



4-1998

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***The Use of Borax to Inhibit the Brightness
Reversion of Bleached CTMP***

by

Chad J. Longcore

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

WESTERN MICHIGAN UNIVERSITY

Kalamazoo, Michigan
April 22, 1998

ACKNOWLEDGMENTS

A special thanks goes to Qi Lin Zhou for all his assistance with the fadometer and providing me with some invaluable tips on its use. He had been able to work out a number of problems on using the instrument before I was ready to begin my testing. Without this insight it would have taken me much longer to conduct my trials. Thank you.

ABSTRACT

This thesis evaluated the ability of Borax to inhibit the yellowing process of paper that was made from bleached chemithermomechanical pulp (BCTMP). Paper made from BCTMP has a tendency to lose brightness (photoyellow) when exposed to ultra violet (UV) light. The light initiates a series of chemical reactions to take place that results in the formation of yellow ketone and quinone products. A combination of boric acid and borax was applied to the surface of the paper to interfere with these chemical reactions and prevent the formation of the yellow products that cause photoyellowing. The effectiveness of these additives was also compared with a previously used inhibitor (ascorbic acid).

Borax was only effective at inhibiting brightness reversion when it was added in combination with boric acid. The boric acid worked almost as well as the ascorbic acid when used alone. When the two were used in combination the effects were increased with an equal addition level of the additives individually.

TABLE OF CONTENTS

INTRODUCTION	5
GOALS AND OBJECTIVES	6
BACKGROUND	7
EXPERIMENTAL PROCEDURE.....	11
MATERIALS AND EQUIPMENT	11
METHODS	11
EXPERIMENTAL DESIGN	12
RESULTS AND DISCUSSION.....	14
CONCLUSIONS	22
RECOMMENDATIONS	24
APPENDIX A: RAW DATA.....	25
LITERATURE CITED.....	29

INTRODUCTION

Advances in mechanical pulping and bleaching technologies have enabled these pulps to be produced with TAPPI brightness values well above 80%. At these brightness values, the pulps could potentially be used for high-grade paper products like business forms, tablet and writing paper, and publication papers for books. However, these pulps have a tendency to yellow on exposure to light and this has restricted their use to lower value products like newspapers, advertising inserts, directory paper, and some catalogue papers – all short life products. It has been suggested that, if the rate of brightness reversion could be reduced from 3 months to 36, the potential market for bleached CTMP would be expanded by 2.2 million tons per year – a four-fold increase.¹

There have been several studies done to look into this problem and to begin understanding what mechanisms are involved. Several approaches have been used to inhibit this process, all with varying degrees of success. It is the intent of this project to and to gain a better understanding of brightness reversion and to study another group of additives that could eventually be used to inhibit the light induced reversion process.

GOALS AND OBJECTIVES

The objectives of this project is to determine if surface applied borax and boric acid is able to inhibit the brightness reversion of paper made with bleached CTMP and by how much. The second objective of this thesis is to compare the results obtained from the boric acid and borax runs with a previously studied inhibitor (ascorbic acid) and determine which is more effective.

BACKGROUND

The mechanisms involved in brightness reversion have been studied for a number of years. However the most significant advancements in understanding it have come within the last few years. The basic process of photoyellowing occurs as a result of exposure to light, especially light in the near ultraviolet (UV) range around 260 to 600 nm in wavelength. The light is absorbed by the chromophore groups of the lignin and various intermediate radical products are formed.² These radicals then form other radicals, most notably phenoxy and ketyl radicals. These radicals react further to form the yellow ketone and quinone products causing the brightness reversion. The ketone and quinone products also act as secondary chromophores that continue the process. Figure 1 illustrates the major steps in this reaction process.³

There have been three strategies used to attack the problem of photoyellowing: 1) Apply a UV absorber to the surface that would prevent the light from reaching the chromophore groups and therefore preventing the reaction process from starting. 2) Eliminate or modify the chromophore groups so they are unable to produce the radicals. 3) Use a radical scavenger to consume the radical compounds as they are formed and before they have a chance to form the colored ketone and quinone products.

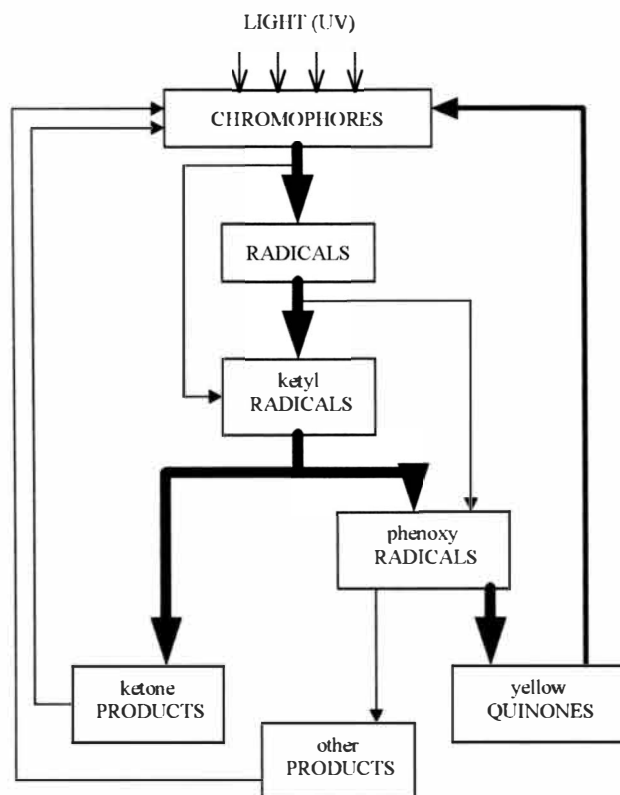


Figure 1: Major steps in reversion process.

