A Simplified Pulping & Bleaching Process for Pith-Containing Nonwoods: Trials on Whole Corn Stalks

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ABSTRACT

Whole corn stover, without depithing, was subjected to conventional soda and soda-AQ pulping trials, followed by TCF bleaching. The same stover was also pulped and bleached using EAZP, a patented four-stage process developed for pith-containing nonwoods. The fully-bleached pulps from the EAZP process had superior freeness compared to those from the conventional processes. Tensile strength, smoothness, and opacity for the EAZP pulps were comparable to those for hardwoods, while tearing strength was lower. The EAZP pulps were easier to refine than hardwood pulps.

INTRODUCTION

The Challenges of Pith-Containing Nonwoods

Nonwood plant materials have traditionally been used for non-specialty papermaking only in countries that have minimum forest resources. However, interest is increasing in the use of nonwoods in North America and other well-forested countries. This interest is due to several factors, including regional shortages of hardwoods, a rapid growth in demand for wood in wood products (lumber, board, building materials, furniture), and a steady increase in wood prices.

Unfortunately, the use of nonwoods, as compared to wood, is fraught with challenges. These challenges have been well-documented (1, 2) and include the following:

- annual harvesting and requisite storage needs
- most nonwoods cannot be processed in wood-processing equipment
- low bulk density, and thus high shipping and storage costs
- more extreme fiber properties in many cases, including bi-modal length distribution
- more variability in properties
- presence of silica, which fouls equipment rapidly
- presence of pith, which reduces drainage and yield

It is the last challenge listed above that is the focus of this paper.

Some nonwood plant materials contain a significant content of pith. For example, approximately 33-35 % of the oven-dry weight of sugar cane bagasse is pith, while corn stalks have a pith content of approximately 21 % (3). Pith, found in the center of the plant stalks, consists of only small amounts of usable papermaking fiber. Most of its mass consists of parenchyma cells, used by the plant for storage of water and food. These thin-walled cells offer little resistance to chemical penetration, relative to the other parts of the plant, so they preferentially absorb pulping chemicals and are completely dissolved; the result is high chemical consumption and low yields (3). In addition, the fine nature of residual pith after pulping significantly reduces the drainage rate of the resulting pulps, making washing and dewatering difficult. Finally, it has been noted that pith cells, if left in the final pulp, can result in reduced sheet opacity (4).

Given these difficulties, it has long been accepted that a pulping facility using nonwoods with a high pith content must have a fiber preparation section featuring wet or dry depithing. Indeed, a large amount of the literature on bagasse pulping has been dedicated to the design and operation of depithing processes (4, 5). Unfortunately, this depithing requirement can be detrimental to the success of a modern nonwood facility, including the following problems:

1. Depithing adds significant capital costs to the nonwood mill, which already has a high capital cost-to-production ratio.
2. There is potential for fiber damage and loss of good material during the depithing operation.
3. Some method must be found for disposal or use of the resulting large quantities of wet or dry pith.

For some time, research at NC State has been focused on finding simpler, less costly processes to produce bleached pulp and paper from nonwood raw materials. Much of the initial efforts were focused on corn stalks, because of the abundance of these residues in North America (5). Part of the research on corn stalks involved removing the need for mechanical depithing prior to pulping. The end result was the development of a new, simplified pulping and bleaching process – EAZP.

The EAZP Process

The EAZP process was developed as a unique, highly-simplified pulping and bleaching process for nonwoods, and it was awarded a patent in 2001 (6). The process is based on two shortcomings identified in traditional approaches to nonwood pulping:

- Traditional pulping methods tend to be too severe, using high alkali charges and high temperatures. Such conditions are often not warranted, given the low lignin contents and low level of lignin condensation in many nonwoods. The result, in many cases, is actually higher Kappa numbers, lower brightness levels, and poor bleachability.
- Traditional pulping methods do nothing to passivate or chemically remove pith, making mechanical depithing necessary

The process, carried out on raw materials which have not been depithed, involves a mild delignification step, followed by acid chelation, ozonation and a final pressurized peroxide treatment (other bleaching stages may be substituted for the latter). The acid and ozonation steps may been combined, resulting (for corn stalks) in a three-stage process that converts raw materials into papermaking pulps with a brightness of 85 % ISO or greater.

