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A Study of the Use of Borates in Semi-Chemical Pulping

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Abstract

The purpose of this project was to identify sodium metaborate as a pulping chemical in semi-chemical pulping with soda ash. The experimental design included four digester cooks with 0%, 10%, 20%, and 40% addition of the borate compound. The resulting yields were 81.3%, 79.2%, 77.4%, and 74.5% respectively. Therefore, under the definition of pulping, sodium metaborate was considered a pulping chemical. The pulps were mechanically refined. The resulting screened rejects increased with increasing borate addition. Handsheets were made and tested for strength and optical properties. The tensile and mullen strengths of the handsheets increased with addition of borates up to 20%, but degradation of the bonding properties occurred at high addition levels (40%). The tear strength increased dramatically (up to 24.1%) with the addition of borates to the pulping liquor. Brightness and visual color were slightly improved. The results indicate that the sodium metaborate was an effective pulping chemical with a tendency to be selective in delignification. Further work should be performed to compare the effect of substitution against conventional non-borate pulping, and possible changes in bleached pulp quality.

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Introduction

The purpose of this project was to identify sodium metaborate as pulping chemical in the semi-chemical pulping process. Pulping methods are used in the paper industry to separate individual cellulosic fibers from wood sources. This can be accomplished by chemical and/or mechanical means. There are three major categories of pulping methods: mechanical, chemical, and semi-chemical. The mechanical pulping methods utilize grinding and shredding methods to separate wood into fiberous pulp. The key mechanism in pulping is the use of mechanical energy. This method has the advantage converting high percentages of wood into individual fibers (85-95%). The resulting pulp consists of short, impure fibers. Chemical pulping is divided into to main categories: kraft and sulfite. Kraft pulping is performed at alkaline pH's. This process involves cooking wood chips under pressurized and heated conditions in a solution of sodium hydroxide and sodium sulfide. The resulting yield of pulp is low (40-55%). This process produces pulp that consists of long, strong fibers. The pulping mechanism use here is the attack of lignin compounds in the wood chips by the cooking chemicals. The lignin is solubilized and thus the fibers are easily separated. The sulfite process produces similar results at an acidic pH and utilizes sulfurous acid and bisulfite as the cooking liquor. The semi-chemical pulping method is an intermediate process that utilizes the properties of both of the other methods. Chemicals are used to partially delignify wood chips in a heated, pressurized environment. The "softened" wood chips are then defiberized by a mechanical means. The resulting pulp yields are normally 55-85%. Pulp characteristics are usually between the values of chemical and mechanical pulps.

The use of semi-chemical pulping process is becoming more popular in the pulp and paper industry. Chemical pulp mills are infamous for foul odor emissions from the use of sulfur compounds in the pulping chemicals. Therefore, a need to eliminate sulfur in the pulping process has become vital. Chemical mills tend to require large operations for chemical recovery. The high capital costs needed for chemical mills is another factor for the increasing loss of interest in chemical pulping methods. Chemical pulps have the advantage of stronger and more bleachable characteristics over mechanical pulps. This has lead to a greater interest in developing pulping methods that will produce pulps with comparible quality of chemical pulps and more economically feasible.

The use of borates in the paper and pulp industry has been limited to other pulping methods and is utilized for purposes other than delignification. Semi-chemical pulps normally utilize sodium carbonate (soda ash) and sodium hydroxide as the pulping chemical. This project investigates the use of slightly alkaline borate compounds as an additive to delignify wood chips. The success of this project is based on a decrease in yield with the addition of sodium metaborate to soda ash in the cooking stage. The result of a decrease in yield signifies that the borates dissolved wood components under pressurized and heated conditions. This project then investigates the resulting pulp and handsheet properties to identify the effects of using borates. Finally, the results of the properties are used to identify the selectivity of borates in the pulping process.

This project will hope to note a large difference in pulping characteristics associated with addition of borate. A notable effect on pulp yield could identify borates as a more effective pulping chemical than conventional soda ash. The results can be used to further study on the possible cost effectiveness and increased quality.

Background

The use of borates in the pulp and paper industry has been investigated over the past two decades. Their use has been applied in many different areas: as a preservative for storage of fiber sources, as an additive in oxygen pulping, as an auto-caustisizing agent in kraft cooking processes, and as a buffer chemical in soda pulping. Borates have not been directly studied for use as a pulping chemical in the semi-chemical pulping process. The results of the past applications indicate that borate compounds could have an inherent delignifying reaction with wood sources.

Borates are a known preservative of wood substances. Past studies using bast plants, bamboo, and green wood logs have been performed prove this fact. In a study performed on the use of borax in the storage of nonwoody bast plants, the decay of the stored plants was measured and compared to untreated plants.(1) A mixture of borax and an amino acid surfactant was sprayed onto stacked bast plants. The results showed that the plants did not decay. After pulping with sodium hydroxide, the resulting pulp was able to be bleached without separating the borax from the plants.

In a similar study, borax was compared with two other preservatives to study the resulting decay of bamboo.(2) Three lots of bamboo were treated with each of the preservatives and stored for twelve months. Then, sulfate pulping and resulting handsheet properties were investigated and compared to untreated bamboo. The results indicate that the borax compound gave the best protection. Fiber losses were cut by 28-30% and pulp yield losses were reduced by 30-35%.

Borates have been used for storage of wood logs to reduce the losses of fiberous material due to decay. One such study treated green logs with aqueous solutions of borates and stored them for a period of one year.(3) The treatment prevented loss of wood substances and preserved the strength of handsheets and hardboard made from them. In another project, the effect of kraft pulp yield from the use of borate as a preservative was investigated.(4) After one year of storage, wood logs treated with borates and untreated wood logs were pulped in a kraft pulping process. Kraft pulp yields of fresh logs were 57.2%, yields of untreated stored logs were 41.2%, and borax treated logs gave a 45.1% yield. The borax had an effect of increasing yield by nearly four percent. An investigation of storage of wood chips with borate preservative in a silo was performed in another study.(5) In this study, two lots of maple chips, one treated and one untreated, were stored for one hundred days in separate storage silos. After this time period, it was found that fungi that causes severe deterioration was only found in the untreated chips. The untreated chips lost 2.4% of its wood substance, while, the treated chips lost only 1.4%.

The use of borates as an additive chemical in the oxygen pulping process have also been investigated. One such study compared this method with conventional kraft pulping.(6) The study was conducted on a various wood sources: poplar, spruce, and mixed hardwood. Yields of 59% bleachable-grade pulps were obtained for all pulps. The poplar and mixed hardwood pulps had pulp yields that were 8-9% more than kraft pulping. The strength properties were comparable to kraft pulps, except the tear value which was 20% lower than kraft pulps.(6) The spruce oxygen pulps were significantly lower than the kraft pulps. This indicated that the use of borates in oxygen pulping was limited to specific wood species. Other studies indicated that the resulting pulp strength of softwood was improved with some sacrifice in yield.

Borates have also been used for pretreatment of wood chips in the kraft pulping process. A study was performed pretreating chips with 2% and 4% borax to improve the kraft pulping qualities.(7) The results concluded that delignification increased with increasing concentration. Borax treated pulp had a lower brightness than the untreated pulp, but the strength properties were increased. As a result, the pretreatment allowed the pulping time to be decreased without a loss of yield.

