Extraction of hardwood biomass using dilute alkali

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ABSTRACT: Near neutral hemicellulose extraction involves extracting wood hemicellulose using green liquor before conventional kraft pulping. The objective of this work was to develop correlations that could be used in process design and economic studies. Experimental data are presented for the extraction of northeast hardwood chips using green liquor. The effect of green liquor application rate, liquor-to-wood ratio, and H-factor on the removal of sugars and organic acids is discussed. Response variables include wood yield, total and soluble lignin, component sugars, acetic acid, lactic acid, formic acid, and furfural. Empirical correlations are developed that embody green liquor application rate, liquor-to-wood ratio, and the H-factor. Parameters are presented for the response variables after the extraction and hydrolysis processes.

Application: This study might help kraft pulp mills determine the amounts of sugars and organic acids they could potentially extract from wood using dilute alkali.

Interest in renewable resources as a source of energy and chemicals has increased, in part because of a desire to decrease the dependence of the United States on petroleum and other fossil fuels. The concept of an integrated forest products biorefinery (IFBR) has been advanced by numerous investigators who envision converting woody biomass, dedicated annual crops, and municipal waste into bioenergy and basic chemicals that heretofore have been derived from petroleum [1]. One biorefinery concept involves extracting hemicelluloses, which normally end up in the black liquor of kraft pulp mills, before pulping and using the extract for the production of alcohol and organic acids [2,3]. The process involves extraction of hemicelluloses and acetic acid from hardwood chips, conversion of component sugars to ethanol or butanol, and recovery of acetic acid as a co-product. Advantages of the near neutral hemicellulose extraction process are that the loss of pulp yield is small and the physical properties of the resultant bleached pulp are similar to those of conventional kraft pulp [4].

OBJECTIVE AND SCOPE

This study was performed to investigate the effects of green liquor application rate (GL), liquor-to-wood (L/W) ratio, and H-factor (in hours, h) on the removal of sugars and organic acids from mixed northeast hardwood chips. The objective of this study was to establish correlations that relate green liquor application rate, the L/W ratio, and H-factor to response variables that include wood yield, lignin removed, and component sugars extracted from carbohydrates, as well as acetic, formic, and lactic acids. The relationships are suitable for planning and preliminary process design studies for the near neutral hemicellulose extraction process applied to a kraft pulp mill where the acetic acid and alcohols derived from sugars would be by-products from the pulp mill.

RELATED STUDIES

Pre-extraction of mixed northeastern hardwood at 160°C for various periods show that with increasing application of green liquor at constant H-factor and liquor-to-wood ratio, the pH of the extract increases and less of the wood is dissolved [4-7]. At high green liquor application rates, the component sugars (e.g., xylose, mannose, and galactose) decreased after hydrolysis, while the acetic acid and other organic acids (e.g., formic acid and lactic acid) increased. The lignin content in the organic fraction removed from the wood increased as the green liquor application rate increased. Soluble lignin was highest at the highest value of H-factor and highest green liquor application rate. Low final pH values for the extract occur at low green liquor application rates and the lignin became highly sticky [4]. The pressure in the digester increased during the extraction period [4,5]. This increase in total pressure in the extraction vessel was attributed to decomposition of sodium carbonate resulting from consumption of alkali and the accompanying decrease in pH.

In a study of green liquor extraction of mixed southern hardwood, Walton presented a systematic series of curves for the sugars extracted after hydrolysis and for acetic acid and organic acids [8]. The pulps following extraction were subjected to conventional kraft pulping. Experiments were performed with and without the use of anthraquinone (AQ) as a pulping catalyst. Pulp viscosity increased as more of the hemicelluloses were removed in nearly all of the extracted pulps. Removing the lower degree of polymerization hemicelluloses

caused an increase in the overall pulp viscosity, because the viscosity measurement averages the degree of polymerization of the cellulose and hemicelluloses in a weighted average. Measurement of the fiber strength factor and wet zero span breaking length showed that kraft pulps pre-extracted by green liquor were equivalent to kraft control pulp.

Jin et al. [9] described a process that uses green liquor as a pretreatment for the production of ethanol in repurposed kraft mills. Extraction experiments were conducted at 160°C using application rates of 4% to 20% total titratable alkali. The residual wood produced by the green liquor process could be readily processed into component sugars using enzymes. The green liquor pretreatment was unique in that the residual wood yield and retained carbohydrates (about 90%) were high, while still enabling sufficient delignification to allow efficient enzymatic hydrolysis.

