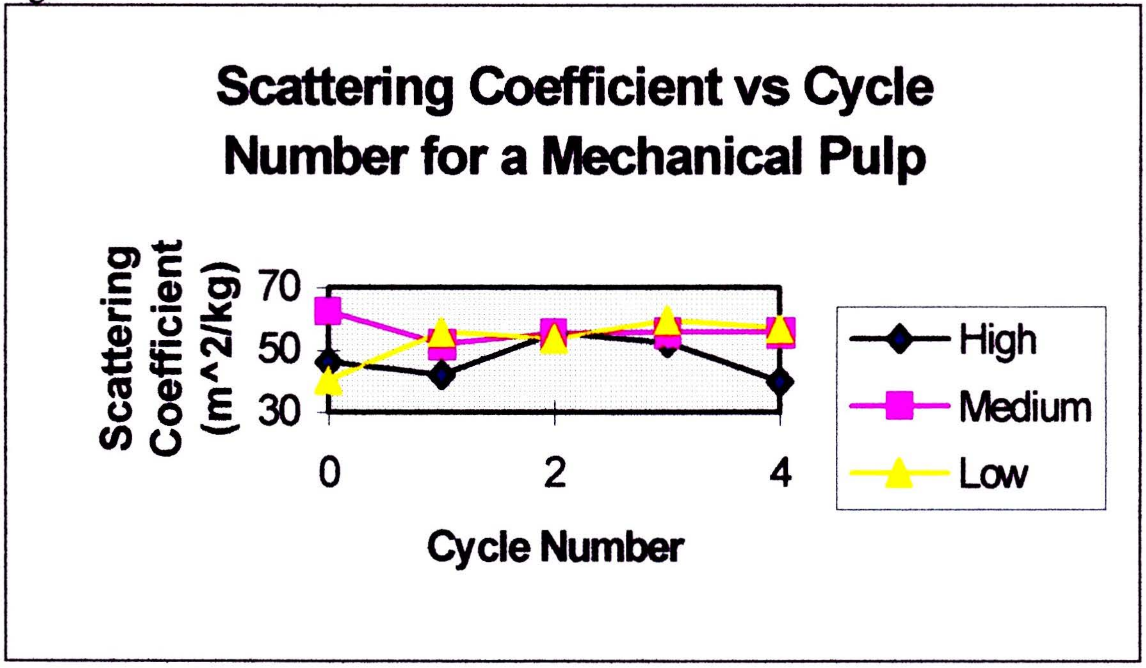
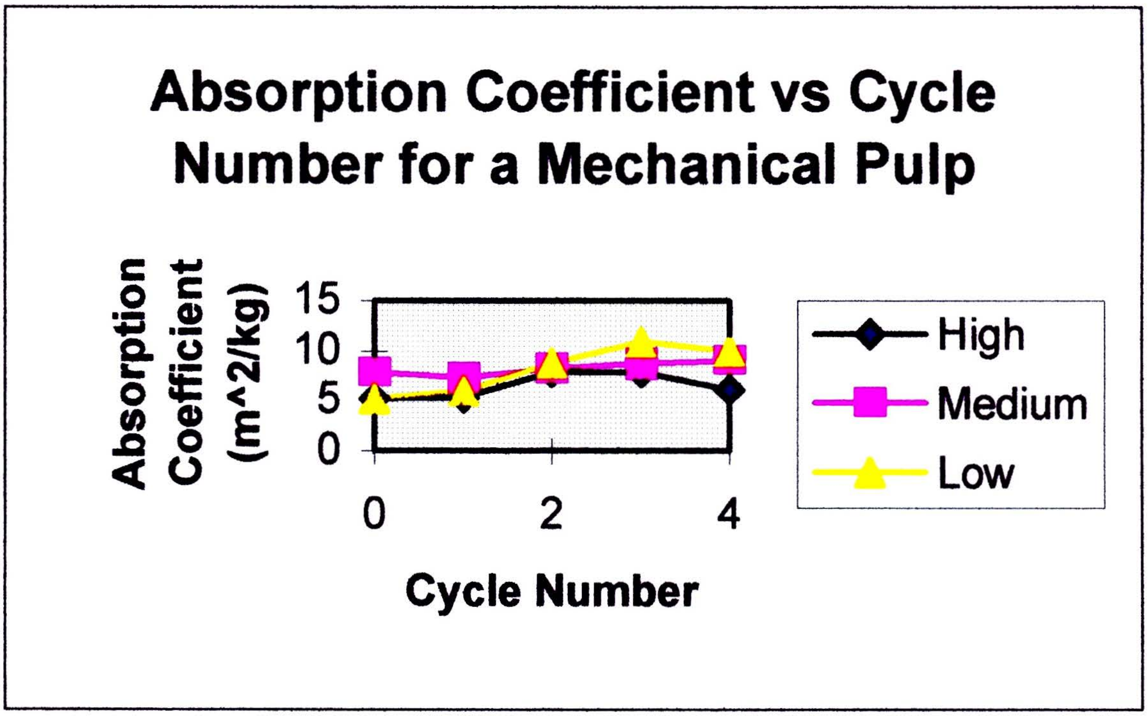