Most previous work involving borates utilizes the auto-caustisizing nature of borates for replacement of sodium hydroxide in kraft and soda pulping. Spent liquor in the kraft pulping process must under-go extensive recovery measures to regenerate the pulping chemicals. The recovery process requires a lime-kiln operation and reaction with calcium oxide (lime). A conventional recovery system is very costly and complicated to operate. The sulfur containing emissions are very odorous and unpleasant to residents in the area of the pulp mill. The drive to eliminate these problems has led to the investigation of auto-caustisizing chemicals such as borates. The process of auto-caustization is based on the reaction between borates and sodium carbonate in a furnace. As a result, carbon dioxide is released and the caustic soda is regenerated for direct use in pulping.(8) The spent liquor, then, can be burned in a furnace and dissolved in water to reproduce the same alkaline salt for pulping. Therefore, no separate caustisizing step is needed for liquor recovery. A study showed that a direct replacement of one mole of borate for each mole of sodium hydroxide was possible without noticeably changing the yield or mechanical properties.(9) The effect of using borates for this purpose has led to extensive study on the resulting pulp quality. The result of one such study indicated that there were negligible losses in pulp yield and a slight increase in screened rejects.(10) Another study states that the yield and quality of pulp was not affected by borates.(11)

The odor, low yield, and high capital costs associated with kraft mills has led to an increased use of soda pulping. Borates have been studied in sulfur-free pulping processes as a buffer compound to improve the pulp properties. In soda pulping, dioxane is added as a protection for cellulosic chains to reduce degradation. Borax was added to this process with the result of increasing yield, fine structure, and chemical reactivity.(12) Yet, in another study using borates in soda-anthroquinone pulping, the pulp yields and quality were unacceptable.(11)

Although these previous studies have some contradictory results, most of them lead to the conclusion that borates seem to have a delignification affect. These studies attempted to utilize borate for a specialized area of chip storage of pulping processes. This project studies the delignification and pulping ability of borates. A previous study with soda-oxygen pulping indicated that a borate compound increased the selectivity of the pulping liquor for delignification.(13) In another report, the reaction of glycosides present in wood with borate ions was investigated. The results show that even the weakly alkaline borate ions degraded some glycosides much faster than sodium hydroxide at the same concentration. The borate ions acted as generators of hydroxide ions and degraded the glycosides into acidic compounds. This sensitivity of glycosides to borate ions could result in a pulping action during semi-chemical pulping.

In order for the hypothesis of this project to by substantiated, a couple of requirements must be met. A chemical is considered to be a pulping chemical if the reaction with solid wood components results in solubilized material, ie. decrease in yield. For borate to be considered an "effective" pulping chemical, the borate must readily attack the lignin component of the wood while not decomposing a significant portion of the cellulosic and hemi-cellulosic material. Once a decrease in yield is met, the results of handsheet testing should give a good indication of pulp quality. High contents of lignin would decrease the strength properties. Also, brown lignin components will create a darker sheet, ie. low brightness. Therefore, a correlation can be made in this project between the lignin content and the pulp properties.

Experimental Procedure

The experimental design of this experiment was controlled so that the only variable present was the borate concentration in the cooking liquor. The supplies needed consisted of mixed hardwood chips, sodium metaborate, and sodium carbonate. The equipment used for this experiment was: M&K digester, Waring blender, 200 mesh screen, PFI laboratory refiner, 6-slot vibrating screen, Noble and Wood handsheet maker, and all testing equipment. All of the equipment was available in laboratories in the Paper Department at Western Michigan University. The sodium carbonate was supplied by the paper department pilot plant. The sodium metaborate was supplied by U. S. Borax. The mixed hardwood chips were supplied by Menasha.

First, the moisture of the hardwood chips were determined to be 40.2%. Then, four separate batches of wood and liqour were prepared for cooking in the M&K digester. The following table illustrates the batch designs:

Batch Design:				
	Wood	***Liquor :Wood***	***Soda Ash***	***Borate***
Control -	250 g	4 : 1	30 g	0 g
Batch 1 -	250 g	4 : 1	30 g	3 g
Batch 2 -	250 g	4 : 1	30 g	6 g
Batch 3 -	250 g	4 : 1	30 g	12 g

Each set of cooks was performed in the M&K digester. The continuous and set heaters were both turned on and the cook was allowed to pressurize. When the pressure reached 10 psi, the pressure was released to let volatile compounds be released from the cooking chamber. The digester was pressurized again until a pressure of 170 psi was reached. At this point, the heaters were turned off and the pressure was slowly released. The cook times were 54-57 minutes total.

The wood chips were then rinsed with water for five minutes and placed in the Waring blender. The chips were disintegrated in the blender for five minutes at low speed. After blending, the pulp was washed with water over a 200 mesh screen. Samples were taken for pulp yield determination. The spent cooking liquor was saved for pH testing.

Each of the pulps were split into four equal parts for refining in the PFI refiner. The samples were refined for 10,000 revolutions in the PFI refiner. Then, the pulps were screened for shives and knots in the 6-slot vibrating screen. Samples were taken for freeness determination and screened rejects determination.

Knowing the consistencies of the pulp, samples were taken for making handsheets. Ten handsheets with a basis weight of 78 g/m2 were made for each pulp batch. The Noble and Wood handsheet maker was used for this. The handsheets were allowed to condition over-night in the testing lab. The handsheets were then cut into test specimens for testing: tear, tensile, stretch, burst, and brightness. The tear values were tested using a 16-sheet thickness and resulted in eight outcomes for each set. The burst was performed on each side of the handsheets for a total of 20 readings. Tensile and stretch were performed once for each sheet for a total of 10 readings. The brightness was performed on each side of the sheets once for a total of 20 readings for each set.

Table 3 - Raw Data for Control Cook

Time (minutes)	Temperature (degrees C)	Pressure (psi)
0	0	0
5	57.5	6
7	72	9
7.5	79	0
12	100	12
17	119	28
22	134	50
24	141	60
26	147.5	74
28	154	89
30	162	105
32	168	124
34	175	144
36	181	163
37	184	169
38	186	170
39	181	148
40	176	120
41	171	105
42	167	94
43	163	85
44	158.5	74
45	154	64
46	151	56
47	147	47
48	142	39
49	138	33
50	133	26
51	129.5	22
53	121	15
55	112.5	10
57	107	6

Table 4 - Raw Data for Batch 1 (10% Addition)

Time (minutes)	Temperature (degrees C)	Pressure (psi)
0	0	0
4	60	6
6	76	10
11	105	14
14	117	26
17	126	37
20	137	52
22	144	64.5
24	151	79
26	158	95
28	165	114
30	172	134
31	175	142
32	178	153
33	181	162
34	184	170
35	185	167
36	180	135
37	175	119
38	170	103
39	166	92
40	162	82
41	158	73
42	154	65
43	151	57.5
44	147	52
45	144	45
46	140	39
47	136	33
48	132	29
49	127.5	24
50	123.5	20
51	120	16
53	112	11
55	103	<6

Table 5 - Raw Data for Batch 2 (20% Addition)

Time (minutes)	Temperature (degrees C)	Pressure (psi)
0	0	0
3	52	<6
5	78	6
6	82	10
11	104	14
14	117	24
17	128	38
20	140	56
22	147	70
24	154	86
26	161	103
28	169	122
30	176	139
31	178.5	149
32	181	158
33	184	167
34	186	170
35	183	145
36	176	119
37	170	102
38	166	90
39	161	79
40	156.5	69
41	152	60
42	148	53
43	145	46
44	141	40
45	137	35
46	133	30
47	129	26
48	126	21
49	121	18
51	114	12
53	108	8
54	105	<6

Table 6 - Raw Data for Batch 3 (40% Addition)

Time (minutes)	Temperature (degrees C)	Pressure (psi)
0	0	0
3	48	<6
5	65	<6
7	83	10
12	106	14
15	116.5	23
18	127	36
21	138	52
23	145	63
25	152	78
27	159	94
29	166	111
30	169.5	121
31	173	133
32	176	144
33	180	155
34	183	164
35	185	170
36	187	165
37	179	127
38	172	106
39	166	90
40	160	76
41	154	63
42	149	53
43	144	44.5
44	139	37
45	133	30
46	129	25
47	124	20
48	119	15
49		11
50	111	7
51	104	<6