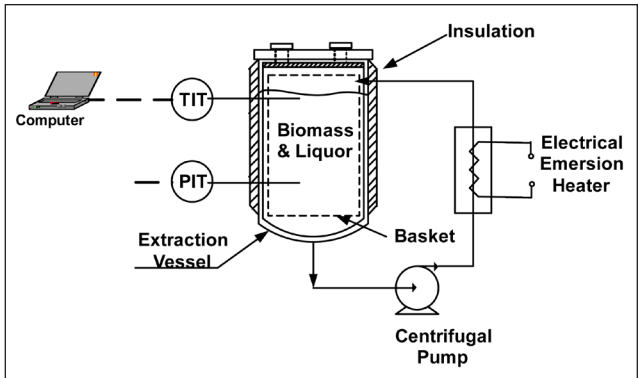
Al-Dajani and Tschirner [10] studied pre-extraction of poplar wood chips under strong alkaline conditions (1 to 2 molar sodium hydroxide [NaOH]) and relatively low temperatures (50°C to 90°C). At these conditions, about 40-50 kg of hemicellulose oligomeric sugars could be extracted per ton of wood without detrimental effect to the overall pulp yield or the physical properties of the resulting kraft pulp. Similar results were obtained by Yoon and co-workers, who studied the extraction of mixed southern hardwood chips with alkaline solutions [7]. At sodium hydroxide addition levels of 10% to 20%, approximately 17% to 40% of the wood was dissolved, and the resulting extracts were strongly alkaline, with pH values about 13. Subsequent kraft cooking of the extracted chips yielded 5% to 7% less pulp than conventional kraft pulps. However, the final pulp yield was not affected when reduced alkali charges were used that were just sufficient to neutralize the acids released during the pre-extraction process.

PRE-EXTRACTION EXPERIMENTS

Mixed northeast hardwood chips were obtained from a local mill. The chips were screened using a Weyerhaeuser chip classifier. The chips that were used in the experiments were less than 10 mm in thickness and were retained on the 5/8-in. and 7/8-in. screens. The extraction experiments were conducted in an indirectly heated, 7 L circulating digester (**Fig. 1**). The extraction experiments were performed using 900 g of wood (bone-dry basis) at 160°C with a 55 min ramp to temperature. In an attempt to preserve final pulp yield, 0.05% AQ based on wood was added before the extraction stage. The time-temperature heating schedule was measured using the H-factor variable applicable to lignin removal for kraft pulping.

Experimental design

The experimental design consisted of three sets of experiments (**Table I**). In the first data set, the green liquor application rates were 0%, 0.5%, 2%, 4%, and 6% total titratable alkali, based on the mass of ovendry wood [4]. Green liquor extraction experiments were conducted by varying the green liquor application rate at a constant L/W ratio of 4.0 and



1. Laboratory pre-extraction reactor.

Experiment No.	Green Liquor Application (%)[a]	Liquor-to-Wood Ratio	H-Factor (hours)
1	0 (Water)	4	778
2	2	4	771
3	4	4	802
4	6	4	807
5	2	2.5	410
6	2	5.5	804
7	2	4	1254
8	2	4	433
9	0.5	4	790
10	2	2.5	819

[a] 0.05% AQ was added based on wood.

I. List of experiments performed.

800 h. The extraction experiment designated as 0% was conducted using deionized water (autohydrolysis). A second set of extraction experiments was performed at L/W ratios of 2.5, 4.0, and 5.5, while keeping the green liquor application rate constant at 2% and the H-factor constant at 800 h. The third set of extraction experiments was performed at H-factor values of 400, 800, and 1200 h by fixing the green liquor application rate at 2% and the L/W ratio at 4.0. Lastly, experiment 5 was performed. It was performed at a green liquor application rate of 2%, an L/W ratio of 2.5, and an H-factor of 410 h to complete the experimental data.

After each pre-extraction experiment, the digester was cooled to below 100°C and the extraction liquor was drained from the vessel, cooled, and then refrigerated for component analysis. Chips were not washed after pre-extraction. Wood yield was determined gravimetrically by using the following procedure. The partially macerated wood was thoroughly dried in the oven at 105°C. A sample of the dried wood was then ground and the ash content estimated by combustion in a muffle furnace at 900°C. The ash-free yield of macerated

wood following extraction was then estimated by comparing the mass of ovendry wood before and after hemicelluloses extraction by correcting for the sodium adsorbed in the wood during the extraction process [11].

Analysis of extracts

The pH value of the extracts was determined by using a pH meter. The total solids content of the extracts was estimated by following TAPPI T-650 ("Solids content of black liquor"). The component sugars in the extract were measured using high performance anion exchange chromatography (HPAEC) by the methods described by Tunc [12]. Acetic, lactic, and formic acids and furfural in the extract were determined before and after hydrolysis of the extract by using high performance liquid chromatography. The lignin content was estimated by measuring the concentration of acid-soluble and Klason lignin using TAPPI T-222 ("Acid-insoluble lignin in wood and pulp") and TAPPI UM-250 ("Acid-soluble lignin in wood and pulp"), respectively.

