4-1981

The Effect of Oxygen Treatment of Thermomechanical Pulp on Strength and Hydrosulfite Bleachability

Robert L. DeAmico
Western Michigan University

THE EFFECT OF OXYGEN TREATMENT OF THERMOMECHANICAL PULP ON STRENGTH AND HYDROSULFITE BLEACHABILITY

by

Robert L. DeAmico

A Thesis submitted
in partial fulfillment of
the course requirements for
the Bachelor of Science Degree

Western Michigan University
Kalamazoo, Michigan
April, 1981

TABLE OF CONTENTS

ABSTRACT

The literature review for this thesis was done on the expectation of acquiring an ozone generator for experimental work. This expectation was never realized. Consequently, a low consistency oxygen treatment under mild alkaline conditions and room temperature was done instead. The two major considerations were to determine the effect of this treatment on strength properties and development, and on hydrosulfite bleachability. It was found that the brightness of the pulp was reduced on alkaline oxygen treatment, but pretreatment increased the bursting strength development caused by hydrosulfite bleaching, at the same freeness level. A substantial reduction in freeness level was experienced on alkaline oxygen treatment, and response to refining was reduced on chemical treatment, both oxygen and hydrosulfite.

A NOTE TO THE READER

When the idea for this thesis was first approved, it was with the intention to study the effect of ozone treatment of thermomechanical pulp on hydrosulfite bleachability. At that time the search for an ozone generator was begun along with the literature review. It was not until the middle of the second term that the search for an ozone generator was aborted, leaving little time for the design of a new experiment complete with a new literature search.

Thus, it was assumed that a study with oxygen rather than ozone might be suitable, since both reagents effectively cause the oxidation of pulp constituents. Some of the chemical reactions discussed in the introduction of this thesis might apply equally to the oxygenation reactions, but degree of reaction is probably reduced due to the difference in reactivity of the two reagents. Interestingly enough, some of the results of the oxygenation study carried out correlate to a good degree to various findings reported in the literature review presented. These are discussed in the report.

Overall, then, the literature survey and the experimental work do not match exactly, but some threads, thin as they may be, seem to tie the two parts together to some degree.

INTRODUCTION

Treatment of cellulosic materials with ozone is not a new concept. As early as the first decades of this century its use as a bleaching agent for the textile industry was being investigated. Today, ozone is emerging in the pulp and paper industry in two major areas. First, as a pulping agent, in hopes of finding a substitute for sulfur compounds and secondly as a bleaching agent, to reduce the usage of chlorine and chlorine compounds which place a burden on mill effluent treatment systems

The scope of this thesis is to make an evaluation of ozone as a bleaching agent and strength developing agent for a thermomechanical pulp. Experimental work in this area has been minimal, although Liebergott[3] in Canada and Soteland[7-10] in Norway have done some revealing work.

In recent years much attention has been paid to the application of ozone to chemical pulps, and although much of this work does not have direct application to treatment of mechanical pulps, some of these studies have aided in the understanding of the cellulose-ozone reactions. These particular studies will be discussed in more detail.

THE CELLULOSE-OZONE REACTION

The use of ozone, a gaseous reagent, as a chemical modifier of a solid substrate, such as cellulose or pulp, poses some interesting problems. Schuerch[6] did some preliminary studies with ozone and proposed the following model for the

reaction of a gas, with a solid phase:

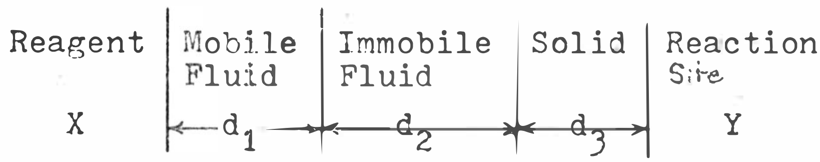


Figure 1. Model of reaction of gaseous reagent with a solid substrate where X denotes the gaseous reactant molecule, d_1= free flowing phase in which the reagent is carried by convection, d_2= immobilized solvent or fluid phase through which the reagent moves by diffusion, d_3= solid phase where again the reagent moves by diffusion, and finally Y= the reaction site.

In a rate study by Dorée[2] it was found that for a given reaction time cellulose degradation at low moisture content $\left(\frac{W\ H_2O}{W\ dry\ solid} \times 100 \right)$ was negligible with only superficial surface oxidation occuring. Likewise, at high moisture content the rate of degradation was reduced, this time by the slow rate of diffusion of ozone through the liquid layer. Schuerch went further to state that in low consistency suspensions, ozone passed through the suspension without hardly being absorbed at all. Doree found that reaction rate of cotton cellulose with ozone was at a maximum at a moisture content of around 50%.

Since according to the proposed model, the reaction tends to be diffusion rate controlled, it would be logical to attempt

to minimize d_2 and d_3. In light of the findings of Dorée and Schuerch it could be concluded that capture of the ozone molecules by a thin aqueous film is more efficient than capture by the cellulose polymer itself. However, moisture increases too far beyond the fiber saturation point again substantially decrease the reaction rate. Schuerch found that for a semi-bleached softwood kraft pulp, the optimum reaction rate occurred at a moisture content of around 40%, and therefore concluded that due to varying densities and compositions, different pulps will have optimum reaction rates at different moisture contents. The reaction rate maximum in any case is reached when the individual fibers are totally separated from each other by a free flowing solvent layer saturated with ozone.