Recent work to modify or eliminate the chromophores has been unsuccessful. The compounds are very complex and are not fully understood, and an effective method to modify or eliminating them has not yet been achieved. Mainly because there are so many different groups of chromophore compounds known to exist in lignin – which include carbonyl, stilbenes, phenyl coumarans, coumaryl alcohols and biphenyls, and quinone methides. With so many different groups it has been difficult to define which ones are the most significant trouble makers and target them for treatment. It should also be noted that even if it could be narrowed down to a few select compounds, the chemistry of chromophores in lignin may be subtly different from that of model

compounds in solution, therefore making the process of studying them very difficult.⁴

The application of chemicals to absorb the near ultraviolet light has brought relatively good success, at least at the laboratory level.

Hydroxybenzophenones have been studied extensively and are able to significantly stabilize mechanical pulps.⁵ However the application rates are relatively high and it is an expensive chemical to use. Much too expensive for any commercial application to even be considered.

The work done using radical scavengers has provided some significant results as well. Ascorbic acid, thiols, thioethers, phosphinic acids, and diene-type organic compounds are a few of the radical scavenging anti-oxidants that have been tested with varying degrees of success.^{6 7 8 9} These compounds work by consuming the various radicals as they are being formed and preventing the formation of the final ketone and quinone products. It is in this area that this thesis is looking into further.

With that in mind, the paper industry is not the only industry to use radical scavengers. There are a number of industries that use these chemicals, however only a few use wood fibers extensively. Mechanical pulps are also used in a variety of applications other than the production of paper.

Unbleached high yield mechanical pulps are also used by the construction industry as blowing insulation. However in order for the pulp to be used as insulation it must pass strict fire and corrosion tests. Mixtures of borax and

boric acid are used to provide the fire retardant properties required for this application.

Flame retardants act to form surface barriers that interfere with the combustion oxidation process.¹⁰ Borax, because of an abundance of available H^+ ions it is a good hydrogen donor and radical scavenger. It is the radical scavenging ability of borax that will be tested to inhibit the light induced brightness reversion process. Although many other radical scavengers have been used successfully, none of the past work has looked into borax or boric acid as a potential yellowing inhibitor. If it is shown that borax can inhibit the photoyellowing process then it would introduce another, possibly more effective and less expensive additive for further study.

EXPERIMENTAL PROCEDURE

MATERIALS AND EQUIPMENT

The pulp used in this project was a bleached aspen CTMP. The pulp was refined slightly in a laboratory PFI mill. The borax was supplied by US Borax Inc., the specific product used in this project was called Neobor. The chemical name of the compound is sodium tetraborate pentahydrate. The ascorbic acid and boric acid were obtained from the WMU chemistry department. The fadometer used in this study was a SunTest CPS+, provided by the Paper Department of WMU. All runs were conducted in this instrument with a xenon arc lamp and using filter D. According to the operating instructions for the instrument filter D best simulated the light spectrum of sunlight, including a “natural” distribution of light in the UV range.

METHODS

The pulp was refined slightly using a laboratory PFI mill, following TAPPI method T-248, for 1000 revolutions and reaching a final freeness of 290 CSF. The slight refining was conducted to make the fibers more receptive to chemical treatment. After refining the pulp was formed into handsheets using the british handsheet maker and allowed to air dry. Distilled water was used to make the handsheets and during all stages of the treatment process. This was done to prevent any ions present in the water to react with the additives or with the lignin in the sheet. The chemicals (ascorbic acid, boric acid, and borax) were then dissolved in distilled water at 5% wt./wt. concentrations. A spray

bottle was used to surface apply the chemical additives to the desired application level outlined in the experimental design (Table 1).

The samples were surface treated for two main reasons. First, ultra violet (UV) light has a very short wave length and thus does not travel very deeply into the sheet. Therefore only the surface of the sheet needs to be protected. A prime example of this is would be a newspaper that has been exposed to the sun for a significant period of time. The top surface, facing the sun, ends up faded and the under side is relatively untouched.

The second reason to surface apply, is that it eliminates the worry of retention problems and the possibility for competing reactions with other wet-end additives. Both of which would reduce its effectiveness and would result in higher, more costly, addition rates. Therefore, if a radical scavenger is to be used in a commercial process they would most likely be sprayed or applied as a size press application.

After treatment the samples were placed in the fadometer and exposed to light for a total of 12 hours. The TAPPI brightness values were checked at 3 hours intervals. According to previous research done on photoyellowing 12 hours in an instrument of this size is equal to about 6 months of normal light conditions.¹¹

EXPERIMENTAL DESIGN

The following table illustrates the experimental runs that were conducted during this project. There were a total of 64 runs with 32 distinct

chemical addition levels. In runs 1 through 32 mixtures of borax and boric acid were used, and half of the samples were exposed to light, while the second group was not. The unexposed samples were run through the same routine as the light exposed samples, however when they were placed in the fadometer they covered by a piece of heavy cardboard while the light exposed samples were placed on top. The purpose of the unexposed samples was to provide a baseline of what the additives did to the brightness of the sheets when they were exposed the 35°C temperature of the fading chamber. It has already been shown by previous work that heat can induce fading of mechanical pulps also.

The lower half of the table, runs 33 through 64, show the ascorbic acid and boric acid samples. Runs 1, 9, 17, and 25 are duplicates of runs 33, 41, 49, and 57 respectively. These duplicate runs were conducted to test the repeatability of the experimental methods and procedures.