Correlation of extraction data

Data for the experimental response variables (y) were smoothed and correlated using empirical correlations that embody green liquor application rate (GL), L/W ratio (LW), and the H-factor (H). The correlation used for acetic acid, total acid and lignin is as follows, Eq. (1):

$$y = A + B * [H\ (LW + a) \times (GL + b)]^c \quad (1)$$

The correlation for component sugars, furfural, and wood yield is as follows, Eq. (2):

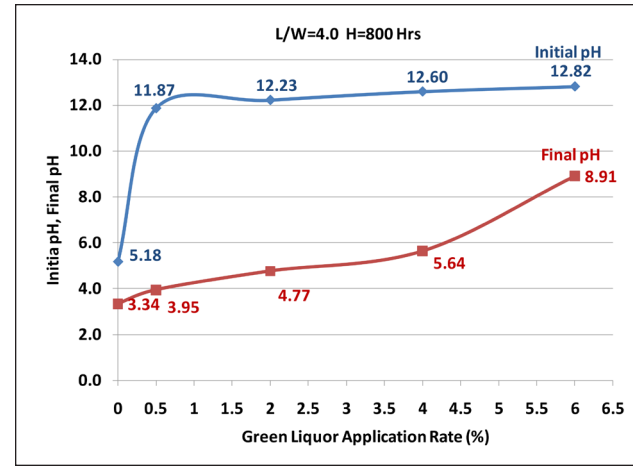
$$y = A + B\left[\frac{H\ (LW + a)}{(GL + b)}\right]^c \quad (2)$$

The values for the empirical constants A, B, a, b, and c in Eq. (1) and Eq. (2) were determined using regression analysis.

RESULTS AND DISCUSSION

Luo [13] presents a detailed discussion of the experimental results. The major sugar measured after hydrolysis was xylose, along with lesser sugars (mannose, galactose, arabinose, and glucose). Appendix A summarizes the empirical parameters determined for the response variables (y) for component sugars after hydrolysis: total sugar, acetic acid, total acids (acetic, formic, and lactic acids), furfural, total lignin, soluble lignin, and wood yield. For the acetic acid and total acids, data are presented before and after hydrolysis. The R^2 values for the response variables were all greater than 0.90, except for arabinose, which had an R^2 value of 0.82, and acetic acid after hydrolysis, which had an R^2 value of 0.87. Satisfactory correlations were obtained for acetic acid (0.92) and furfural (0.91). No satisfactory correlations could be obtained for lactic and formic acids.

Figure 2 illustrates how the pH of the extract and the loss



2. Initial and final pH of the extract following green liquid extraction.

of wood solids varied during the extraction experiments. Data are shown for experiments in which the green liquor application rate was varied at a constant L/W ratio of 4.0 and 800 h.

The initial pH of the extraction liquor varied between 11.9 and 12.8 for the green liquor experiments; for the autohydrolysis experiment using deionized water, the pH was 5.2. The final pH of the extract liquor varied between approximately 3.3 for the autohydrolysis extraction to 8.9 in the experiment using 6% green liquor. As the pH decreases, sodium carbonate decomposes and the pressure in the extraction vessel increases [4,11].

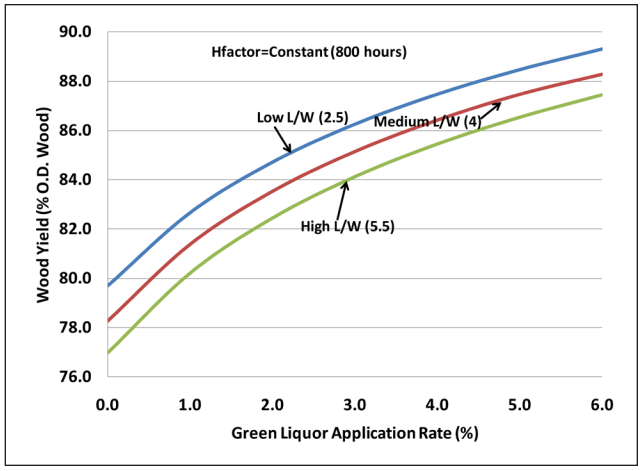
Wood composition

The wood used in this study consisted of birch, beech, and maple in approximately equal proportions. **Table II** shows the composition of the northeastern hardwood mixture [4,11]. The major hemicellulose component in the mixture was xylan. The acetyl group and uronic acid group contents were estimated to be about 3.65% and 2.80%, respectively. The difference in composition of mixed northeastern hardwood and that of mixed southern hardwoods composed of sweetgum and oaks is mostly that the northeastern hardwoods have more acetyl groups and less uronic acid groups