This study was followed up[5] by one in which several solvents were used which were believed to preferentially "wet" lignin in hopes to increase the specificity of attack of the ozone toward the lignin. Ozone attack, like many other reactions is not specific for any single wood component, that is, it reacts with cellulose, hemicelluloses and lignin. It was found that addition of specific organic solvents to aqueous systems of unbleached kraft enhanced the rate of reaction, but did not significantly affect the specificity of the reaction. Specificity of the reaction was determined by measuring cellulose degradation as indicated by cuprammonium viscosity versus brightness gain, a rough indicator of "lignin degradation."

Secrist and Singh[11] experimented with the ozonization of a hardwood kraft pulp and found the same large loss in degree

of polymerization of cellulose as other workers did. Using physical testing and electron microscopy data they were able to show that ozonization resulted only in surface modification of the fiber however, with the inner cell wall remaining intact for the most part. Of interesting note is the fact that after ozonization the tensile strength of the individual fibers remained unchanged for the most part. This fact could help to explain the increased strength and faster response to refining of ozonated pulps in more recent studies.

OZONE-LIGNIN REACTIONS

The interest in ozone-lignin reaction became significant when studies conducted with wood meals revealed that the resultant pulps would brighten significantly upon mild ozone treatment without much loss in yield. The -C=C- bonds in lignin, both aliphatic and aromatic are believed to be a major cause of the coloration in lignin and these double bonds are known to be oxidized by ozone. The mechanism for the primary ozone attack on the phenolic structure is as follows:

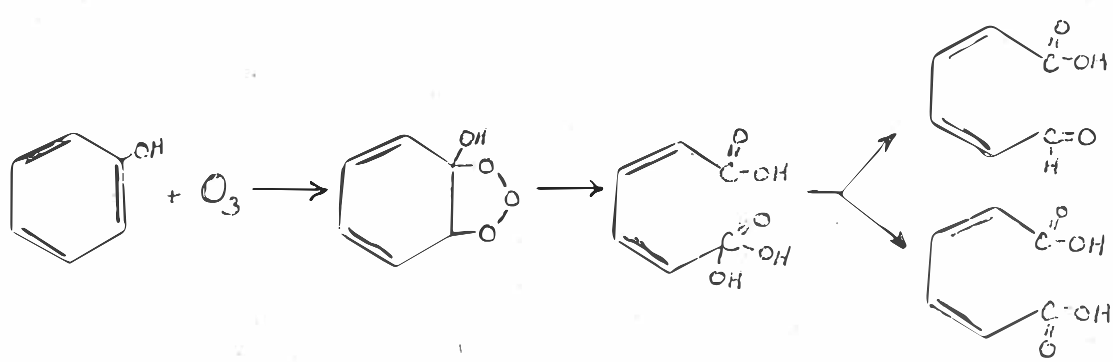


Figure 2. Mechanism of ozonolysis of phenolic compounds.

In spectroscopic studies conducted by Soteland[7] it was noted that a distinct decrease in infrared absorbtion in the skeletal aromatic region occurred on ozonolysis, along with a simultaneous increase in the carbonyl region. After considerable study the following model was proposed. Ozone attack would occur first with the coniferyl aldehyde groups,

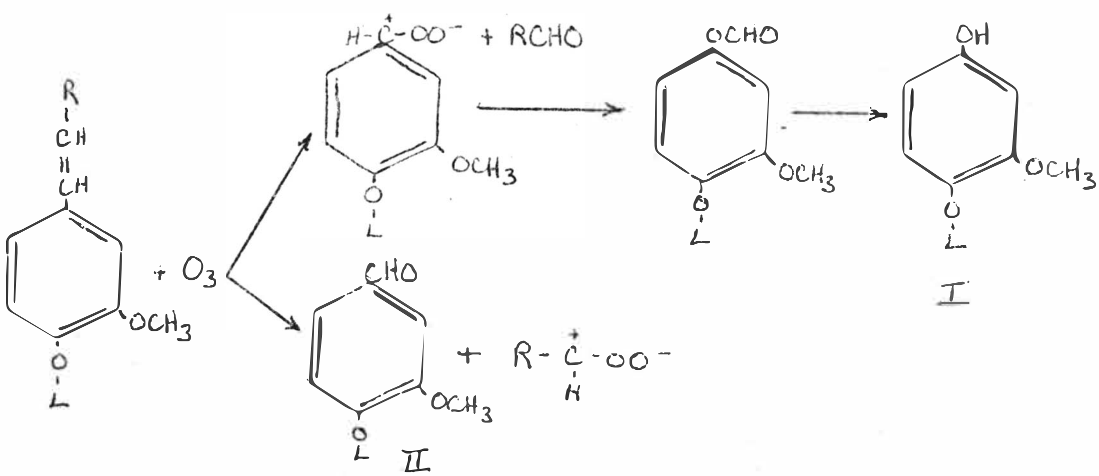


Figure 3. Step one of ozone attack on lignin.

with II being the favored product. Since relatively few of these groups exist in most lignins the yield would not be influenced greatly and color should improve. Also, very little ozone is required to break these bonds. The next sites to react, with slightly higher ozone concentration would be syringyl and guaiacyl groups:

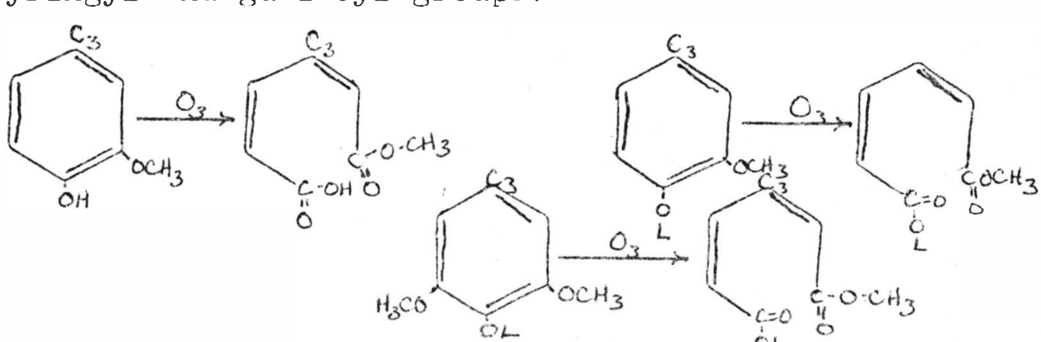


Figure 4. Ozone attack of guaiacyl and syringyl groups in lignin.

Finally, these structures would break up into smaller fragments, with further ozone treatment, some of which would be soluble. Thus the yield will decrease but at the same time the brightness will improve.

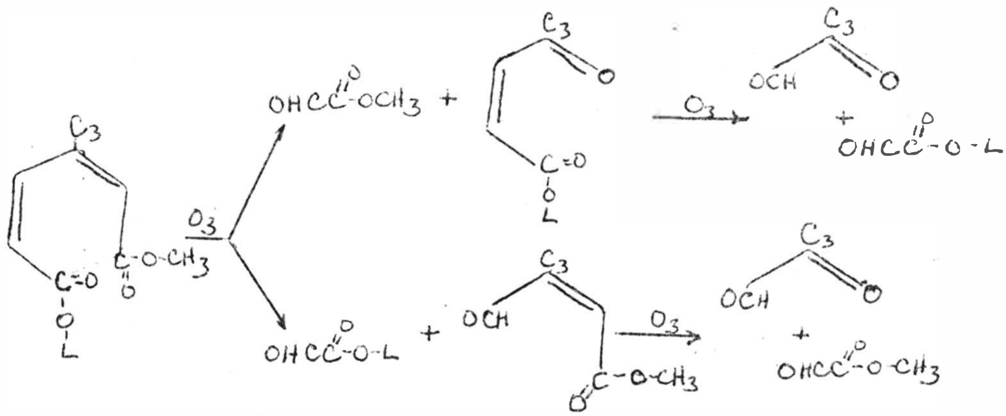


Figure 5. Degradation of ozonized lignin units by ozone.

PULP-OZONE REACTIONS

As was stated earlier, there is great potential for the use of ozone as both a pulping and a bleaching agent. The scope of this thesis is to evaluate ozone as a potential bleaching agent for thermomechanical pulp primarily. Bleaching of a pulp of this type differs from the bleaching of a chemical pulp in that the objective in bleaching a chemical pulp is to remove any residual lignin and other colored matter from the pulp. The object of bleaching a mechanical pulp is to only decolorize or whiten the lignin and other components without actually removing them. Yield is very important in mechanical pulping operations, and this must always be taken into consideration.

In his initial studies, Liebergott[3] found that ozone tended to whiten spruce groundwood pulps, but upon washing

and drying the pulp, the brightness would revert back to or below its original value. The resultant pulps however had considerably greater strength, and very low yield loss.

Several pretreatments were evaluated with the best results being obtained when a combination of 0.6% H_2O_2+2.0% Na_2SiO_3+ 1.0% NaOH (all %'s expressed as % on O.D. pulp) was sprayed on the pulp just prior to ozonolysis. Following a 1% ozone treatment a brightness gain of 12 points was observed with less than a 1% yield loss. The brightness was relatively stable, losing only one point after an hour of aging at 105°C.

Another interesting and important observation from this study was that reaction time had a considerable effect on the final brightness of the pulp. By varying the gas stream flow rate Liebergott was able to adjust the time in which 1% ozone would be applied to the pulp. A brightness increase of about 6 points was observed by allowing 30 minutes for the reaction time instead of 5 minutes. Osawa(4) went further to state that fluctuating the ozone pressure tends to increase the reaction rate, since this promotes transport of the ozone by convection as well as diffusion in the d_2 and d_3 regions according to the proposed model.

Soteland(6-7) and Osawa(4) attempted to determine the specificity of the ozone reaction for spruce pulps. Using a wood meal Osawa found that reaction with lignin was approximately twice as rapid as that with holocellulose up to the point where 60% of the lignin was removed. In a more direct

experiment, Soteland used a spruce thermomechanical pulp and analyzed the wash water after ozonolysis. He found that 75% of the dissolved material in the washwater were lignin degradation products and oxidized extractives. The remainder of the material consisted of degraded carbohydrates from cellulose and hemicelluloses.

In light of the earlier findings that ozone tended to act only as a surface modification treatment of whole wood fibers, Allison(1) conducted a study on the treatment of an Asplund or high temperature thermomechanical pulp (HTMP) with ozone. End use application of the pulp was to be in construction board grades. After ozone treatment, he subjected the pulp to refining and bleaching processes using chlorine, peroxide and dithionite based bleaching agents.