EXPERIMENTAL METHODS

Soda and Soda-AQ Trials on Corn Stalks

Initial trials on non-depithed corn stalks were based on the challenge of producing a bleached pulp with a brightness of 85 % ISO or higher, with an acceptable freeness, using a sulfur-free pulping process and totally-chlorine-free (TCF) bleaching process.

The corn stalks were obtained from a farm in Iowa, air-dried, and aged for one year. Analysis of the raw material showed that it was 70 % stalk and 30 % leaves and husks. The raw material was in good shape and free from fungus attack or other degradation.

Prior to pulping, the raw material was soaked in hot tap water (130 F) for 30 minutes and then drained.

Pulping trials were carried out using a Paprican-designed, high-consistency pressure reactor of 11.4-liter capacity, equipped with a rotating shaft with lifting “fingers.” This reactor has been considered favorable for its ability to emulate a screw-type digester.

After pulping, a sample of black liquor was obtained from each cook and tested for pH and residual alkali.

The cooked material was collected in a screen box with a 150-mesh bottom, to permit the liquor and pulp to be separated. The cooked material was then passed through a Bauer 8-inch refiner to effect fiberization. A plate gap of 0.035inches was used.

Pulp collected in the screen box was washed thoroughly, collected, then fed into a Voith laboratory vibrating flat screen, with a screen slot size of 0.010 inches. Material passing through the screen (accepts) was collected in the 10-mesh screen box, collected, centrifuged, allowed to equilibrate for at least 12 hours, then weighed and tested for consistency for yield analysis. Material retained on the screen (rejects) was collected, oven-dried, and then weighed.

Testing of the screen accepts included Kappa number, ISO brightness, and Canadian Standard Freeness. All testing was carried out according to TAPPI standard methods.

Additional trials were conducted using Anthraquinone (AQ). The AQ used was obtained from a domestic US supplier and was in the form of a dispersion with 50 % active solids. The AQ was mixed vigorously into the cooking liquor prior to its addition to the raw material. All other methods were the same as described above for the soda cooking trials.

Chelation (Q) stages were carried out in sealed plastic bags placed into a heated water bath and kneaded periodically. Sulfuric acid was used, and distilled water was used for dilution. The chelant was a commercial-grade solution of DTPA. Conditions were as follows: 5 % consistency, pH 3.5, 0.5 % DTPA on OD fiber, 50 C, 30 minutes. After chelation, the pulp was washed with distilled water.

Atmospheric peroxide (P) bleaching stages were carried out in sealed plastic bags placed into a heated water bath and kneaded periodically. Conditions were as follows: 3 % H_2O_2 on OD, 3 % NaOH on OD, 0.5 % on OD each of sodium silicate, magnesium sulfate, and DTPA, 10 % consistency, 80 C, 90 minutes. After each stage, the pulp was washed thoroughly with distilled water.

Pressurized peroxide (Pp) bleaching stages were carried out at medium consistency in 3-liter, stainless pressure bombs. The pulp was mixed with chemicals in a kneading-style kitchen mixer for approximately 10 minutes prior to being placed into the bombs. Distilled water was used for dilution. The bombs were placed on a rotating rack in a convection oven. Conditions were as follows: 4 % H_2O_2 on OD, 4 % NaOH on OD, 0.2 % DTMPA on OD, 0.5 % on OD each of sodium silicate and magnesium sulfate, 10 % consistency, 105 C, 90 minutes.

EAZP Trials on Corn Stalks

The conditions used in each stage are shown in Table 1.

Table 1. Process conditions used for each stage of the EAZP process

E	14 % NaOH on OD; 8:1 liquor-to-fiber ratio; 118 C for 60 minutes
A	5 % H_2SO_4 on OD; 0.5 % DTPA on OD; 10 % consistency; 60 C for 60 minutes
Z	1 % ozone on OD; 3 % consistency; acid to pH 1.5; 30 C for 10 minutes
P	4 % H_2O_2 on OD; 5 % NaOH on OD; 0.2 % DTMPA on OD; 0.5 % silicate on OD; 0.5 % $MgSO_4$ on OD; 10 % consistency; 105 C for 90 minutes

The same corn stover used for the soda and soda-AQ trials was used for the EAZP trials.