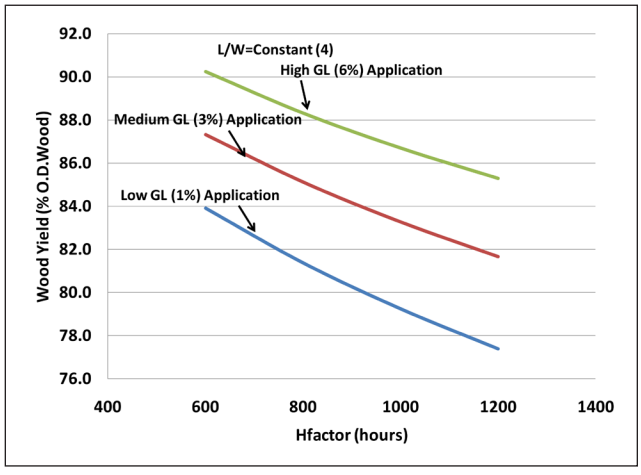
Chemical Component	Amount (% by wt.)	Chemical Component	Amount (% by wt.)
Arabinan	0.56±0.01	Lignin	26.5±0.2
Galactan	1.22±0.02	Extractives[a]	0.61±0.05
Glucan	42.7±0.6	Ash	0.51±0.05
Xylan	22.8±0.4	AcG[b]	3.65±0.08
Mannan	2.23±0.05	UAG[c]	2.80±0.10

[a] Dichloromethane (DCM) as solvent.
[b] AcG : Acetyl groups.
[c] UAG : Uronic acid groups.

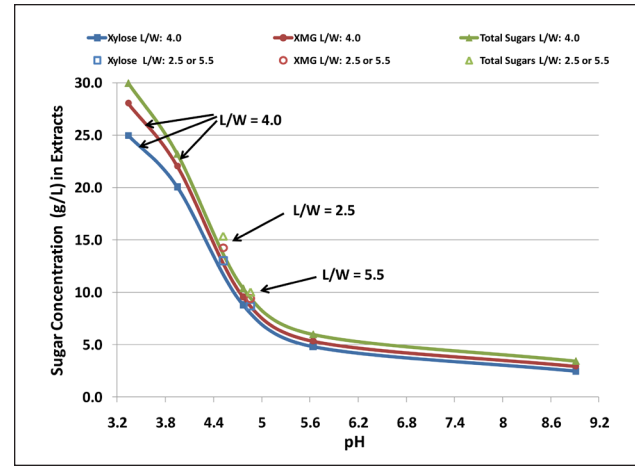
II. Composition of northeastern hardwood mixture (% on wood).



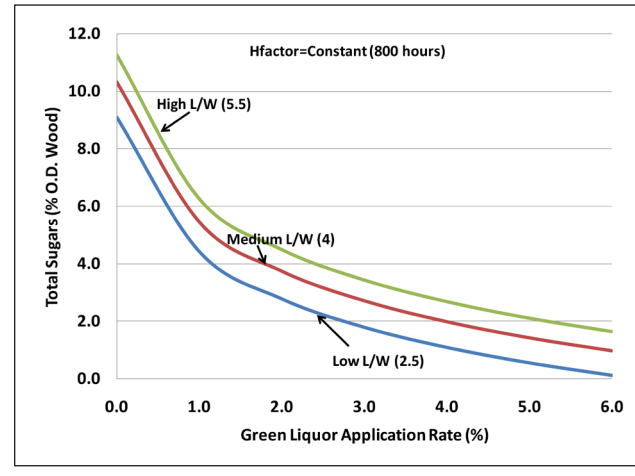
3. Effect of green liquor application rate on wood yield.



4. Effect of H-factor on wood yield.



5. Total sugar concentration after hydrolysis versus pH at different green liquor charge and liquor-to-wood ratios.



6. Effects of green liquor application rate and liquor-to-wood ratio on extracted sugars after hydrolysis.

than southern hardwoods [4]. The higher acetyl group content for northeastern hardwoods is advantageous when acetic acid is one of the co-products.

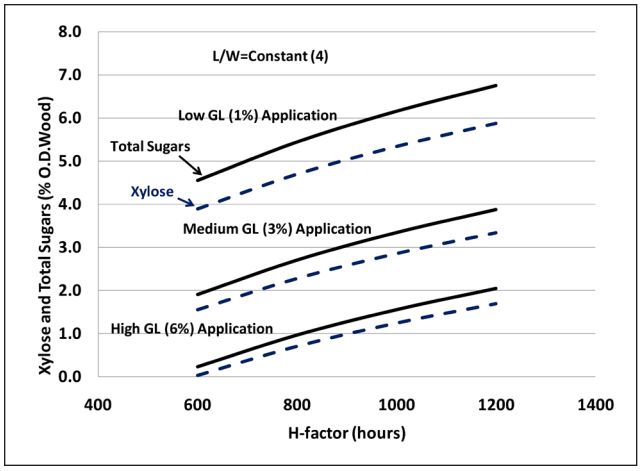
Wood yield

Wood yield is defined as the fraction of the wood remaining after extraction (**Figs. 3** and **4**). The wood yield data or wood remaining after pre-extraction were smoothed by using Eq. (2) and had an R^2 value of 0.95. The wood yield varied from 80% to 90%, depending on the extraction conditions. The material balance or wood recovery closed to between 90% and 99%, depending on the experimental conditions. Wood yield increases with increasing green liquor application rate; thus, less wood is dissolved when compared to autohydrolysis (Fig. 3). At a fixed L/W ratio of 4.0, as the H-factor is increased additional wood is dissolved; thus, the wood yield or residual wood following extraction decreases (Fig. 4).