Table 1: Experimental Design

		<u>Exposed to Light</u>				<u>NOT Exposed to Light</u>			
		Boric Acid (%)				Boric Acid (%)			
		0	1	2	4	0	1	2	4
Borax (%)	0	1	9	17	25	5	13	21	29
	1	2	10	18	26	6	14	22	30
	2	3	11	19	27	7	15	23	31
	4	4	12	20	28	8	16	24	32
Ascorbic Acid (%)	0	33	41	49	57	37	45	53	61
	1	34	42	50	58	38	46	54	62
	2	35	43	51	59	39	47	55	63
	4	36	44	52	60	40	48	56	64

RESULTS AND DISCUSSION

As it was mentioned before runs 1, 9, 17, and 25 are duplicates of runs 33, 41, 49, and 57 respectively. This was done to check the repeatability of the experimental design and procedures. The following graph (Figure 2) shows the results of the duplicate runs for 2% boric acid, runs 17 and 49. These runs provided very good results, and were the worst of the four duplicate runs. After 12 hours of fading the final change in brightness values of run 17 was 26.20, and run 49 was 27.44. That works out to about a 5% difference between the two runs, which is an acceptable margin of error. This all indicates that the experimental procedures of this thesis were repeatable.

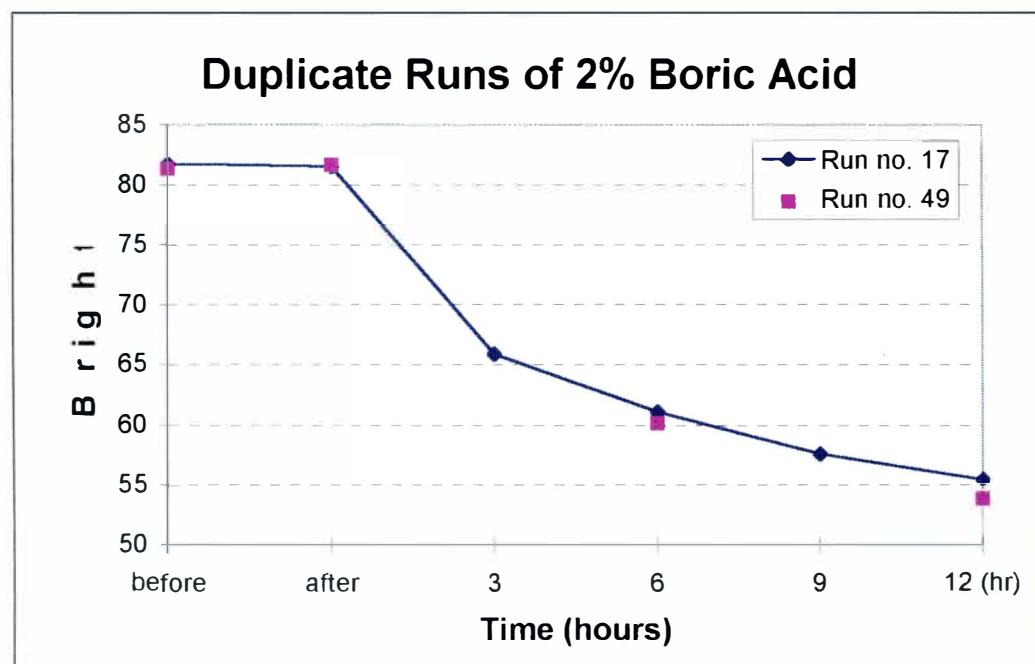


Figure 2: Duplicate runs of 2% boric acid.

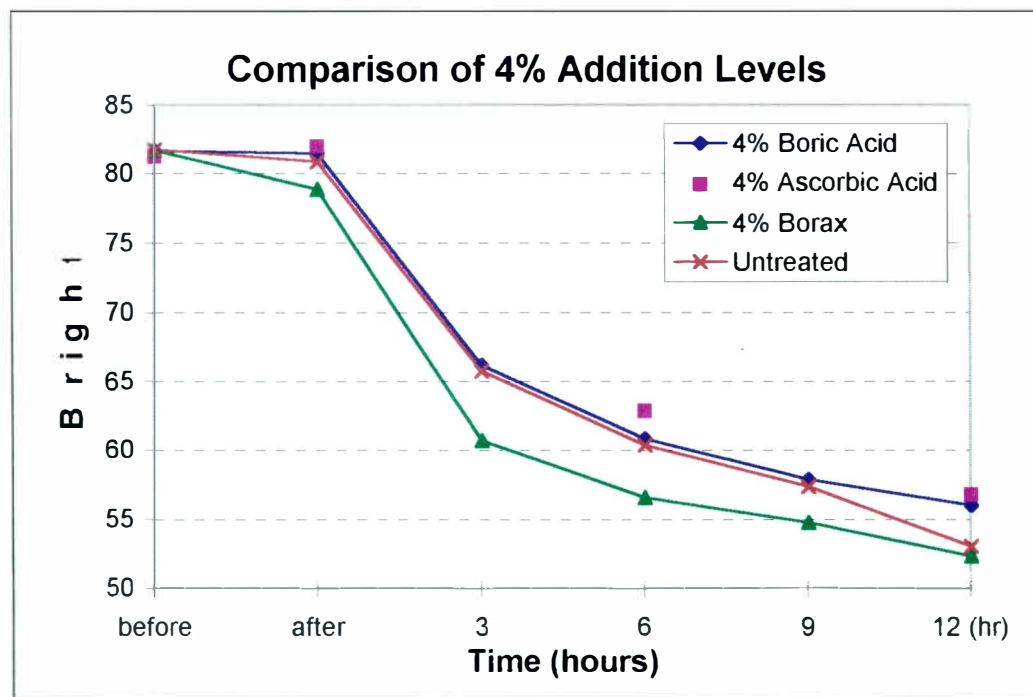


Figure 3: Comparison of 4% addition levels.