FIGURE 1

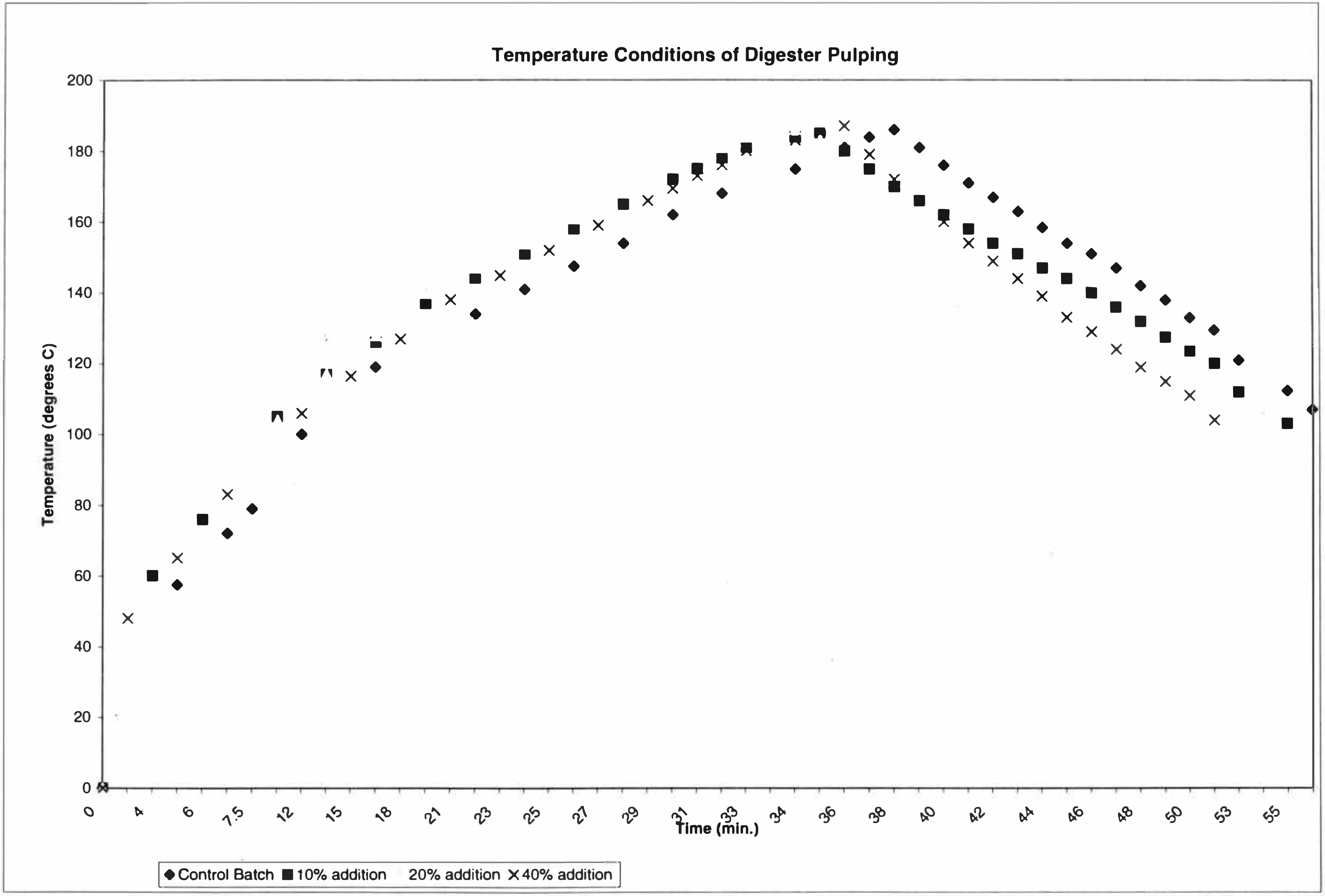
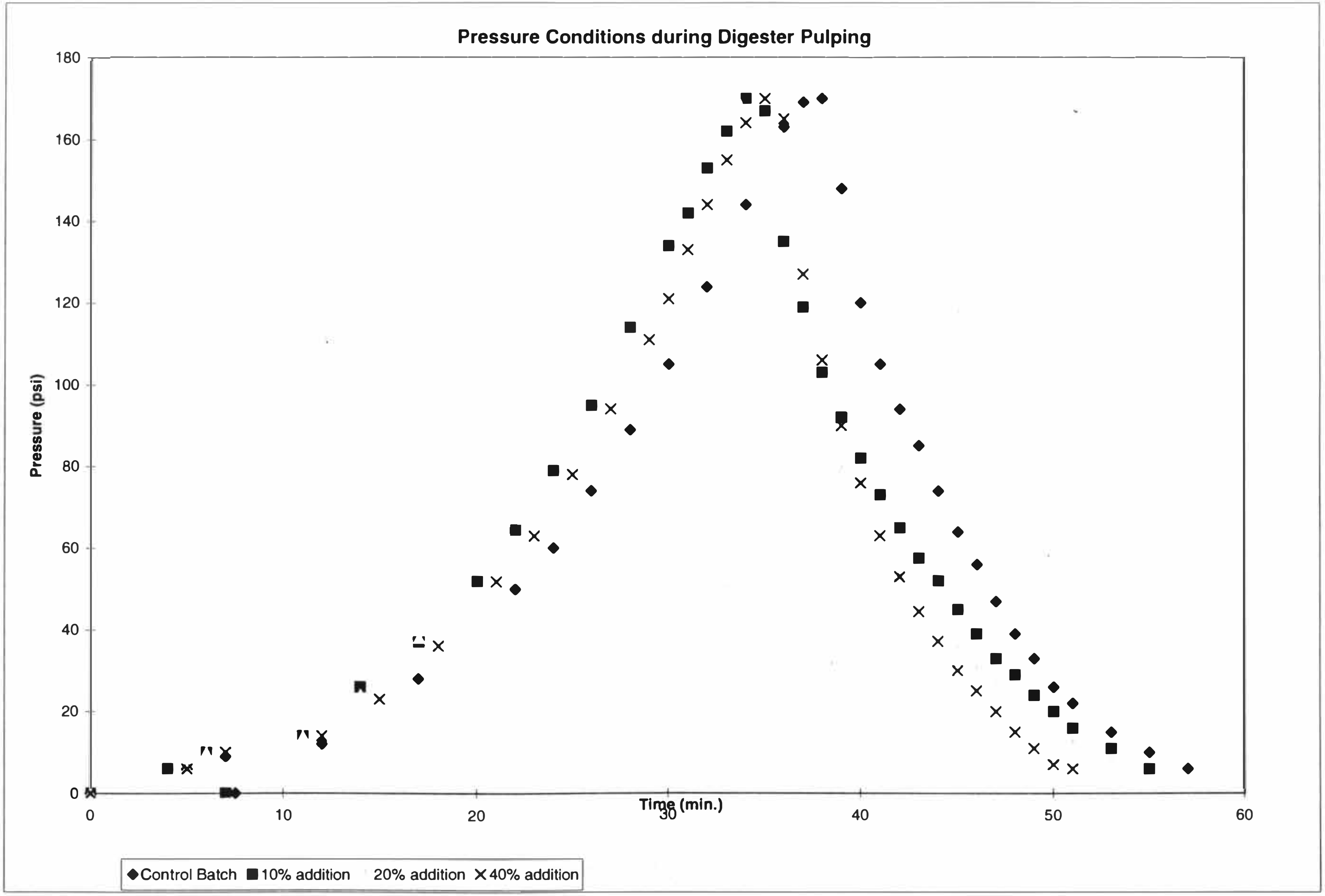
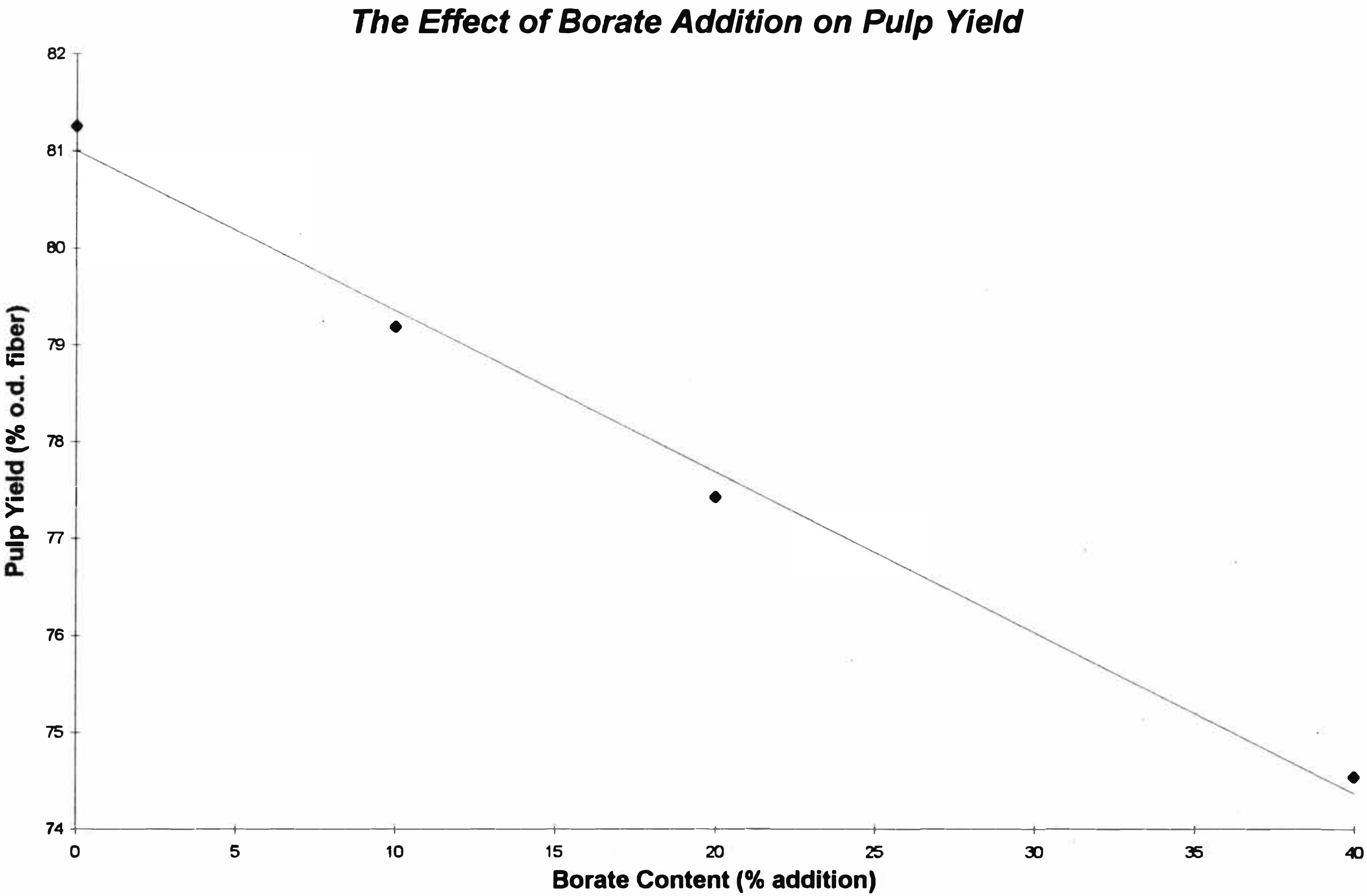