Prior to each trial, the stover was soaked in hot tap water (130 F) for 30 minutes and then drained.

The initial alkaline (E) stage was carried out in the Paprican high-consistency reactor, as described previously. The cooked material was collected in a screen box with a 150-mesh bottom, to permit the liquor and pulp to be separated. The cooked material was then passed through a Bauer 8-inch refiner to effect fiberization. A plate gap of 0.035inches was used.

No screening step was carried out. The refined material was washed thoroughly, centrifuged, allowed to equilibrate for at least 12 hours, then weighed and tested for consistency for yield analysis. The pulp was tested for Kappa number, ISO brightness, and Canadian Standard Freeness.

The acid chelation (A) stage was carried out in sealed plastic bags placed into a heated water bath and kneaded periodically. Sulfuric acid was used, and distilled water was used for dilution. The chelant was a commercial-grade solution of DTPA. Upon completion of the stage, the pulp was immediately placed into a poly-mesh bag and centrifuged for 5 minutes, with a resulting consistency of approximately 35 %. The material was immediately treated with ozone.

The ozone (Z) stage was carried out at low consistency, using a 1-gallon, stainless commercial food blender fitted with a non-cutting rotor and a tube for sparging ozone gas into the vortex. The top of the blender was sealed and fitted with an outlet, onto which was fitted plastic tubing. The tubing was then connected to a gas washing bottle filled with KI kill solution. A Polymetrics ozone generator, equipped with an ozone concentration meter, was used to generate ozone gas. By introducing a known flow rate and concentration of gas into the blender and then titrating the kill solution, it was possible to calculate the actual ozone consumption by the pulp. Prior to ozonation, the pulp was diluted to 3 % consistency using distilled water, and sulfuric acid was added to achieve a pH of 1.5.

Upon completion of the Z stage, the pulp was diluted to an approximate consistency of 0.5 %, using distilled water. The resulting slurry was screened in a Voith flat screen with 0.010-inch slots. Material passing through the screen (accepts) was collected in the 10-mesh screen box, collected, centrifuged, allowed to equilibrate for at least 12 hours, then weighed and tested for consistency for yield analysis. Material retained on the screen (rejects) was collected, oven-dried, and then weighed. The pulp was tested for Kappa number, ISO brightness, and Canadian Standard Freeness.

The final pressurized peroxide (P) stage was carried out at medium consistency in 3-liter, stainless pressure bombs. The pulp was mixed with chemicals (hydrogen peroxide, sodium hydroxide, sodium silicate, magnesium sulfate, reagent-grade DTMPA) in a kneading-style kitchen mixer for approximately 10 minutes prior to being placed into the bombs. Distilled water was used for dilution. The bombs were placed on a rotating rack in a convection oven.

After the P stage, the pulp was washed thoroughly with distilled water, centrifuged, allowed to equilibrate for at least 12 hours, then weighed and tested for consistency for yield analysis. The pulp was tested for Kappa number, ISO brightness, and Canadian Standard Freeness.

RESULTS AND DISCUSSION

Control trials were conducted, using soda pulping and TCF bleaching. The results are shown in Table 2, representing approximately 8 different trials

It was possible to produce a bleachable-grade brownstock (18-25 Kappa) using soda pulping, but the freeness values were significantly lower than is considered appropriate for chemical pulps. In order to reach the target brightness of 85 % ISO, it was necessary to increase the severity and complexity of the TCF bleaching sequence, first by converting the first P stage to a pressurized stage (Pp), then by adding a second acid chelation stage (Q). During this progression, brightness did increase, but the freeness values decreased sharply. This decrease was attributed to the presence of residual pith material. A bleaching sequence of Q-Pp-Q-P was able to produce final brightness in the desired range, but the resulting freeness values of 270-300 CSF were significantly lower than desired.