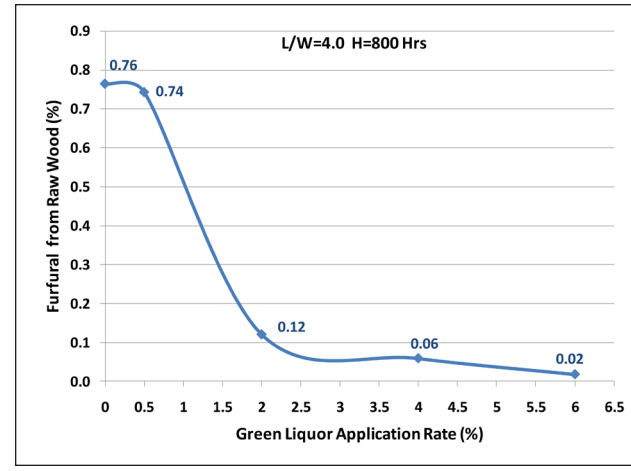
Total extracted sugars

Total sugar concentration is the sum of the glucose, arabinose, xylose, mannose, and galactose content. **Figure 5** presents data as a function of pH. The total sugar concentration smoothly decreases with increasing extract pH, irrespective of the green liquor charge or L/W ratio. The total sugar extracted, when plotted as a percentage on wood, shows a similar trend as shown in Fig. 5, as do the data for the combined concentration or sum of the xylose, mannose, and galactose determined in the HPAEC analysis. At a high L/W ratio of 5.5, higher quantities of sugars are removed compared with the trend line for an L/W ratio of 4.0. The opposite is true for an L/W ratio of 2.5. This behavior may be explained by the following hypothesis. The pH determines the degree of hydrolysis of the dissolved hemicelluloses and thus its degree of polymerization. The degree of polymerization in turn determines the solubility of the hemicellulose fragments. Thus, if the amount of liquid solution available for dissolution is large (i.e., the L/W ratio is large), then more sugars will be removed from the wood, and vice versa. The sugar concentrations measured before acid hydrolysis are very small. Thus, almost all sugars in the extract, except perhaps for arabinose and galactose, are oligomers [4].

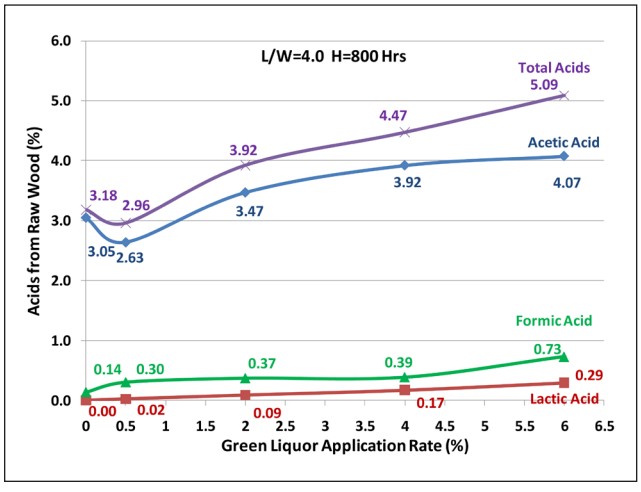
Figure 6 illustrates the total amount of sugar as a function



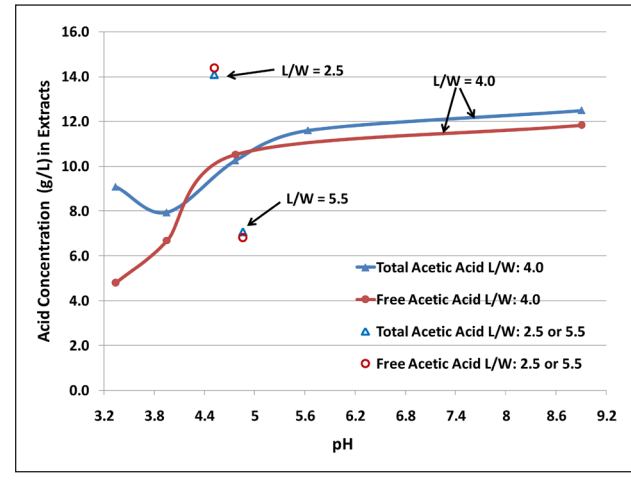
7. Comparison of xylose to total sugars after hydrolysis as a function of H-factor.