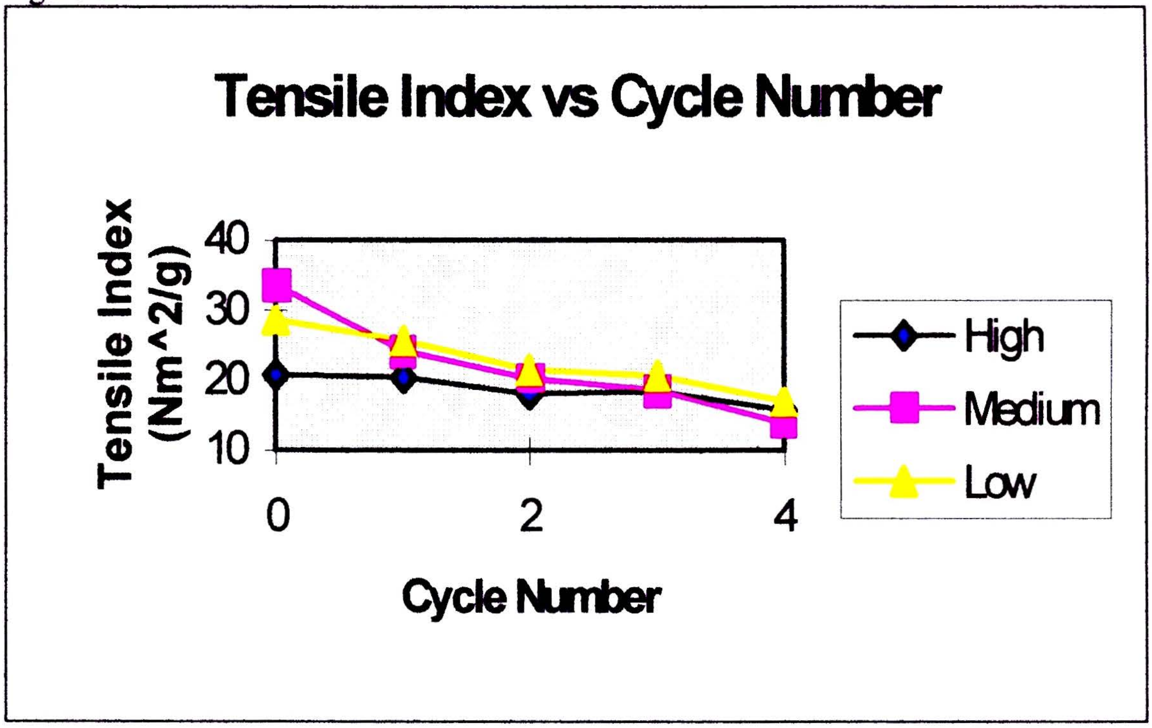
Figure 12:



The absorption coefficient for the mechanical pulp (Figure 12), like that of the chemical pulp, did not reveal any significant effect of recycling on the absorption coefficient, nor did there seem to be any effect of initial freeness level.

The tensile index for the mechanical pulp (Figure 13) behaved much like that of the chemical pulp. It fell as the number of recycles was increased. If for some reason the data point for the middle freeness in cycle 0 is skewed, whether through testing error or sampling error, then the effect of freeness level for the mechanical pulp is the same as that of the chemical pulp with the high freeness having the low tensile strength, and the low freeness having the higher tensile strength throughout the recycling process.

Figure 13:



The tear index for the mechanical pulp remained fairly constant throughout the recycling process. There does not appear to be any relationship between the number of recycles and the tear strength for the mechanical pulp. The data may be skewed, however, due to the low numbers obtained on the Elmendorf Tearing Tester. The numbers that were obtained ranged between 6 and 14 Elmendorf units. They may not have been high enough on the scale to fall into a range where the tester can accurately measure the tearing strength. One way to correct this problem would have been to use more plies, however, more plies were not available at the time of testing.

The zero-span tensile for the mechanical pulp (Figure 15) behaved much like the zero-span tensile for the chemical pulp. It did not appear to be effected much by recycling. As mentioned before, zero-span tensile is an indication of individual fiber strength and not bonding potential and should be less affected by recycling. It may, however, be affected by the initial freeness level because the more a fiber is refined, the weaker the fiber becomes, which may reduce the zero-span tensile strength. This is especially true for pulps which have been beaten to very low freenesses.