The most outstanding results of this study were that with increasing amount of ozone applied, the rate of response of the pulp to beating increased. Higher strength values were reported for ozonized pulp at a given freeness value, and both tensile and tear factors showed dramatic improvement upon ozonization. No dramatic improvements in brightness were noted, however.

Bleaching response using the chemical agents mentioned was analyzed. It was shown that chlorine based bleaching methods produced very poor brightness responses. Gains using peracetic acid and hydrogen peroxide were quite similar, but only moderate. Consequently ozonized HTMP was considered to

be unacceptable as a source of papermaking fibers, but instead was well suited for production of construction board.

Allison also noted the power requirements for the production of ozone in his report. That is, using conventional laboratory equipment, for every 1% ozone consumed per ton of pulp, 100 kilowatt hours of energy is required to supply the ozone.

To determine which type of pulp might benefit the most from ozone treatment, Soteland(7) compared groundwoods and thermomechanical pulps produced both from softwood and hardwood species under varying conditions.

Major findings were that the softwoods showed a brightness loss of 2-4 units after a 3% ozone treatment while the hardwoods sustained substantial brightness increases. Spruce pulps gave the best tensile strength response per percent ozone applied, as well as having the best overall yield after ozonization. As opposed to groundwood pulps, for which tear strength was virtually unaffected, thermomechanical pulps showed slight improvements. TMP yields were also higher, in the 95% or better region, whereas yields for groundwood pulps ranged from 90% to 95% after a 5% ozone application.

Both Allison(1) and Soteland(5) examined several variables which could affect the results of ozone treatment. It was noted in these studies that prior extraction of spruce TMP with acetone resulted in greater tensile strength development rate upon ozonization. Tear strength was also improved, but rate of response was unaffected. Also, yield losses were far greater.

Temperature control during ozonization did not have a significant impact on strength characteristics. At the same time buffering of the system during ozonization tended to decrease the enhancement of pulp strength. Also, the pH of post-ozonization treatments was critical. As the percentage of ozone applied to the pulp increased, the amount of alkali soluble material increased. Consequently, alkaline extractions reduced yield and at the same time brightness gains were reduced and pulp strength remained virtually unchanged.

Finally, for thermomechanical pulps, ozone treatment tended to increase the strength of the pulp with no change in freeness. Drainage characteristics of the pulps produced were unaffected, while wet web strength and response to neutral and rosin sizing were vastly improved.

SUMMARY

The use of ozone as a bleaching agent and strength developing agent for thermomechanical pulps has a great potential. Some of the positive attributes of such a pulp have been reviewed in the latter part of this literature review. Most of the work in this area is still in the experimental and laboratory stages while the use of ozone on chemical pulps is becoming closer to an industrial reality. Some of the problems involved in using ozone have been highlighted in this review. It is hoped that the experimental work of this thesis will help to broaden the base for development of ozone technology.

EXPERIMENTAL

As mentioned in the note to the reader, the experimental work for this thesis had to be revised after it became apparent that an ozone generator would not be available for use within the time constraints of this project. The basic consideration was to bleach a thermomechanical pulp using a two stage sequence as follows: an oxidation step (i.e. ozone treatment), followed by a reduction step (i.e. a conventional hydrosulfite bleach). Hydrosulfite treatment of mechanical pulps is quite common and its effects are well documented in the literature. Several oxidative treatments have also been studied, with the most commonly used agent being peroxide.

In order to make the study as cohesive as possible and yet explore some new aspect of mechanical pulp bleaching, oxygen was chosen as the oxidative agent for the study. Like ozone, it is applied as a gas and it has been shown to behave chemically in a similar fashion on pulp systems, but at a slower rate since it is less reactive. The ultimate goal of the experiment, then, was to see what effect oxygen treatment would have on hydrosulfite bleachability. More specifically, the object was to determine if oxygen treatment might increase the ultimate brightness level after the second stage hydrosulfite treatment.

Now, some studies have been conducted where thermomechanical pulps have been treated with oxygen under alkaline conditions, but these were mainly 'cooking' operations where

yields were substantially reduced. Thus room temperatures and a mild alkali treatment were selected to reduce yield losses and hopefully achieve some brightening effect. The following paragraphs give a more detailed description of the experimental conditions used.

The objective of the experimentation was twofold. That is, to study the effect of low consistency oxygen treatment at low temperature and alkaline conditions on: 1) strength properties and development, and 2) hydrosulfite bleachability.

Five separate samples were used to make the above determinations. Beater runs were performed on four of the five runs to observe the impact of mechanical treatment on pulp properties, and how chemical treatments affected response to mechanical treatment. The PFI mill was selected for refining, and a 30g. OD charge at 10% consistency was used in each case. Clearance between the inner and outer surfaces was set at 0.10mm. and four beating periods were selected. These were 0, 2500, 5000, and 8000 revolutions.

The first beater run was a control run. No chemical treatment was used. The thermomechanical pulp for the study was 100% northern spruce, and was supplied from a mill source at approximately 4% consistency in a five gallon plastic pail. It had been cleaned, screened and a chemical preservative added. Six handsheets for each level of refining were made using the British Sheet Mold according to standard procedure. Average weight of the handsheets after conditioning

was 1.5g. The sheets were tested according to TAPPI procedures for, opacity, burst, tear, and tensile strength. Pulp tests done for each run were G.E. brightness and Canadian Standard freeness.