9. Effect of green liquor application rate on the formation of furfural in drained liquor following hydrolysis.



8. Effect of green liquor application rate on organic acids after hydrolysis.



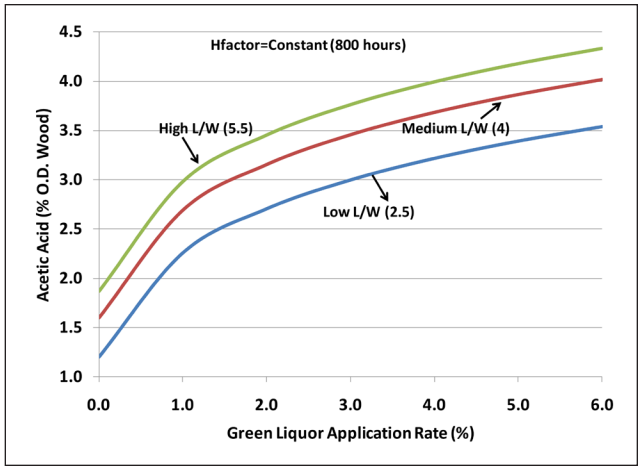
10. Acetic acid concentration versus pH at different green liquor charge and liquor-to-wood ratios, both before (free acetic acid) and following hydrolysis (total acetic acid).

of the green liquor application rate at a constant H-factor of 800 h at three different L/W ratios. Increasing the green liquor application rate and decreasing the L/W ratio decrease the amount of sugars available in the extract. **Figure 7** illustrates that the predominant sugar extracted is xylose. The amount of sugars being extracted will increase as the H-factor increases. This is true for all of the L/W ratio values. However, once the H-factor is fixed, increasing the L/W ratio increases the amount of sugars extracted.

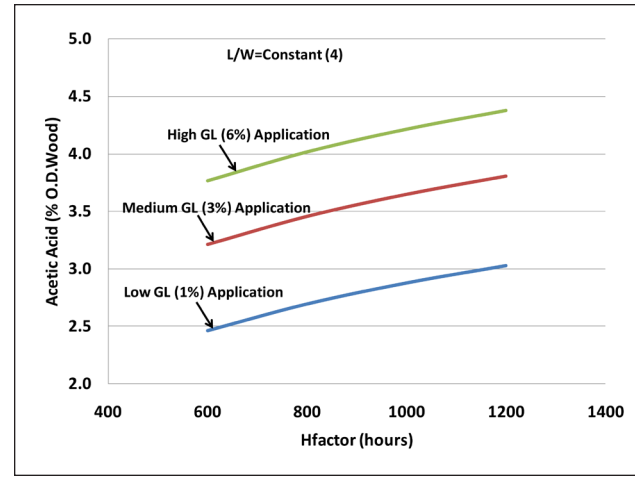
Organic acids and furfural

Figure 8 shows experimental data for acetic, formic, and lactic acids following the hydrolysis step. The data are plotted as a function of the green liquor application rate at constant values for the H-factor and L/W ratio. Contrary to the data on the extracted sugars, a significant amount of acetic acid was detected in the extract before acid hydrolysis. This acetic acid is termed "free" acetic acid. It consists of the sum of the hydrolyzed acetyl groups that are present as sodium acetate and as acetic acid. The split between the sodium acetate and acetic acid in the extract will depend on the acidity constant (pKa) of acetic acid (4.8). The acetic acid concentration measured after full acid hydrolysis of the extract is termed "total acetic acid." The acetic acid, and lactic and formic acids, increase as the green liquor application rate increases. Total acetic acid, for example, increases from about 3.05% to about 4.07% as the green liquor application rate increases from 0% (auto hydrolysis) to 6%. Similarly, total acids increase from about 3.18% to 5.09%.

Figure 9 shows the furfural in the drained liquor following hydrolysis. These data show that furfural is formed extensively at low pH values, as discussed by Sjöström [14]. Furfural results from low green liquor application rates and during hydrolysis by decomposition of xylose. Furfural forms especially during autohydroysis because of the lower pH. Lactic acid and formic acid are known to form from alkaline peeling reactions and during acid hydrolysis, and additional formic acid is thought to be formed during acid hydrolysis [15].