The next graph (Figure 3) shows the brightness reversion of runs 1 (untreated), 4 (4% borax), 25 (4% boric acid), and 36 (ascorbic acid). This graph indicates how well each of the additives performed individually at the highest concentration tested. The borax performed the worst, it actually dropped the brightness of the sheets right after treatment by 2.84 points. The brightness never completely recovered from this initial drop, however it did appear to slow the rate of brightness reversion slightly between the 9 and 12 hour measurements when compared to the untreated sample. Unfortunately data was only obtained up to 12 hours of light exposure. It would be interesting to see if this trend continued. It is possible that the borax works to slow at inhibiting the reaction of the secondary chromophores, thereby slowing the brightness reversion later in the reversion process.

The boric acid and ascorbic acid performed about equally, and provided a marginal improvement over the untreated samples up to the 9 hour measurement and then a significant improvement at the 12 hour reading. It is interesting that the slopes of the boric acid, ascorbic acid, and borax are about equal at all stages of the fading process. This might also indicate that the additives are only working once the concentration of radical compounds are at high enough levels. That would explain why the boric and ascorbic acids do not seem too effective until after 12 hours of fading.

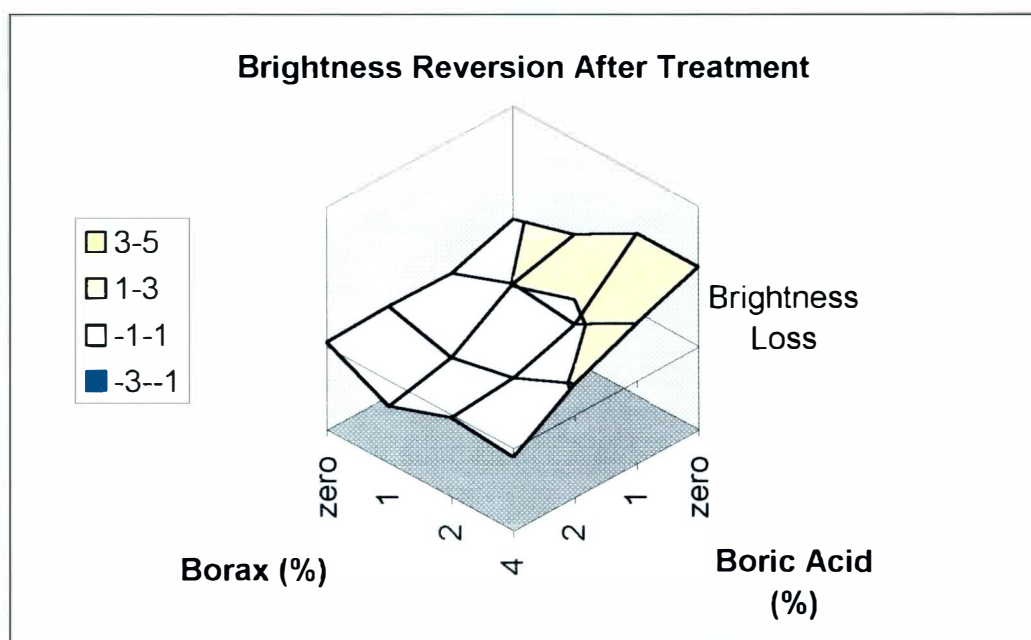


Figure 4: Borax and boric acid after treatment.

Figure 4 is a surface plot of the sixteen runs consisting various concentrations of borax and boric acid. The X and Y axis have the concentrations of the additives and the Z axis represents the amount of brightness reversion, with the largest brightness loss at the top of the graph. In this graph the brightness drop caused by the addition of borax is also see as it

was in Figure 3. The yellow part of the graph shows a brightness loss of between 1 and 3 points just by the addition of borax to the sheets. It is interesting that when boric acid was added with the borax it prevented the borax from dropping the brightness. At the 4% addition of boric acid and borax the brightness actually increased by 0.3 points of brightness.

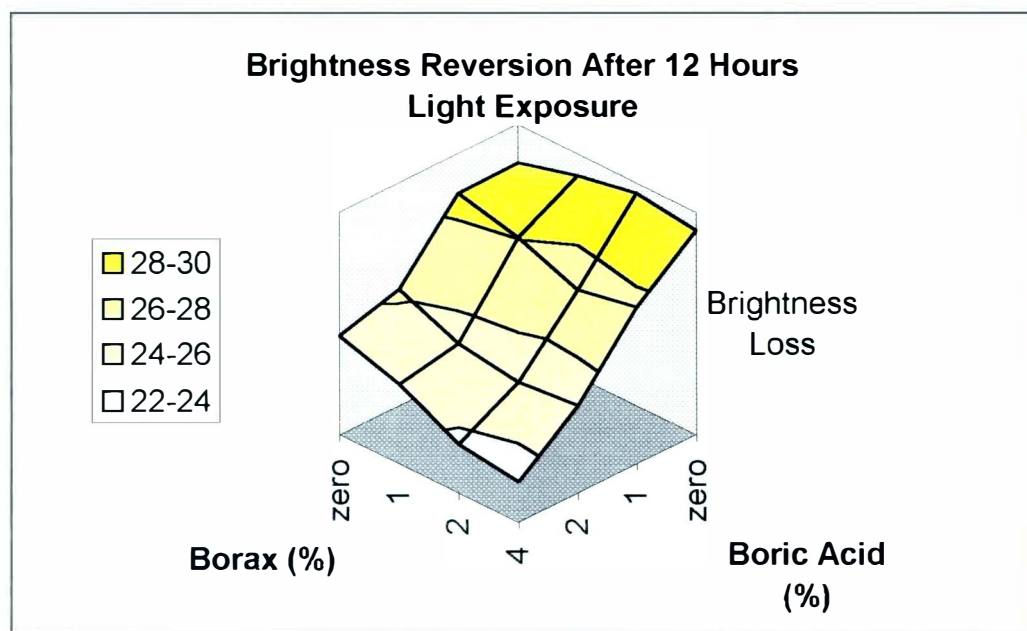


Figure 5: Borax and boric acid after 12 hours of light.