Figure 14:

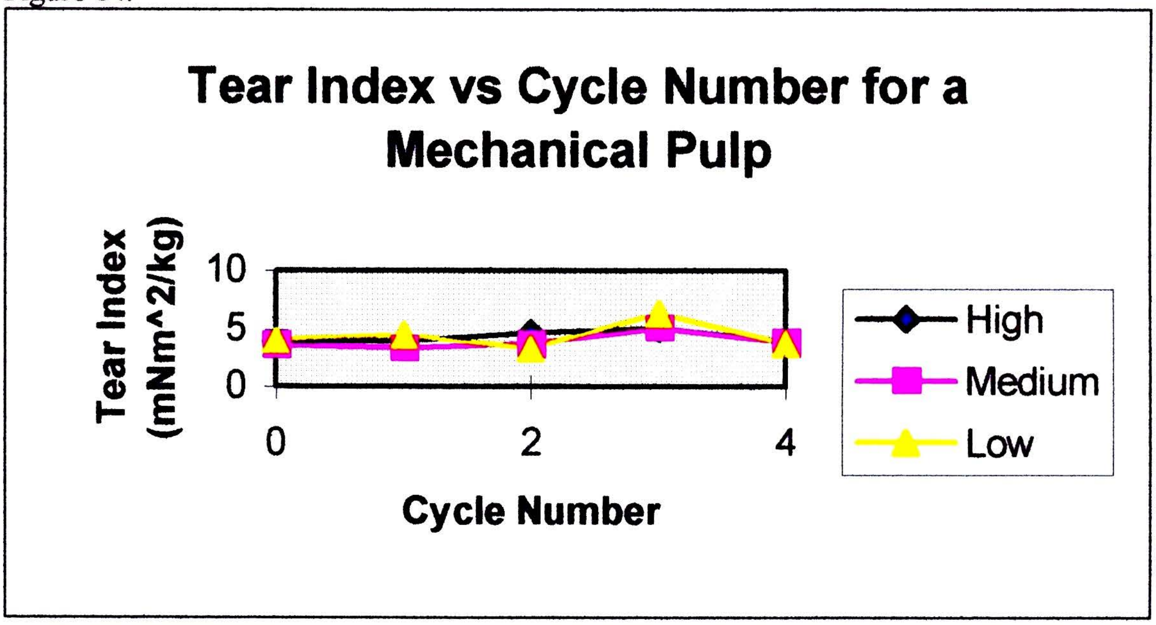


Figure 15:

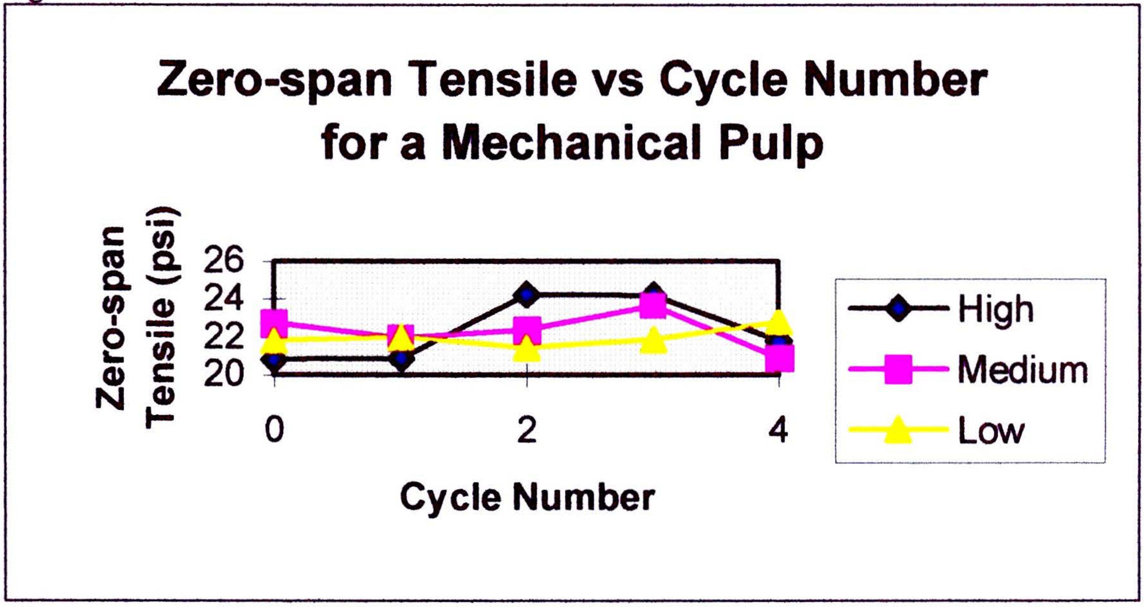
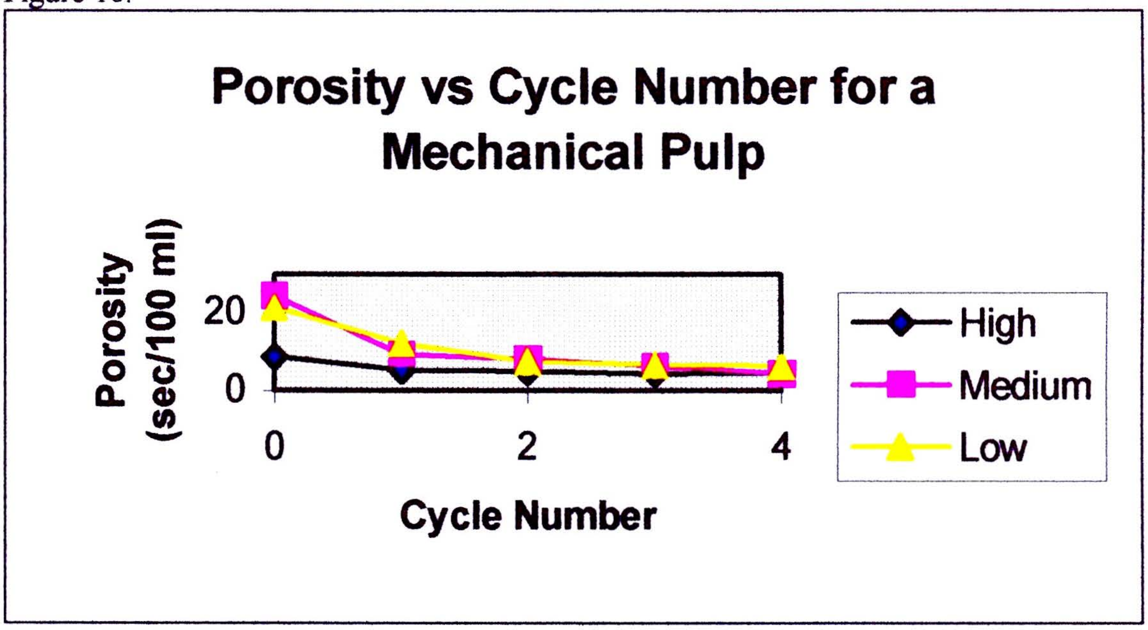


Figure 16:



The porosity for the mechanical pulp (Figure 16) behaved in the same way as the porosity of the chemical pulp as the number of recycles was increased. It also behaved the same way with respect to freeness level as the chemical pulp.

Conclusions

Brightness Opacity, scattering Coefficient, absorption coefficient and zero-span tensile were not affected much by recycling for the chemical pulp. The initial freeness level also did not appear to have much effect on these properties as recycling was increased. The scattering Coefficient and the absorption coefficient behaved about the same for the mechanical pulp. The brightness and opacity for the mechanical pulp appeared to fall slightly but not significantly.

Recycling has an adverse effect on tensile strength. The freeness level had the effect of keeping the tensile strength for the low freeness above the tensile strength for the middle freeness and the tensile strength for the high freeness below the middle freeness for each recycle level. The mechanical pulp behaved in much the same way.

The Tear strength rose initially as the number of recycles was increased, but then fell off slightly as it was recycled further. The effect freeness level was the opposite of the tensile strength for the first couple of recycles. The low freeness having the lower tear strength. This, however, did not carry through the rest of the recycles. Recycling did not have much effect on the tear strength for the mechanical pulp, however, the data may not be accurate.

Recycling increases the porosity of handsheets for both chemical and mechanical pulps. Increasing the freeness level decreased the porosity of the sheet at each recycle level.

The chemical and mechanical pulps behaved similarly in this experiment. This might not be the case if the fibers were refined between each recycle level. The mechanical pulp may, in fact, improve in strength due to the fibers becoming more flexible as the number of recycles is increased. The magnitude of change may also be affected if fines are reintroduced at each recycle level. The properties may not change quite as quickly, especially in the first recycle.

Recommendations

One recommendation for further study would be to compare other pulping methods such as TMP and CTMP to the methods contained in this report using the exact same experimental procedure. Another recommendation would be to do two runs on the same type of pulp as described in the experimental section except that with one of the runs retain the fines by using the white water system on the Nobel and Wood Handsheet Maker. A third recommendation may be to compare different wood species using the Experimental design used for this thesis.

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