The second run was made using a 250g. OD. sample of the pulp adjusted to 3% consistency. The pH was increased from 4.5 to 8.5 using sodium hydroxide. Immediate darkening of the pulp was observed as the slurry went to the alkaline side. Oxygen was then introduced into the bottom of the pail at a rate of 0.75 L/min. through a piece of 5/16" I.D. tygon tubing for one hour. The pulp was agitated constantly for this period.

After the oxygenation treatment, the pulp was allowed to stand for one hour before the pH was brought back down to 4.5. Brightness pads were then made on a Büchner funnel. Three 30g. OD. batches were then dewatered to 10% consistency for PFI mill treatment. Four 30g. OD. batches were placed in separate two liter glass beakers for hydrosulfite treatment. The remainder of the pulp was used to make handsheets.

Next, the four beakers from the previous run were placed in a water bath and allowed to equilibrate at 50°C. The pH was adjusted to 5.0 in each beaker and V-Brite, a sodium hydrosulfite agent with added stabilizers supplied by Virginia Chemicals Co. was added at a 3% level (based on weight of chemical per OD. gram of pulp). The pH during the bleaching period remained constant throughout. The hydro-

sulfite was dissolved in just enough distilled water prior to adding it to the pulp. The mixtures were allowed to stand for one hour, after which brightness pads were made from a composite of the four beakers. The pulp was then dewatered on a Büchner funnel and washed once with one liter of distilled water. The pulp was dewatered again to a 10% consistency for the PFI mill beater run.

Finally, a portion of the untreated pulp was treated with the sodium hydrosulfite as described above, without prior alkaline oxygen treatment. This was done to determine exactly what effect the alkaline oxygen treatment had on the pulp. Due to a shortage of pulp, the 5000 revolution run in the PFI mill was omitted.

When the pH of the pulp was returned to the acid side after the alkaline oxygen treatment it was noted that the original pulp was visually brighter than the treated pulp. Thus, a secondary control was performed to determine if the presence of oxygen under alkaline conditions helped to deter this inversion. A small sample of original pulp was adjusted to 3% consistency and a pH of 8.5 and allowed to stand for one hour. The pH was then readjusted to 4.5 and a brightness pad made to compare to the alkaline oxygen treated sample. No strength tests were performed on this control sample.

RESULTS AND DISCUSSION

Of primary consideration was to determine the bleaching response of the pulp to alkaline oxygen treatment. Table I gives a comparison of the brightness levels for each of the various treatments. As mentioned before, it was noted that the alkaline oxygen treatment did not improve pulp brightness. On the contrary, brightness was reduced by two points after the treatment. This loss was not a total surprise considering that as pointed out in the literature on ozone treatments, similar losses were reported on the treatment of softwood mechanical pulps. It is significant to note, however, that the presence of oxygen reduced the brightness loss compared to a simple alkaline treatment. The oxygen cut the percent loss by more than half.

Further, the first stage alkaline oxygen treatment did not increase the overall effectiveness of the sodium hydrosulfite bleaching as was hoped. Essentially this work measured only the overall effectiveness since 3% chemical addition is about double the normal mill dosage. An increase was anticipated in the event that the alkaline oxygen treat-

Table I. Comparison of Brightness Levels For Various Treatments

	Untreated	Alkaline	Alk. O_2	O_2/V-Brite	V-Brite
Brightness, G.E.	57.6	50.8	55.3	62.3	65.1
Gain	-	-	-	7.0	-
% Gain	-	-	-	12.7	-
Overall Gain	-	(6.8)	(2.3)	4.7	7.5
% Overall Gain	-	(11.8)	(4.0)	8.2	13.0

ment might expose more chromorphic groups susceptible to reduction. It was noted that the overall brightness gain was two to three points less when the alkaline oxygen treatment was used, with the loss occuring due only to the first stage treatment. In this aspect the thesis was somewhat disappointing.

Strength tests performed on the pulp were tensile, tear and burst. The burst test gave the most consistent results which are summarized in Figure 6. It can be seen from the curves that the ultimate bursting strength occured before the midpoint of mechanical treatment. Thus, extensive treatment of the pulp in a PFI mill generated a considerable amount of fines which reduced sheet strength. Also, any chemical

Figure 6. Burst factor as affected by chemical and mechanical treatment.