Figure 5 represents a graph of the same runs as Figure 4, however this graph is after 12 hours of light exposure where the one before was right after treatment. It has already been shown that borax when used alone causes brightness reversion and that boric acid improved the brightness stability. This graph shows that when both additives were used in combination, the poor effects of the borax were canceled out. As more boric acid was used, more brightness stabilization was obtained. It is possible that the boric acid and borax were working to prevent brightness reversion in slightly different ways.

It is very possible that the borax and boric acid were consuming different radicals and therefore inhibiting the reversion process along multiple pathways. It is also possible that one of the additives could be regenerating the other as it is being consumed by the reversion process, thereby increasing the useful life of the scavenger.

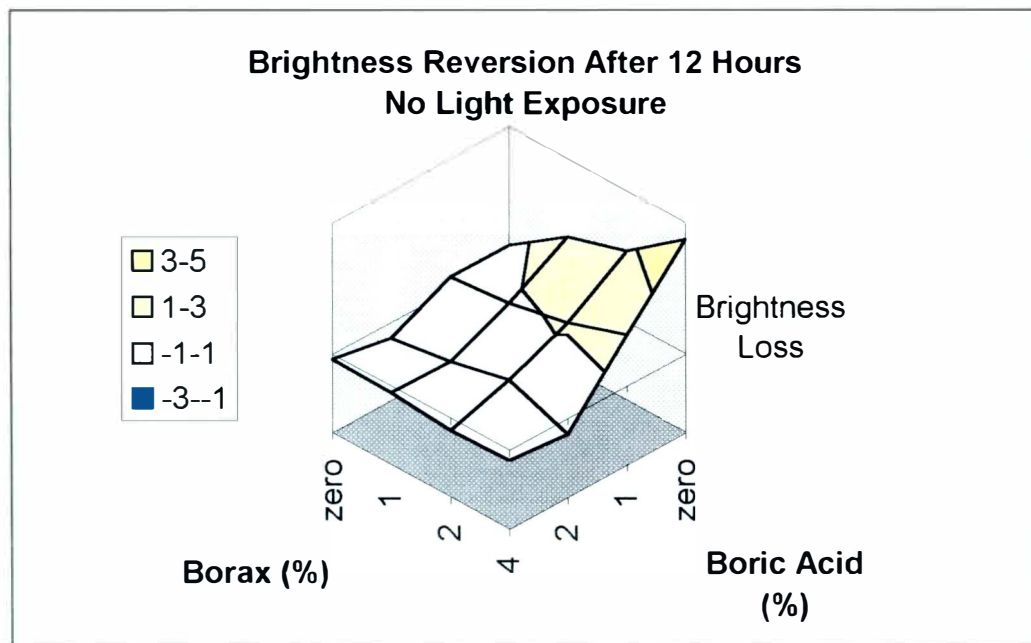


Figure 6: Borax and boric acid after 12 hours unexposed to light.

Figure 6 is a graph of the unexposed samples using the same addition levels as before. This graph shows the brightness reversion after the same 12 hour time period as before. It indicates that when the samples are left in the dark the boric acid treated samples appear to increase in brightness just slightly at the 2% and 4% boric acid addition levels. This happened at all of the 4% boric acid addition level samples, even when borax was also applied. The boric acid when applied at 2% or higher seemed to work very well at controlling the harmful effects of the borax. The samples treated with borax only showed just

the opposite trend as the boric acid. They had more brightness reversion after 12 hours when compared to their brightness after treatment. This indicates that the borax does not work to inhibit the thermal reversion process, and boric acid does.

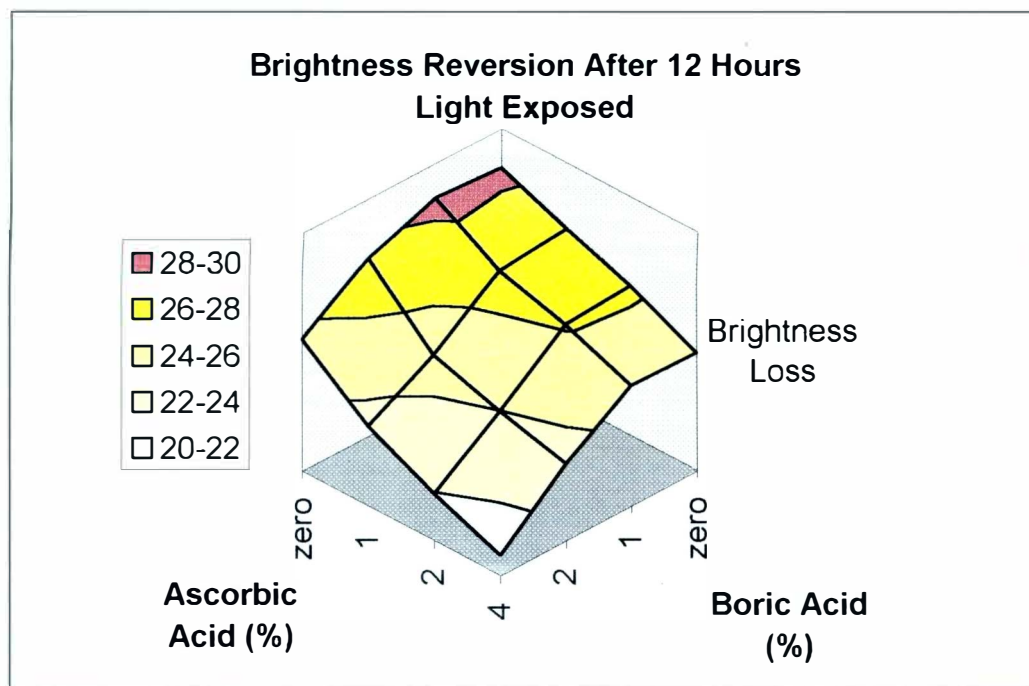


Figure 7: Ascorbic acid and boric acid after 12 hours light exposed.