11. Effects of green liquor application rate and liquor-to-wood ratio on extracted acetic acid before hydrolysis.

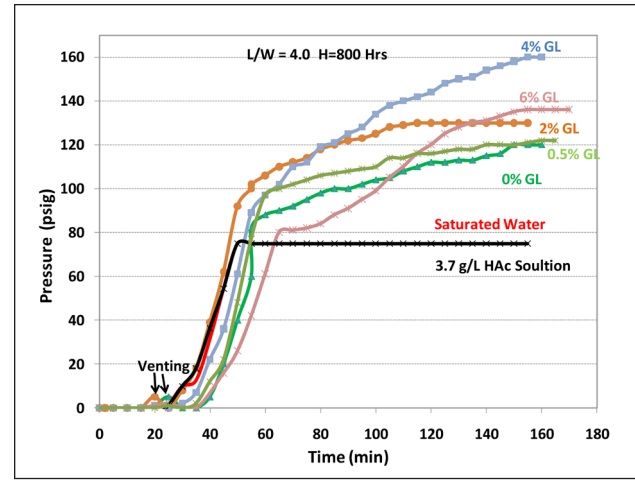


12. Effects of green liquor application rate and H-factor on extracted acetic acid before hydrolysis.

Figure 10 shows experimental data for acetic acid plotted as a function of the extract pH. The free acetic acid concentration is the acetic acid before hydrolysis and the total acetic acid is that after hydrolysis. The results show that the concentration of total acetic acid increases from a pH of about 4 and reaches a plateau at about 12±0.5 g/L at pH 6 or higher (Fig. 10). Considering that the original wood contains 3.65% as acetyl groups (Table II), the total acetic acid concentration at complete hydrolysis would be about 12.7 g/L. Thus, at pH 6 or higher the hydrolysis of the acetyl groups in wood proceeds to completion at 160°C and 800 h. The minimum in total acetic acid concentration is about 8 g/L at pH 4 and was thought to result because alkaline catalyzed hydrolysis increases at pH values above the pKa of acetic acid (pKa = 4.8), while acid catalyzed hydrolysis increases below the acetic acid pKa [4].

The free acetic acid values are essentially the same as the total acetic acid concentration at about pH 5 or higher. We interpreted this to mean that all dissolved sugar oligomers are deacetylated. Only at pH less than 4 is the free acetic acid concentration less than the total acetic acid concentration. Thus, the sugar oligomers in the water extract still are partially acetylated, and about half of the removed acetyl groups are attached to the oligomers and half are free. Figure 10 also shows that the acetic acid concentration at L/W ratio of 2.5 is about 55% higher than that at a L/W ratio of 4.0 at the same pH, and it is about 25% lower at L/W ratio of 5.5. This is expected based on the volume of extract available for dissolution of acetic acid.

The acetic acid data for the extract before hydrolysis were smoothed using Eq. (1). The regression equation before hydrolysis had an R^2 value of 0.92 (Appendix). **Figures 11** and **12** show the smoothed data for acetic acid before hydrolysis. Increasing the green liquor application or increasing the L/W ratio will increase the amount of acetic acid in the extract (Fig. 11). Similarly, increasing the H-factor and the L/W ratio will increase the acetic acid content in the extract (Fig. 12).



13. Pressures during extraction experiments (liquor-to-wood ratio= 4.0, H-factor = 800 H).

Digester pressure and decomposition of bicarbonate

No pre-steaming was done during the experiment, but the digester was vented after about 25 min (**Fig. 13**). In a normal kraft pulping experiment, in which nonvolatile salts (Na^+, $S^=$, HS^-, etc.) are present and the air is excluded from the vessel, the pressure in the digester is very close to the vapor pressure of water. In the extraction experiments using green liquor, which is predominantly sodium carbonate (Na_2CO_3), the pressure in the extractor after 50 min exceeded the vapor pressure of water by a considerable amount. The digester pressure increased significantly above the saturated steam pressure during extraction (Fig. 13). Analysis of the gases from the digester showed the presence of carbon dioxide (CO_2) that was released as a result of decomposition of carbonate in the green liquor. The hydroxide ions present in green liquor catalyze hydrolysis of the acetyl groups on the xylan polymer with the release of acetic acid, which then reacts with carbonate to form bicarbonate and acetate ions:

$$\text{Xylan-O-Ac} + \text{NaOH} = \text{xylan-O-Na}^{+} + \text{HAc} \quad (3)$$

$$\text{Na}_2\text{CO}_3 + \text{HAc} = \text{NaHCO}_3 + \text{NaAc} \quad (4)$$

When all carbonate (pKa = 10.3) is consumed, the bicarbonate (pKa = 6.35) that is formed decomposes to release CO_2 at near neutral pH by continued reaction with more released acetic acid [4]:

$$\text{NaHCO}_3 + \text{HAc} = \text{CO}_2 + \text{H}_2\text{O} + \text{NaAc} \quad (5)$$

Thus, at a pH below 6 most of carbonate in the green liquor is released as CO_2. The pressure increase above saturated steam pressure at 4% green liquor charge (final extract pH of 5.26) was about 80 psi, which is twice that when extracting with pure water. The latter pressure increase also is caused by CO_2 but now originating from decomposition of uronic acids in hardwood as postulated by Leschinsky [16]. The final pressure at 2% green liquor is similar to that obtained with pure water. Interestingly the pressure increase at 6% green liquor is similar to 2% green liquor because at the alkaline final pH not all bicarbonate is decomposed. Release of hydrogen sulfide (H_2S) from sodium hydrosulfide (NaHS) (pKa of 7.05) when the pH reaches near-neutral condition also might be a concern.

$$\text{NaHS} + \text{H}_2\text{O} = \text{NaOH} + \text{H}_2\text{S} \quad (6)$$

However, the final extract liquor did not smell of H_2S, which suggests that the hydrosulfide anions had reacted with lignin.