Temperature Conditions of Digester Pulping
Temperature (degrees C)
200
180
160
140
120
100
80
60
40
20
0
0
4
6
7.5
12
15
18
21
23
25
27
29
31
33
34
36
38
40
42
44
46
48
50
53
55
Time (min.)
Control Batch
10% addition
20% addition
40% addition

FIGURE 2



Pressure Conditions during Digester Pulping
Pressure (psi)
180
160
140
120
100
80
60
40
20
0
Time (min.)
0
10
20
30
40
50
60
Control Batch
10% addition
20% addition
40% addition

FIGURE 3:



The Effect of Borate Addition on Pulp Yield
Pulp Yield (% o.d. fiber)
82
81
80
79
78
77
76
75
74
0
5
10
15
20
25
30
35
40
Borate Content (% addition)

FIGURE 4:

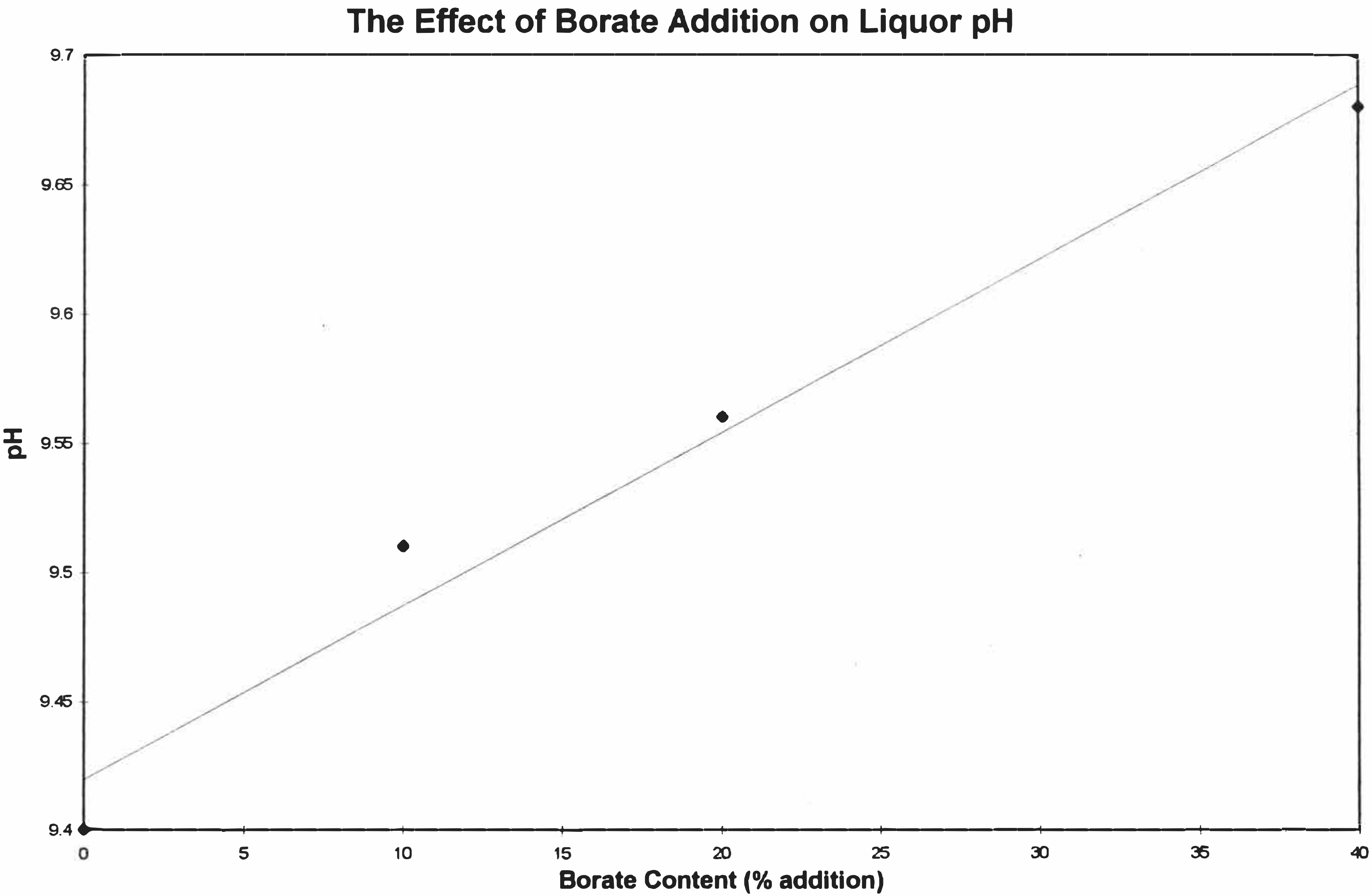

The Effect of Borate Addition on Liquor pH
pH
9.7
9.65
9.6
9.55
9.5
9.45
9.4
0
5
10
15
20
25
30
35
40
Borate Content (% addition)