Figure 7 is a graph of the runs with mixtures of ascorbic acid and boric acid. This graph indicates that boric acid and ascorbic acid work about equally well when used individually. However when the two additives are used in conjunction with each other the benefits are additive. Overall, ascorbic acid worked slightly better than the boric acid, however both contributed to preventing brightness loss.

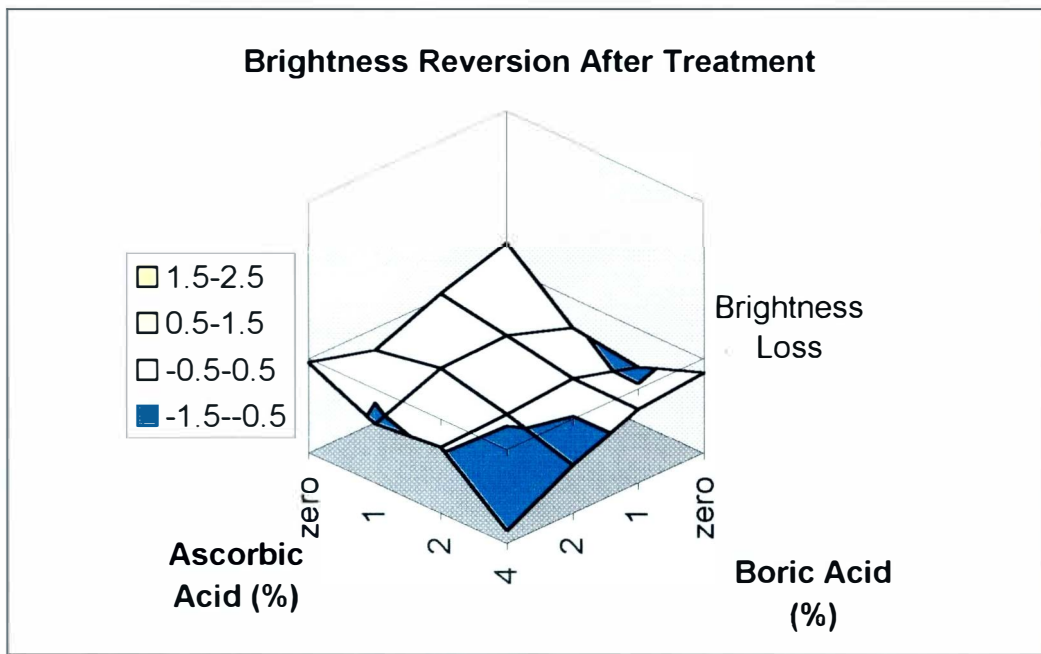


Figure 8: Ascorbic acid and boric acid after treatment.

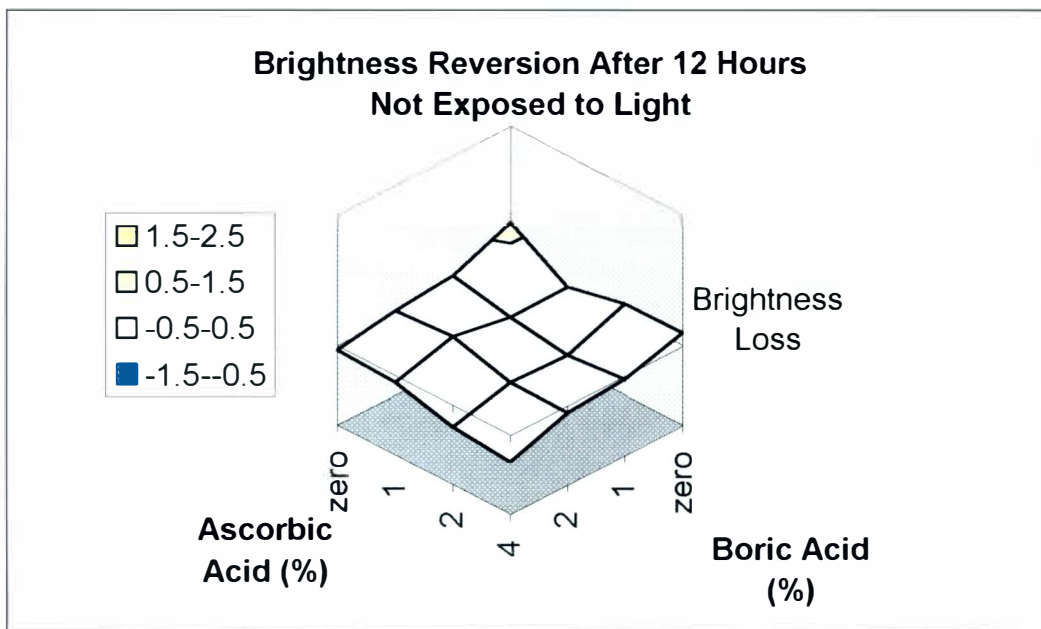


Figure 9: Ascorbic acid and boric acid after 12 hours unexposed to light

Figure 8 is a graph of the brightness change of the ascorbic acid and boric acid samples after the treatment process. It shows a significant amount of bleaching taking place especially at the higher addition levels of both

additives. This bleaching was probably caused by the reduction of some of the ketone and/or quinone products to less colored compounds. It was however short lived. Figure 9 shows the same set of samples after going through the 12 hour treatment routine in the dark. The samples lost the majority of there bleaching and have almost returned back to their original brightness levels before treatment. These results were also observed in other studies.¹² It is believed that while in dark storage the ascorbic acid reacts directly with the lignin and forms ascorbate-derived intermediates that happen to be yellow in color.