CONCLUSIONS

The near neutral hemicellulose extraction process considered here uses green liquor with the addition of AQ for wood extraction before kraft cooking in an effort to preserve pulp yield and quality. The response variables during the extraction process can be represented adequately by empirical correlations represented by Eq. (1) and Eq. (2) in terms of the application rate (GL), L/W ratio, and the H-factor. The pH of the extract increases and greater amounts of acetic acid are extracted as the green liquor application rate is increased. However, a corresponding decrease in the amount of xylan and other carbohydrates recovered in the extract also occurs. At high L/W ratios, higher quantities of sugars are removed compared with the base case L/W ratio of 4.0. The opposite is true for the L/W ratio of 2.5.

Hydrolysis of acetyl groups is favored by high green liquor application rates. The split between the sodium acetate and acetic acid in the extract will depend on the final pH of the extract (Fig. 10) and the pKa value (4.8) of acetic acid. Also, at low final pH values for the extract, significant portions of the acetyl groups remain unhydrolyzed from the xylan polymer but are liberated during acid hydrolysis. At high green liquor application rates, and thus high final pH values, peeling reactions lead to the formation of lactic acid and formic acid [15,17].

During the acid hydrolysis step in the process, the carbohydrates are broken down into component sugars. Because of the low pH values and the presence of sulfuric acid, however, formic acid, furfural, and hydroxymethyl furfural also are formed (Fig. 9). The furfural forms predominately from decomposition of xylose; the glucose and other six carbon sugars decompose to hydroxymethylfurfural [14,15]. Materials such as formic acid, furfural, lactic acid, and acetic acid are toxic to many organisms used to synthesize chemicals and energy from component sugars. Consequently, they must be removed to detoxify the extract, which often is quite complex [18].

Carbonate ion is decomposed to CO_2 as the pH is decreased during the extraction process. Consequently, the pressure in the reactor increases (Fig. 13). Extraction with water results in an increase in pressure, but to a lesser extent than extraction with green liquor. The pressure increase associated with water extraction is thought to result from decomposition of glucouronic acid side groups attached to xylose hemicelluloses, as discussed by Leschinski [16]. **TJ**

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APPENDIX

Summary of empirical correlations

The correlations given in Table III are applicable between 0% and 6% green liquor charge, between a liquor-to-wood ratio of 2.5 and 5.5, and for H-factors between 400 and 1300 h.

Item	A	B	a	b	c	R^2	Equation
Mannose[a]	-10.15	9.38	5.86	0.032	0.011	0.96	2
Arabinose[a]	-9.43	9.43	-2.18	0.0007	0.0018	0.82	2
Galactose[a]	-9.68	9.23	0.19	0.133	0.009	0.98	2
Glucose[a]	-9.69	9.29	2.74	0.054	0.0071	0.98	2
Xylose[a]	-20.46	10.13	1.41	0.38	0.113	0.98	2
Total sugars[a]	-20.71	9.94	1.24	0.318	0.12	0.98	2
Acetic acid[a]	-12.43	8.58	-0.599	2.598	0.064	0.87	1
Total acids[a]	-14.86	8.30	1.005	2.424	0.083	0.96	1
Acetic acid[b]	-11.27	8.66	-0.442	0.326	0.058	0.92	1
Total acids[b]	-12.46	8.86	0.354	0.0047	0.067	0.94	1
Furfural[a]	-10.67	8.59	9.45	0.462	0.029	0.91	2
Lignin[a]	-14.43	8.31	-0.89	12.672	0.068	0.93	1
Soluble lignin[a]	-14.30	7.94	+0.40	102.14	0.054	0.92	1
Wood yield[b]	110.43	-2.44	7.28	2.646	0.317	0.95	2

[a] After hydrolysis.
[b] Before hydrolysis.

III. Coefficients for correlations before and after hydrolysis.

ABOUT THE AUTHORS

This work was conducted as part of University of Maine research efforts related to development of the biorefining process applicable to kraft pulp mills. It complements research performed by Adriaan van Heiningen and others into the removal of hemicelluloses from wood using the near neutral hemicellulose extraction process. It presents design correlations for use in economic and technical feasibility studies.

The most difficult aspect of this work was the analysis of the extract quantitatively and attempting to get the material balances to close. There are small amounts of trace materials present in the liquor extract that most likely go unaccounted in the material balance.

The most interesting aspect of the research was the realization that the carbohydrates are broken down into component sugars during the acid hydrolysis step in the process, but because of the low pH values and the presence of sulfuric acid used to hydrolyze the sugars, formic acid, furfural, and hydroxymethyl furfural are formed from the sugars. If the sugars are to be used as feed to a microbiological conversion process, the organic acids and other trace material must be removed to detoxify the extract.

Process engineers who are interested in designing biorefinery systems will find this paper interesting.

Luo

Zou

Genco

An effort is underway to determine the feasibility of upgrading kraft pulp mills to the production of products other than pulp. In our paper, a series of design equations are presented that delineate how much of the component sugars and sugar acids can be extracted from wood using the near neutral hemicellulose extraction process.

In the future, we hope to attract funds to initiate work on the detoxification of the extracts from the green liquor extraction process.

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