Figure 5: The Effect of
Borate Addition on Screened Rejects

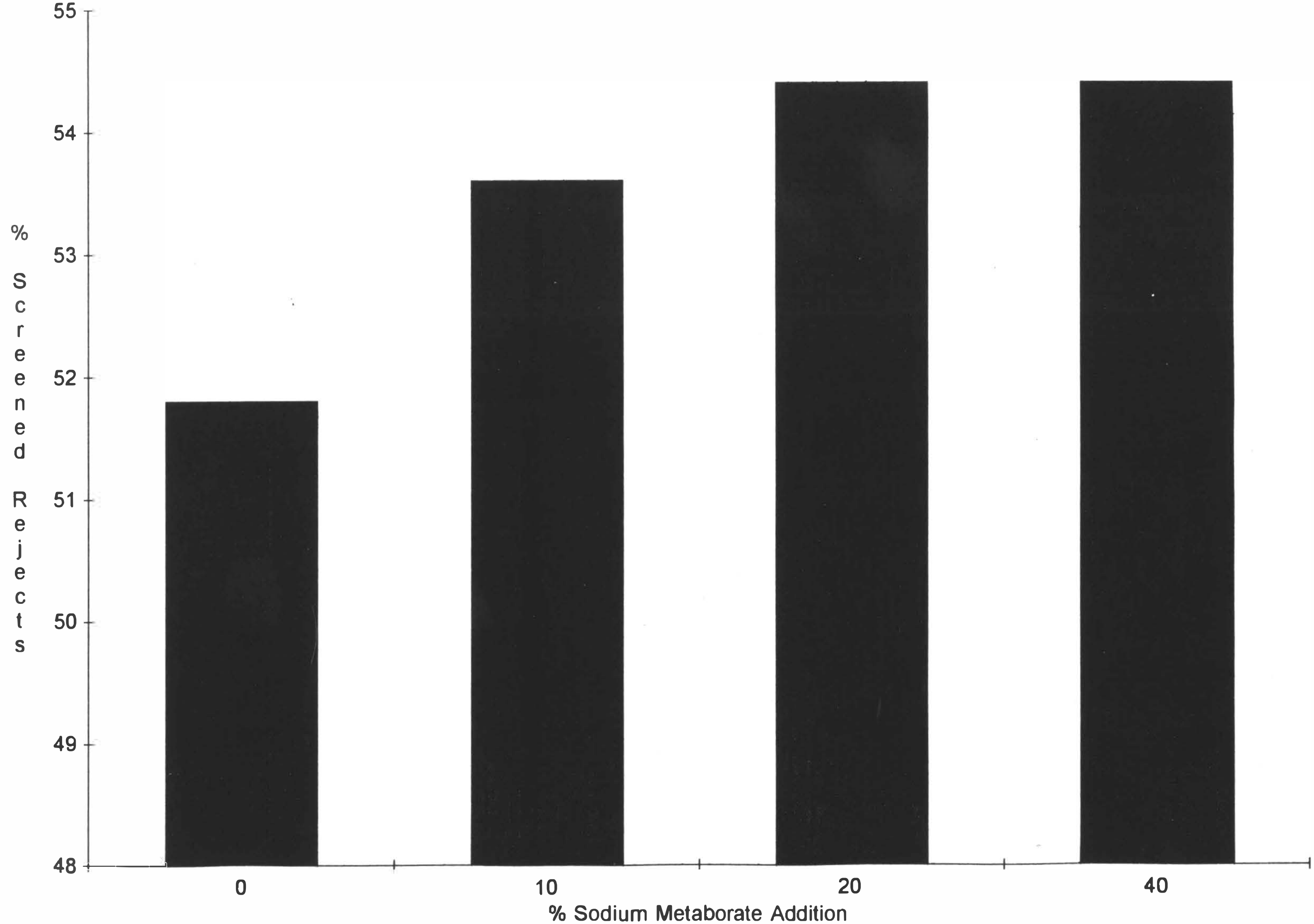


Figure 6:

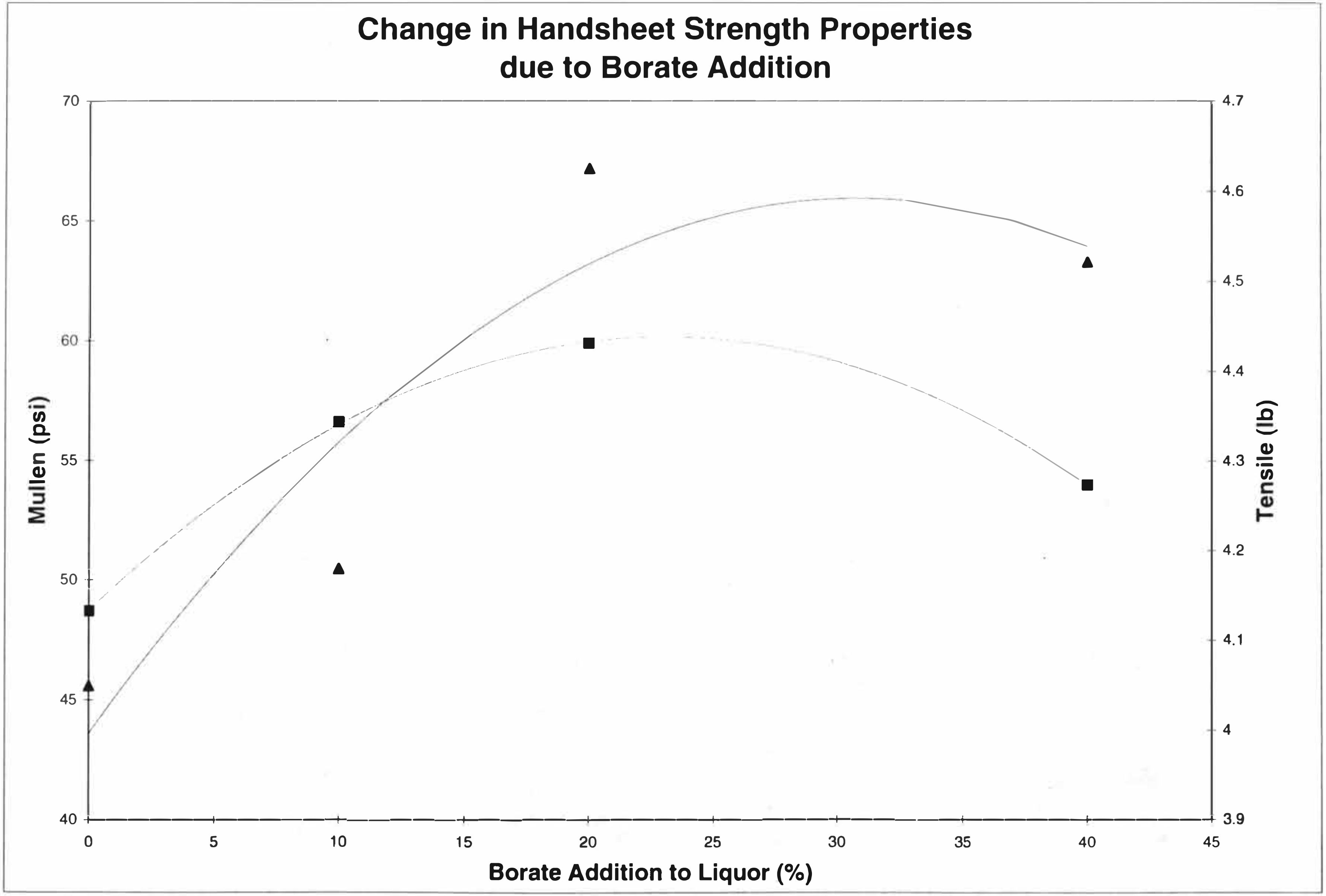

Change in Handsheet Strength Properties due to Borate Addition
Mullen (psi)
Tensile (lb)
Borate Addition to Liquor (%)
70
65
60
55
50
45
40
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
0
5
10
15
20
25
30
35
40
45