CONCLUSIONS

Photoyellowing or brightness reversion is caused by the photooxidation of lignin chromophore groups. However, even though there have been a number of advancements in recent years in the understanding of the reversion process, there is still much to be learned.

Borax, when used alone, reduced the brightness of the sheets directly after treatment by almost 3 points. It stayed at that level below the untreated samples through most of the fading process. However, at the last brightness measurement (12 hours of light exposure) the rate of brightness loss improved slightly over that of the blank runs.

Boric acid showed no significant change in brightness after treatment. The dark storage samples did show a small amount of bleaching at the 2% and 4% addition level. Boric acid also inhibited the reversion process slightly up to 9 hours of fading, then significantly after 12 hours. Boric acid was also able to counteract the darkening effects of the borax treatment when the two were used together. Boric acid and borax appear to be working to prevent brightness reversion in slightly different ways. They could be consuming different radicals and therefore inhibiting the reversion process along multiple pathways. It is also possible that one of the additives could be regenerating the other as it is being consumed by the reversion process, thereby increasing the useful life of the scavenger.

Ascorbic acid showed similar light exposure results as the boric acid did. The ascorbic acid bleached the sheet directly after treatment, in some cases by more than a full point of brightness. This bleached indicates that the ascorbic acid is able to reduce some of the ketone or quinone products to less colored compounds. However, dark exposure showed that this bleached effect was temporary and after 12 hours the brightness values had almost returned to their original, pre-treated levels.

When ascorbic acid and boric acid were used together they had an additive effect on inhibiting brightness reversion. With ascorbic acid appearing to be slightly more effective at the lower concentrations. The most effective way to use the radical scavengers is in combinations. They showed significantly better results when used together. The 2% boric acid-2% ascorbic acid sample showed much better results than the 4% boric acid and 4% ascorbic acid samples. This again indicates that the scavengers are probably scavenging different types of radicals.

Now it has been shown that Boric acid and borax can inhibit the light induced brightness reversion of bleached CTMP and introduced another group of additives for further study.

RECOMMENDATIONS

The following are a list of recommendation for future study that could be conducted at the university level.

1. Look at the effects of borax when used with ascorbic acid. See if ascorbic acid is able to prevent the brightness loss associated with the addition of borax to the same degree that boric acid did.
2. Conduct the brightness reversion runs for a longer period of time, longer than 12 hours. This thesis concentrated on the first 12 hours because that is when the largest amount of brightness reversion takes place. It would be interesting to see what the long term effects are of these chemicals on the brightness.
3. Study the effects of long term dark storage of the treated samples. It would not be very practical to have an additive that works under light conditions and do just the opposite when the rolls of paper are sitting in a warehouse, waiting to be used.

APPENDIX A: RAW DATA

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
none	none	none	1	81.65	80.78	65.71	60.33	57.33	53.03
none	none	1%	2	81.19	79.63	62.9	57.88	55.2	51.98
none	none	2%	3	81.71	78.88	61.33	56.11	54.68	52.09
none	none	4%	4	81.63	78.79	60.64	56.53	54.73	52.3

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
none	none	none	5	81.34	80.6	80.56	80.57	80.67	80.88
none	none	1%	6	81.2	79.51	78.81	79.53	79.91	79.2
none	none	2%	7	81.22	78.58	78.42	78.34	78.77	78.52
none	none	4%	8	82.46	78.77	78.13	78.34	78.74	78.11

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
none	none	none	33	81.51	81.11	N/A	59.46	N/A	53.19
none	1%	none	34	81.32	81.64	N/A	60.62	N/A	53.94
none	2%	none	35	81.67	81.93	N/A	61.81	N/A	55.07
none	4%	none	36	81.17	81.89	N/A	62.79	N/A	56.72

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
none	none	none	37	81.63	80.94	N/A	80.89	N/A	80.98
none	1%	none	38	81.26	81.08	N/A	81.35	N/A	81.28
none	2%	none	39	81.48	81.59	N/A	81.53	N/A	81.26
none	4%	none	40	81.61	81.86	N/A	81.91	N/A	81.37

before = Brightness values before chemical treatment.

after = Brightness values after chemical treatment has dried.

Chemical addition levels are reported as a percentage based on the following:

$$\% = (\text{wt. of additive}) / (\text{wt. of o.d. paper}) * 100.$$

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
1%	none	none	9	81.75	81.58	64.95	60.23	56.99	53.16
1%	none	1%	10	81.73	80.71	65.47	59.86	57.69	53.69
1%	none	2%	11	81.11	80.32	63.85	59.34	57.09	53.89
1%	none	4%	12	81.43	79.37	63.51	58.94	56.96	53.78

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
1%	none	none	13	81.77	80.6	80.83	80.27	80.77	81.27
1%	none	1%	14	81.69	80.94	80.54	80.43	81.3	80.96
1%	none	2%	15	81.21	80.3	80.46	79.83	79.47	80.01
1%	none	4%	16	80.96	78.37	79.29	79.69	79.96	79