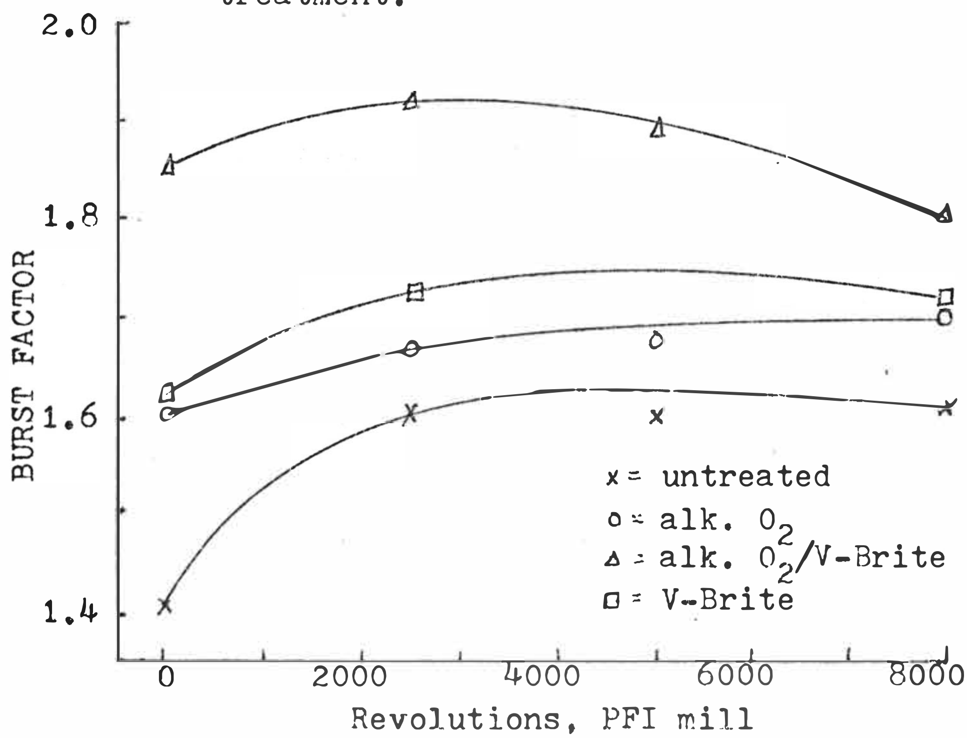
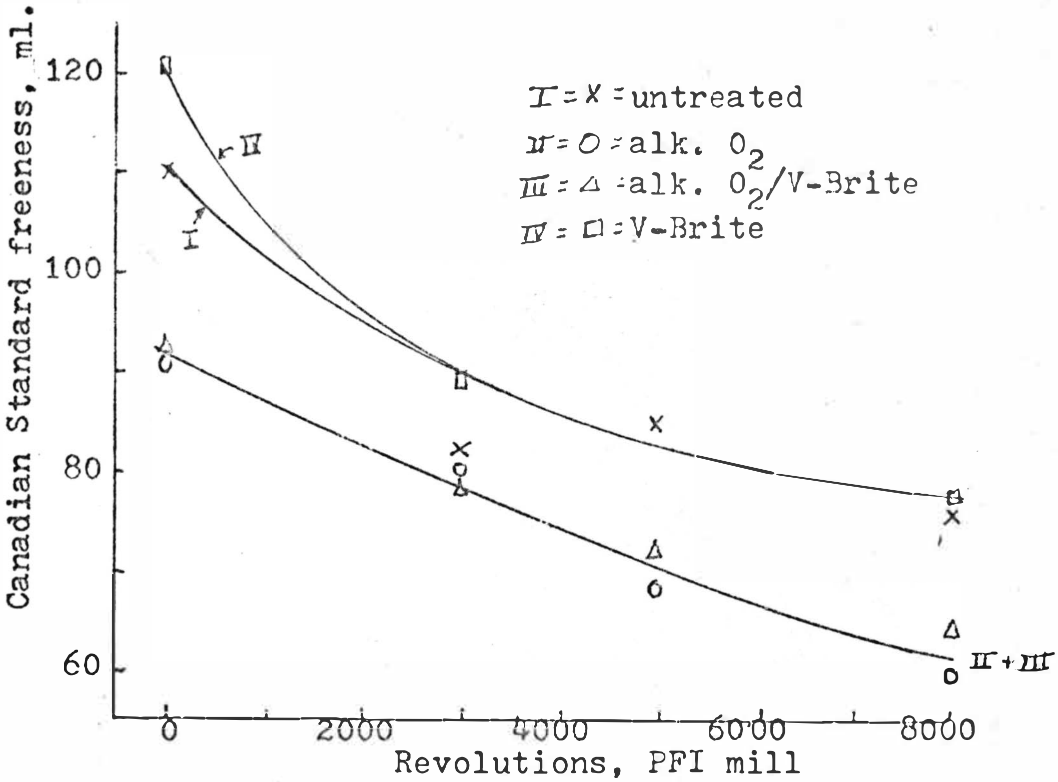


Figure 7. Canadian Standard freeness as affected by chemical and mechanical treatments.



treatment reduced the strength response on mechanical treatment, but increased the bursting strength level. This fact supports some of the literature findings where ozone treatment tended to increase the response to mechanical refining.

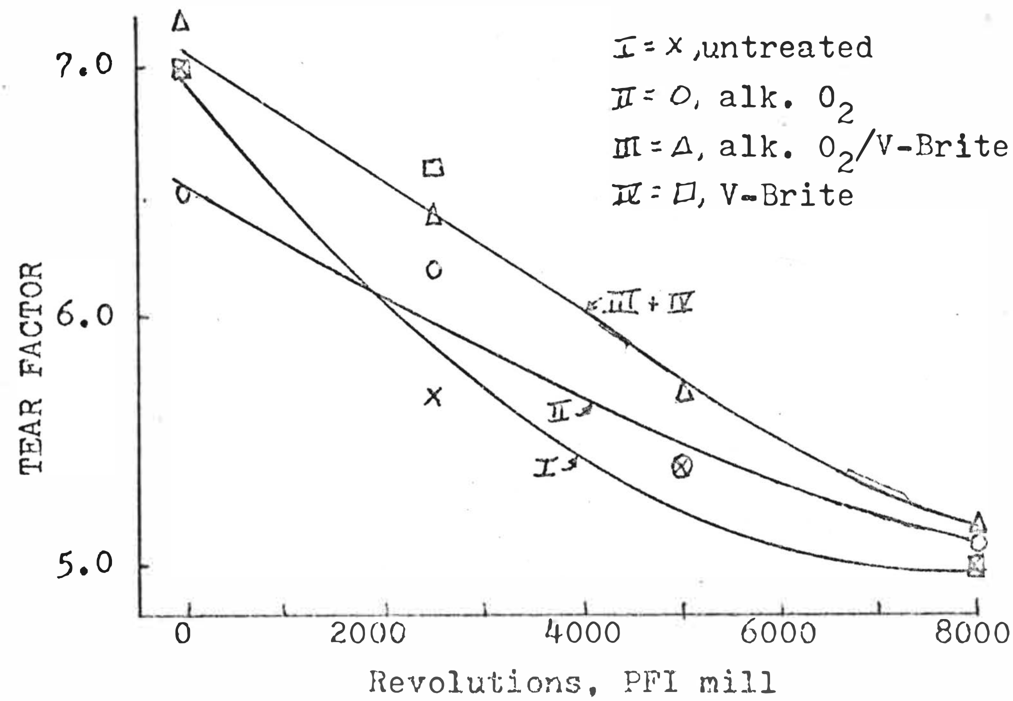
Of even more interest was the fact that the alkaline oxygen treatment increased the strength development on hydrosulfite bleaching. Pulp strength was similar comparing the alkaline oxygen treatment only and the hydrosulfite treatment only. The two stage sequence gave the best strength development.