Figure 7: The Effect of Borate
Addition on Handsheet Stretch

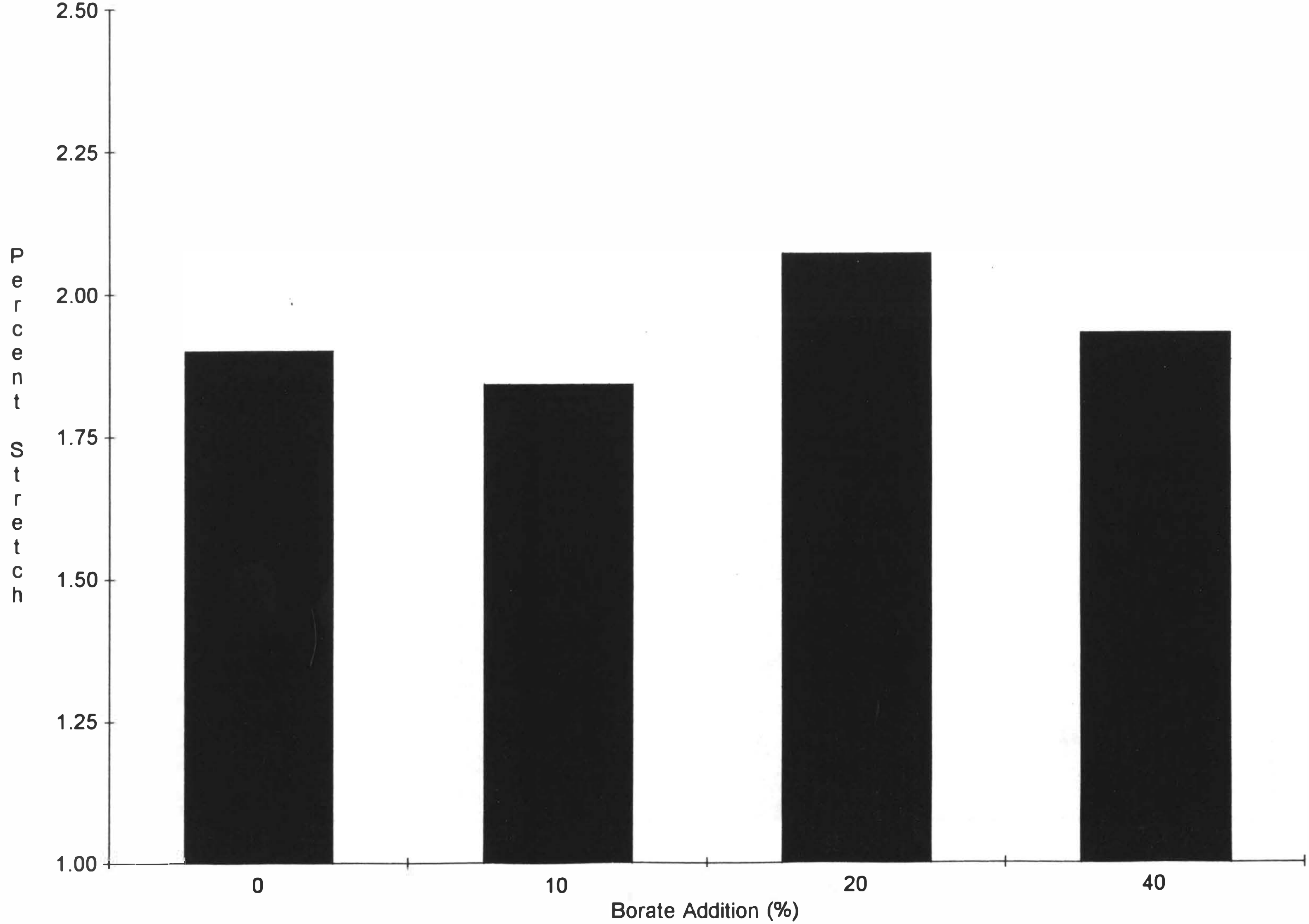
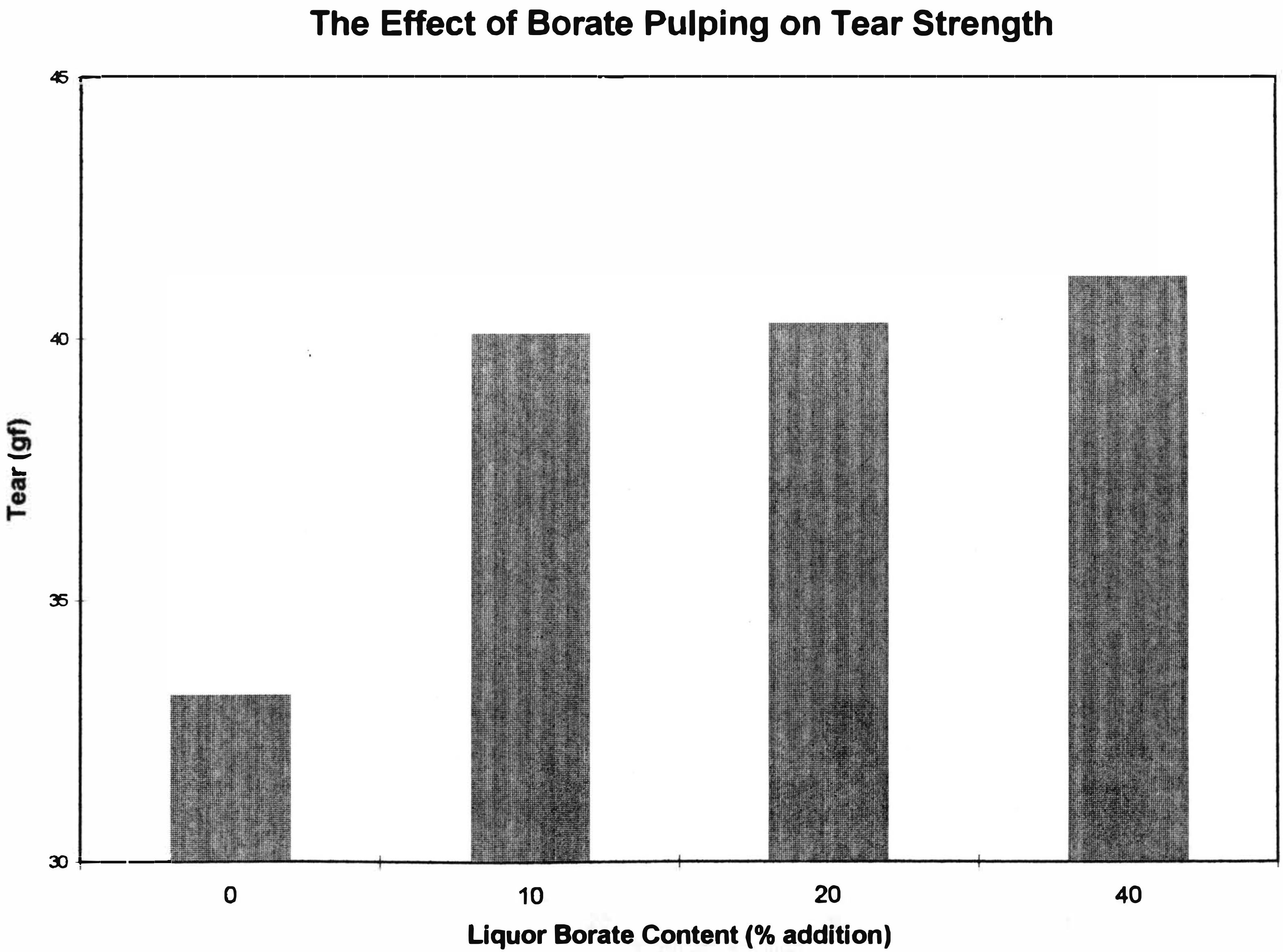
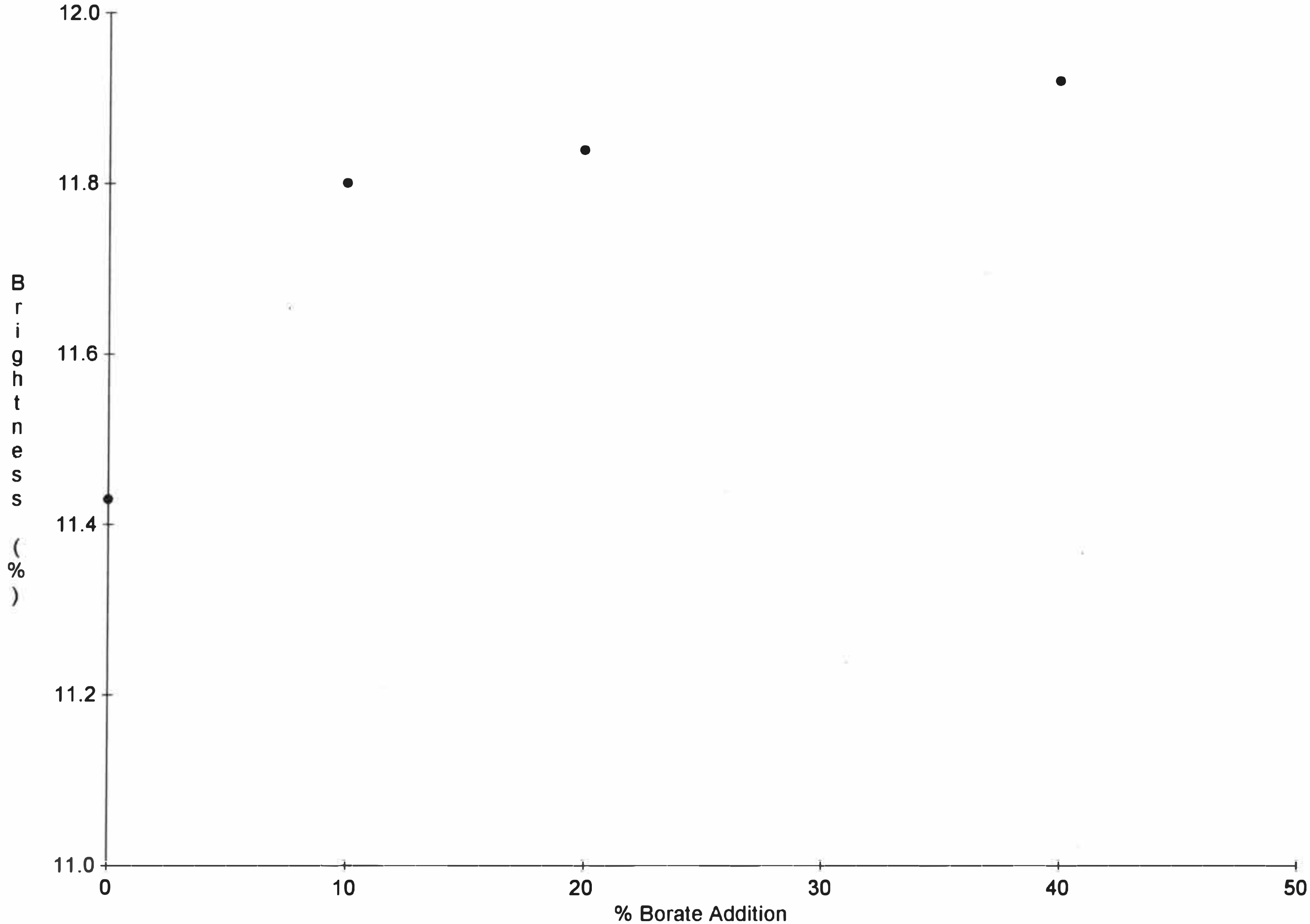