It was decided to use soda-anthraquinone (soda-AQ) pulping to lower the severity of pulping and improve the freeness values of the bleached pulp. The results of these pulping trials, followed by TCF bleaching, are shown in Table 3. As was obtained for the soda pulping trials, the final freeness values were significantly lower than desired.

Table 2. Results from soda pulping and TCF bleaching of non-depithed corn stalks

	Brightness, % ISO	Freeness, CSF
Pulping, 20 % NaOH, 140 C, 90 minutes	20-30	400-450
Bleaching, Q-P-P	68-75	350-400
Bleaching, Q-Pp-P	82-84	280-360
Bleaching, Q-Pp-Q-P	84-88	270-300

Q = acid chelation stage
P = atmospheric peroxide stage
Pp= pressurized peroxide stage

Table 3. Results from soda-AQ pulping and TCF bleaching of non-depithed corn stalks

	Brightness, % ISO	Freeness, CSF
Pulping, 11 % NaOH, 0.1 % AQ 140 C, 60 minutes	14-25	360-420
Bleaching, Q-P-P	78-82	280-330

Table 4 contains the results of EAZP pulping and bleaching.

It was interesting that, using 6 % less alkali and a significantly lower temperature, the E stage was able to produce a similar Kappa number as for the soda process. It was speculated that either a) the harshness of the traditional soda stage led to lignin condensation, or b) the harsh soda cooking conditions led to significant dissolution of pith material, consuming more alkali without reducing the Kappa number. Unfortunately, the yield data for the soda cooks was lost, so it was not possible to conclude if the latter phenomenon was responsible.

After refining, the cooked material was quite coarse, with a significant quantity of fiber bundles and string-like structures. For this reason, screening was conducted later in the sequence (although other trials have shown that screening in either location will produce acceptable results). After ozonation, this coarse fraction was reduced significantly, and the material more closely resembled normal pulp.

The most noteworthy aspect of the Z stage was the large yield loss. Normally, one would expect a maximum yield loss of 1-3 % for the degree of delignification effected in this stage. It is believed that this loss was caused by the chemical attack and dissolution of pith by ozone. This explanation is supported by the significant improvement in freeness after the Z stage; pith is well-known to impede the drainage rate of pulps.

Table 4. Results from EAZP pulping and bleaching of non-depithed corn stalks

	Kappa	Brightness, % ISO	Freeness, CSF	% Yield
E	20.1	29.2	350	57.9
A	19.4	40.2	---	94.7
Z	6.5	56.1	587	75.3
Screening	---	---	---	98.7
P	1.3	87.4	619	93.2

Overall yield = 38.0 %.

For this reason, the Z stage is considered the heart of the EAZP process, in that it serves not only as a powerful delignifying and brightening agent, but also as a *chemical depithing agent*. By attacking and removing pith chemically, there is no need for wet or dry depithing on the front end, resulting in a simpler process with lower capital costs and higher fiber yield. In addition, the dissolution of the pith puts it into a form that can be used as fuel for the recovery boiler, rather than generating a solid waste stream that must be disposed of.

It is interesting that the application of only 1 % ozone on OD pulp could produce such significant reduction in Kappa number as well as a stark removal of pith and other materials. No explanation for this efficiency has been found.

The final pulp had a brightness above the 85 % target, and yet the final freeness was almost 300 points higher than for the corresponding TCF-bleached soda and soda-AQ pulps.

There was some concern about the possible negative effects of the ozone treatment on ultimate sheet strength. Refining curves were generated, using a PFI mill, and the results were compared to data for hardwoods (mixed southern hardwoods and eucalyptus). The results are shown in Figures 1-5.

With regard to refining response, it can be seen in Figure 1 that the freeness decreased more rapidly for the EAZP corn pulp than for the hardwoods. This was expected, because of the thinner cell walls and more fragile nature of the corn pulp fibers.

In Figure 2, it can be seen that the tensile strength of the corn pulp was remarkably similar to that of the mixed southern hardwoods. The behavior of the single-species eucalyptus pulp was somewhat different, but, at comparable freeness values, the corn pulp strength properties were similar.