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
1%	none	none	41	81.26	81.19	N/A	59.34	N/A	52.72
1%	1%	none	42	81.58	81.69	N/A	61.39	N/A	54.67
1%	2%	none	43	81.19	81.51	N/A	62.45	N/A	55.06
1%	4%	none	44	81.64	81.97	N/A	63.24	N/A	56.58

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
1%	none	none	45	81.72	81.67	N/A	81.73	N/A	81.53
1%	1%	none	46	81.42	81.62	N/A	81.82	N/A	81.58
1%	2%	none	47	81.55	81.92	N/A	81.87	N/A	81.6
1%	4%	none	48	81.39	81.88	N/A	81.61	N/A	81.46

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
2%	none	none	17	81.69	81.47	65.82	61.07	57.6	55.49
2%	none	1%	18	81.59	81.97	66.1	61.28	58.43	56.3
2%	none	2%	19	81.76	81.65	66.37	61.73	58.8	56.83
2%	none	4%	20	81.58	80.46	66.72	61.52	58.68	56.45

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
2%	none	none	21	81.55	81.9	81.76	81.5	81.82	82.16
2%	none	1%	22	81.28	81.34	81.08	81.65	81.43	81.58
2%	none	2%	23	81.91	81.58	81.82	81.67	81.37	81.68
2%	none	4%	24	81.52	81.08	80.84	81.16	81.86	82.13

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
2%	none	none	49	81.26	81.61	N/A	60.11	N/A	53.82
2%	1%	none	50	81.09	81.24	N/A	60.56	N/A	56.22
2%	2%	none	51	81.67	82.08	N/A	63.1	N/A	57.68
2%	4%	none	52	81.43	82.16	N/A	63.56	N/A	58.2

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
2%	none	none	53	81.64	81.73	N/A	81.6	N/A	81.55
2%	1%	none	54	81.29	81.09	N/A	81.35	N/A	81.12
2%	2%	none	55	81.55	81.86	N/A	81.91	N/A	81.68
2%	4%	none	56	81.72	82.1	N/A	82.24	N/A	81.86

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
4%	none	none	25	81.55	81.39	66.14	60.82	57.83	55.99
4%	none	1%	26	81.58	82.49	66.56	61.31	58.7	56.72
4%	none	2%	27	81.71	81.81	66.81	62.22	59.79	57.96
4%	none	4%	28	81.64	81.94	67.18	62.87	60.5	58.22

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
4%	none	none	29	81.69	81.93	81.73	81.83	82.12	81.89
4%	none	1%	30	81.54	81.93	81.64	81.42	81.71	81.79
4%	none	2%	31	81.61	81.7	81.88	81.54	81.75	82.09
4%	none	4%	32	81.33	81.76	81.9	81.68	82.01	81.72

Light Exposed

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
4%	none	none	57	81.66	81.72	N/A	61.93	N/A	56.12
4%	1%	none	58	81.52	82.08	N/A	62.25	N/A	58.16
4%	2%	none	59	81.38	81.83	N/A	63.84	N/A	59.42
4%	4%	none	60	81.81	83.12	N/A	65.35	N/A	60.94

NOT Exposed to Light

Boric Acid	Ascorbic Acid	Borax	Run No.	before	after	3	6	9	12 (hr)
4%	none	none	61	81.68	81.59	N/A	81.84	N/A	81.76
4%	1%	none	62	81.25	81.56	N/A	81.41	N/A	81.38
4%	2%	none	63	81.33	82.04	N/A	81.69	N/A	81.73
4%	4%	none	64	81.49	82.87	N/A	82.18	N/A	81.98

LITERATURE CITED

- ¹ Cockram, R.A., "CTMP in Fine Papers", *International Mechanical Pulping Conference Proceedings*, The Finnish Pulp and Paper Research Institute, Helsinki, 1989, p.20.
- ² Andrady, A.L., "Photoyellowing of mechanical pulp. Part 1: Examining the wavelength sensitivity of light-induced yellowing using monochromatic radiation", *TAPPI Journal*, August 1991, p.162.
- ³ Leary, G.J., "Recent Progress in Understanding and Inhibiting the Light-Induced Yellowing of Mechanical Pulps", *Journal of Pulp and Paper Science*, 20(6): J156 (1994).
- ⁴ Leary, G.J., 20(6): J157 (1994).
- ⁵ Dence, C.W, and Reeve, D.W., Pulp Bleaching: Principles and Practice, TAPPI Press, Atlanta, 1996. p.204.
- ⁶ M. Ratto, I. Forsskaki, J. Janson, "Photostabilization of mechanical pulps by polyvinylpyrrolidone", *TAPPI Journal*, 76(6): 67-70 (1993).
- ⁷ X. Pan, L.C. Harvey, "Brightness reversion of mechanical pulps. Part VI: Cooperative photostabilization approaches for high-yield pulps." *Journal of Pulp and Paper Science*, 22(4): J135 (1996).
- ⁸ Ragauskas, A.J., "Photoyellowing of mechanical pulp. Part 1: Inhibition of brightness reversion by unsaturated compounds", *TAPPI Journal*, 76(12): 153-157 (1993).
- ⁹ Dence, C.W, and Reeve, D.W., p.205.
- ¹⁰ "Thermal analysis of chemically treated jute fibers", *Textile Research Journal*, March 1993, pp.143-150.
- ¹¹ Bailey, A.L, and Lamont, L.J., "A standard procedure for accelerated testing and measurement of yellowing by light in papers containing lignin", *TAPPI Journal*, 76(9): 175-180.
- ¹² Schmidt, J.A., and Heitner, C., "Thermal yellowing of lignin-containing pulps: Acceleration by ascorbic acid.", *Journal of Pulp and Paper Science*, 23(11): J532-538.