Figure 8:



The Effect of Borate Pulping on Tear Strength
45
40
35
30
Tear (gf)
0
10
20
40
Liquor Borate Content (% addition)

Figure 9: The Effect of Borate
Addition on Handsheet Brightness



Discussion and Results

The objective of this project was to identify sodium metaborate as a pulping chemical in the semi-chemical process. The sodium metaborate was added to sodium carbonate and water at varying addition levels to create the pulping liquors. A control cook was performed only containing sodium carbonate as a standard for comparison. The borate was added at 10% (batch 1), 20% (batch 2), and 40% (batch 3) addition levels. Each of the cooked pulps were screened, refined, and made into handsheets. The results of pulp and handsheet testing is listed in table 1.

Table 1 - Testing Results					
Pulping		**Control**	**Batch 1**	**Batch 2**	**Batch 3**
Borate Addition	'%	0	10	20	40
Yield	'%	81.3	79.2	77.4	74.5
Liquor pH		9.40	9.51	9.56	9.68
Post-Refining					
Screened Rejects	'%	51.8	53.6	54.4	54.4
Freeness	csf	501	474	480	486
Handsheet Testing					
Basis Weight	g/m2	78.0	78.1	77.9	77.1
Tensile	lb	4.05	4.18	4.63	4.52
Stretch	'%	1.90	1.84	2.07	1.93
Burst	psi	48.7	56.6	59.9	54.0
Tear	gf	33.2	40.1	40.3	41.2
Brightness	'%	11.43	11.80	11.84	11.92

Analysis of the results indicates that there was an effect on several properties such as: yield, liquor pH, screened rejects, tensile, tear, burst, and brightness. While some properties were unchanged: freeness and stretch. These effects will be presented in the following discussion. To better facilitate the discussion, the resulting increase or decrease of the batch results containing borates against the control cook results is presented in table 2.

Table 2 - Percent Difference from Control Results

	Batch 1	Batch 2	Batch 3		
Borate Addition -	10%	20%	40%		
Yield -	-2.5	-4.7	-8.3		
Liquor pH -	'+1.2	'+1.7	'+3.0		
Screened Rejects -	'+3.5	'+5.0	'+5.0		
Tear -	'+20.8	'+21.4	'+24.1		
Tensile -	'+3.2	'+14.2	'+11.7		
Stretch -	-3.2	'+8.9	'+1.6		
Burst -	'+16.2	'+23.0	'+10.9		
Brightness -	'+3.2	'+3.6	'+4.3		

First, the results of the pulping conditions are analyzed. The experimental design call for complete control over all parameters so that all possible variables are held constant, except for sodium metaborate addition. The digester conditions during the cook (temperature and pressure) are difficult to control. The plots of temperature vs time and pressure vs. time will show the extent of cooking intensity. The data accumulated for these conditions are tabulated in table 3 through table 6. The temperature during the cook is dependent on the process itself and can not be controlled by the operator. Figure 1 shows the plots for temperature curve during all of the cooks. From this graph, it can be seen that there is a slight shift in cook time, but the overall area under each of the curves is relatively close. Therefore, the heat intensity on all of the wood chip batches is similar. The pressure intensity of the cooks will be dependent on the digester itself, until the maximum pressure is reached and the operator begins releasing the pressure. At this point, the cook pressure is controlled by the position of the valve opening. From tables 3 through 6 and figure 2, it can be seen that the pressure intensity for each of the digester cook varies only according to time. The time required to reach maximum pressure is again controlled by the operation itself. Overall, the control batch was cooked for a longer period, but with the same intensity. The significance of the longer cook period would be a lower yield of fiber charge, but as will be seen, there wasn't an adverse effect in the results.