The above arguments are interesting when the freeness data as summarized in Figure 7 is considered along with it.

The alkaline oxygen treatment significantly reduced the Canadian Standard freeness, while the hydrosulfite treatment had a negligible effect on freeness. Thus, the strength development due to alkaline oxygen treatment can be related to the reduction in freeness primarily, while the hydrosulfite treatment yields strength increases due to chemical modification which does not affect freeness.

Tear strength data is summarized in Figure 8, and the results due to chemical treatment were somewhat questionable, except that chemical treatments seem to retard the loss of tear strength during early stages of refining. The contribution of oxygen treatment to this effect was again, questionable.

Figure 8. Tear factor ((tear/basis weight)x10) as affected by chemical and mechanical treatments.



Tensile strength results were very inconclusive. A major factor in the results was felt to be due to handsheet making conditions. The blotter paper used had a high degree of curl and caused a crease in the center of each handsheet on flattening for pressing. Since the tensile samples were taken from the center of the sheet, these creases were a major factor influencing the result of each test. Therefore, the test was omitted from consideration in this study.

Other sheet properties measured were sheet density and opacity. As shown in Figure 9, density increased on refining. The hydrosulfite treatment caused a slight increase in density in the unrefined sheets, but after moderate degrees of mechan-

Figure 9. Sheet density as affected by chemical and mechanical treatment.

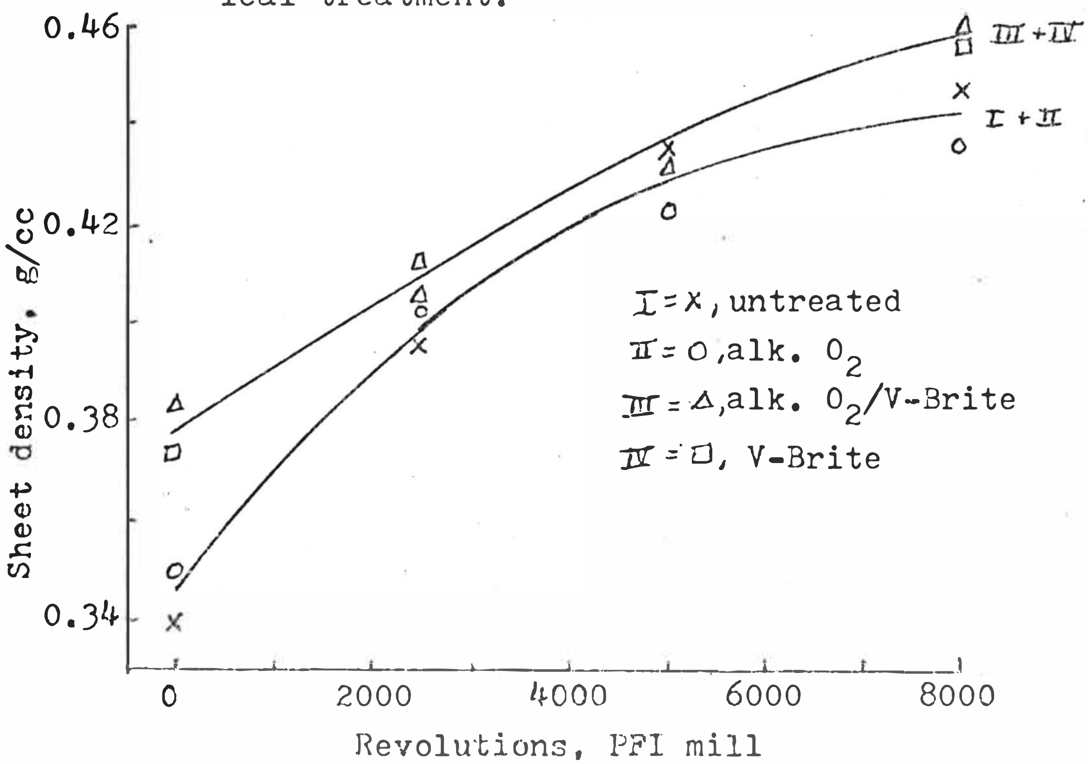


Table II. Effect of various treatments on TAPPI opacity.