An effect on yield is the primary factor for success in this project. The cooking liquor of the control cook (no borates) resulted in a high yield of 81.3%. With increasing sodium metaborate addition, the yield decreases in almost a linear fashion (see figure 3). The resulting yield of charged wood was: 79.2% (10% addition), 77.4% (20% addition), and 74.5% (40% addition). At 40% addition, a decrease in yield of 8.3% was attained. These results indicate that sodium metaborate has a pulping effect. The selectivity of the borates can not be determined here, but a definite solubilization of wood substance is occurring.

Sodium metaborate addition increases the salt concentration of the cooking liquor. Thus, it is expected that the pH would increase with addition of alkaline salts to the liquor. Figure 4 illustrates the linear effect of borate addition on the pH of the spent cooking liquor. This increase in pH probably played a role in the decrease in yield. The pH alone is not enough to result in the drastic changes in yield, therefore, the sodium metaborate reactions with wood constituents are the primary vehicle in yield loss. The pH increased in a linear fashion from 9.40 to 9.68.

The second step in the semi-chemical pulping process is to defibrilize the wood chips by mechanical means. This was accomplished by running the pulp through the Waring blender for five minutes at low speed followed by mechanical refining in the PFI mill for 10,000 revolutions. The resulting pulp was screened over a 6-slot vibrating screen. The percentage of screened rejects is determined using the following equation:

% Screened Rejects = (O.D. fiber rejects / O.D. fiber refined) * 100

The results in table 1 are graphically depicted in figure 5. The borate addition increased the screened rejects from 51.8% to 54.4%, resulting in a 5.0% increase. This implies that the sodium metaborate could be showing selectivity in the pulping process. This statement can not be justified by the screened reject results, but the increase in rejects at a lower yield would tend to relate that the borate reaction is intensified in the wood structures that were penetrated.

The freeness of the pulp was taken after screening to identify any changes in response to refining. The results in table 1 indicate that all of the pulp cooks were refined to 480-500 csf. These results indicate that the pulps did not react differently to refining. Since the pulps are refined to the same freeness, the analysis of handsheet strength properties will not have to incorporate freeness differences. Thus, a better correlation between borate addition and strength properties can be attained at equivalent freenesses.

Normally, when the pulp yield is decreased by delignification, the strength properties of burst and tear will correspondingly increase. The inverse relationship between lignin content and these strength properties is well known through past research and experience. The tensile results of this project show a slight increase of 3.2% at 10% addition, with a significantly larger increase of 14.2% at 20% addition. This increase seems to reflect the delignification effect of borates. At 40% addition, however, the strength decreases from the 20% addition level (see figure 6). This seems to indicate that the extreme concentration of borates has attacked the strength providing components of fibers, ie. hemicellulose and cellulose. When considering this result with the yield and screened rejects results, it becomes apparent that the borates intensify the pulping reactions in the digester. The burst results seem to reflect this relationship also. In table 2 and figure 6, it can be seen that the initial addition of 10% sodium metaborate resulted in a 16.2% increase in burst (mullen) strength. At 20% addition, the burst peaked at an increase of 23.0%, from 48.7 psi to 59.9 psi. Then, as with the tensile, the burst strength decreased significantly to 54.0 psi. The burst and tensile strength of the handsheets are a direct correlation to the bonding strength of the fibers in the sheets. Therefore, it can be concluded that the high addition level of sodium metaborate to the semi-chemical pulping process reduced the total bonding potential of the fibers.

When testing the tensile strength of the handsheet samples, the stretching ability of the sheet is simultaneously tested. In figure 7, the results indicate that a distinct effect can not be found from the addition of borate. The fibers in high yield pulps are stiff and will resist the tendency to stretch. Stretch is usually very sensitive to increased bonding in the sheet, but in this case, the inherent stiffness of the fibers made any correlation of stretch impossible to attain.

Perhaps the most interesting result of this project was the change in tear strength values for the handsheets. In figure 8, it can be noted that a significant increase in tear of 20.8% occurs at the lowest addition level. The tear strength further increases from 33.2 gf with no borates to 41.2 gf at 40% addition, an increase of 24.1%. The tear strength of a sheet is solely associated with the fiber strength. This would indicate that at the tear interface, the fibers are stronger with borate addition or the concentration of fibers is increased. The latter assumption is perhaps the more acceptable. This would indicate that the handsheets of the control pulp contain more non-cellulosic components that lack strength. The handsheets from the borate cooks would therefore have a higher concentration of long fibers. These results may indicate the selectivity of borates for delignification.

Finally, the brightness of the handsheets was analyzed. In figure 9, the results show a slight increase in brightness with borate addition. Brightness increases with delignification due to removal of color components (lignin). Past research showed the borates had an adverse effect on brightness in other pulping methods. Even this slight increase in brightness is interesting to note from this project. Visually, the handsheets seem lighter at high borate addition levels, the color is "more "yellow"". The change in tint or color may not be entirely detected by brightness testing. These brightness results might be a basis for a further study on the subsequent bleaching characteristics in future studies.

Conclusions

There are many conclusions that can be based on the results of this project:

1. The pulp yeild decreased with addition of sodium metaborate.
2. The addition of borate slightly increased the pH of the black liquor.
3. The screened rejects increased with increasing borate addition.
4. The freeness of refined pulp was not affected by pulping with sodium metaborate.
5. The tensile strength and burst strength initially increased with borate addition levels to 20%, but strength degradation occurred at high addition levels (40%).
6. Elasticity (stretch) was unaffected throughout the project.
7. Tear increased extensively by pulping with sodium metaborate, thus showing possible selectivity toward lignin components.
8. Brightness and sheet color were slightly effected by borate addition. Brightness increase was small, and visual color was more "yellow".

Recommendations

There are several recommendations that can be made based on the work presented in this thesis. The first set of recommendations involves properties of the experimental design of this project that could be changed to enhance the validity of this work. During the cooking procedure, the pressure of the digester could be held constant at the maximum pressure for a longer period of time to increase the cooking intensity. The cooked chip should be blended for a longer period of time, or refining to higher revolutions to reduce the screened rejects. More testing could be performed for better information on the pulp quality, such as viscosity, fiber length distribution, and opacity.

The results of this project reflect a need for further study to understand the effects of sodium metaborate. Some possible research includes:

I. Partial substitution of borates for soda ash during pulping.

II. Complete substitution of borates in semi-chemical pulping.

III. The use of a chemical such as dioxane or AQ for increased selectivity.

IV. The effect of borate pulping on optical properties of bleached pulp.

References

1. Kato, Y., Jap. pat. 249,703/86 (November 6, 1986).

2. Guha, S. R. D., Chandra, A., Indian Forester 105 (4): 293-300 (1979).

3. Kumar, S., Beri, R. M., Mehra, M., Timber Devt. Association 25 (4): 24-33 (1979).

4. Beri, R., Kumar, K., Indian Pulp Paper 34 (3): 3-7 (1979).

5. Hulme, M., Tappi Journal 59 (1): 108-111 (1979).

6. Markham, L., CPPA Annual Meeting 64A: 97-104 (1978).

7. Shin, N., J. Tappik 13 (1): 20-26 (1981).

8. Janson, J., Svensk Papperstid. 83 (14): 392-395 (1980).

9. Janson, J., Paperi Puu 60 (5): 349-352, 355-357 (1978).

10. Koran, C., Wandelt, P., Kubes, G. J., Paperi Puu 78 (9): 541-544 (1996).

11. Prihoda, S., Wandelt, P., Kubes, G. J., Paperi Puu 78 (8): 456-460 (1996).

12. Mostafa, N. Y., Cellulose Chemical Technology 28 (2): 171-175 (1994).

13. Gadda, L., Svensk Papperstid. 85 (12): 87-92 (1982).