	Revolutions, PFI mill-			
	0	2500	5000	8000
Untreated	97.4	97.4	97.3	98.0
Alk. O_2	97.9	98.0	97.8	97.7
Alk. O_2/V-Brite	97.8	96.8	97.4	97.7
V-Brite only	97.1	97.4	-	95.9

ical treatment the differences in density between the samples became insignificant.

Even with the increased sheet density, however, the opacity of the sheets remained unchanged as shown in Table II. The minor differences indicated in some cases can be attributed to slight basis weight variations between samples. This phenomenon can be explained by the fact that the refining of mechanical pulps generates fines and consequently more interfaces in the sheet without collapsing the individual fibers and reducing sheet opacity, which occurs in the case of chemical pulps.

CONCLUSIONS

In summary, the alkaline oxygen treatment significantly reduced pulp freeness and increased the strength response to hydrosulfite bleaching. The increased strength after the first stage was attributed primarily to the reduced freeness. The chemical treatments did not affect sheet opacity or sheet density at any given level of refining, although the latter property increased as expected on refining.

The primary objective of this thesis was to observe the brightening response of the pulp to alkaline oxygen treatment followed by sodium hydrosulfite bleaching. As was noted the effectiveness of the hydrosulfite treatment was essentially unchanged and the pulp brightness was reduced only by the alkaline oxygen treatment in the first stage.

SUGGESTIONS FOR FURTHER WORK

During the course of experimentation and after the data was collected some flaws in the experiment became apparent. First, in the case of the control run and hydrosulfite treatment only, the pulp was not initially subjected to the same mixing conditions as occurred in the alkaline oxygen treatment. Thus, some of the freeness reduction reported for the first stage treatment might be attributable to agitation during this stage. This should be resolved.

Secondly, it would be interesting to introduce the oxygen at various pH levels and study these effects. Also, use of a more sophisticated oxygenation system might improve the efficiency and enhance the effects of the oxygenation treatment. Lastly, only the maximum (or nearly so) effect on hydrosulfite bleaching was studied. It remains to be determined if the brightness improvement per amount of hydrosulfite used is increased by the alkaline oxygen treatment or if it has no effect at all.

APPENDIX

The following is a summary of the data collected and used in the tables and graphs in the Results and Discussion portion of this thesis.

Untreated 0 Rev	Untreated 2500	Untreated 5000	Untreated 8000	Oxygen Alkaline 0 Rev	Oxygen Alkaline 2500	Oxygen Alkaline 5000	Oxygen Alkaline 8000	
110	82	84	76	91	81	69	60	Can. Std. Freeness
57.6	~~87.~~-	—	—	55.3	—	—	—	Brightness, G.E.
97.4	97.4	97.3	98.0	97.9	98.0	97.8	97.7	Opacity
.340	.397	.435	.448	.350	.402	.422	.437	Density, g/cc.
1.41	1.61	1.60	1.61	1.61	1.67	1.67	1.70	Burst Factor
44.4	47.0	49.7	47.1	51.4	48.9	53.4	51.1	Tensile, m.
7.0	5.7	5.4	5.0	6.5	6.2	5.4	5.1	Tear Factor

Alk. Oxygen / V-Brite 0 Rev	Alk. Oxygen / V-Brite 2500	Alk. Oxygen / V-Brite 5000	Alk. Oxygen / V-Brite 8000	V-Brite Only 0 Rev	V-Brite Only 2500	V-Brite Only 5000	V-Brite Only 8000	
92	79	72	65	121	89	—	77	Can. Std. Freeness
62.3	—	—	—	65.1	—	—	—	Brightness, G.E.
97.8	96.8	97.4	97.7	97.1	97.4	-	95.9	Opacity
.382	.407	.431	.460	.374	.412	-	.456	Density, g/cc
1.85	1.92	1.88	1.80	1.62	1.73	—	1.71	Burst Factor
49.7	52.3	50.8	53.6	44.9	53.1	-	44.5	Tensile, m.
7.2	6.4	5.7	5.2	7.0	6.6	-	5.0	Tear Factor.

NOTES: Temperature of alk. O_2 treatment ~20°C pH_i = 8.5 pH_f = 8.5

Temperature of V-Brite treatments ~50°C pH_i = 5.1 pH_f = 5.1

BIBLIOGRAPHY

1. Allison, R.W., "Appita." Vol. 32. No. 4, 279-284.

2. Doree, C., Healy, A.C., "Journal of Textile Institute." Vol. 29, 27T (1938).

3. Liebergott, N., "Pulp and Paper Magazine of Canada." Vol. 73. No. 9, 70-73.

4. Osawa, Z. et. al., "Tappi." Vol. 46. No. 2, 84-88.

5. Osawa, Z., Schuerch, C., "Tappi." Vol. 46. No. 2, 79-83.

6. Schuerch, C., "Journal of Polymer Science: Part C." No. 2, 79-95 (1963).

7. Soteland, N., "Norsk Skogindustri." Vol. 25. No. 5, 135-138.

8. Soteland, N., "Norsk Skogindustri." Vol. 27. No. 10, 274-277.

9. Soteland, N., "Norsk Skogindustri." Vol. 28. No. 6, 165-169.

10. Scoteland, N., "Pulp and Paper Magazine of Canada." Vol. 78. No. 7, 45-48.

11. Secrist, R.B., Singh, R.P., "Tappi." Vol. 54. No. 4, 581-584.