In Figure 3, it can be seen that the tearing resistance of the corn pulp was lower than for either hardwood. This difference, uniform over the range of freeness, was attributed to both the lower average fiber length and the more fragile nature of the corn fiber. It is expected that corn pulps will have inferior tear properties compared to wood pulps, regardless of the pulping and bleaching methods used.

In Figures 4 and 5, it can be seen that the smoothness and opacity values for the corn pulps were similar to those for mixed southern hardwoods.

CONCLUSIONS

1. Using the EAZP process on non-depithed whole corn stover, it was possible to produce bleached pulps with significantly higher freeness values than for soda or soda-AQ pulps bleached with TCF sequences.
2. The Z stage of the EAZP process produced a significant drop in yield and a concurrent improvement in drainage; it is believed that this effect is due to the attack and removal of pith.
3. Bleached pulps produced using the EAZP process had tensile strength, smoothness, and opacity properties similar to those for hardwoods.
4. Bleached pulps produced using the EAZP process had inferior tearing strength compared to hardwoods.
5. Bleached pulps using the EAZP process were easier to refine than hardwoods.

FUTURE WORK

Work is ongoing to see how the EAZP process works on whole (non-depithed) bagasse, which is another nonwood with a very high content of pith. These results will be presented with the corn stover data at the 2005 Fall Technical Conference.

Work is also ongoing to see what the effect of stover pretreatment (shredding, pre-steaming, etc.) is on the EAZP process.

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8. NC State University, internal hardwood refining study data.
9. NIST Study 8496.

Figure 1. Refining response for corn stover pulps from the EAZP process, compared to mixed hardwoods (8) and eucalyptus (9).

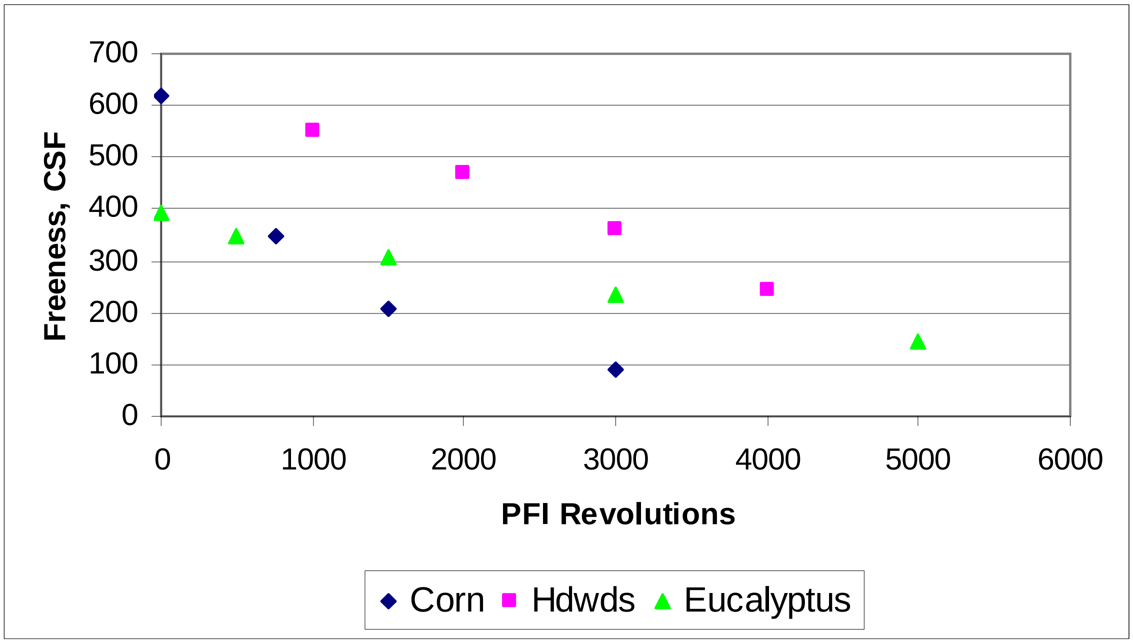


Figure 2. Tensile strength response for corn stover pulps from the EAZP process, compared to mixed hardwoods (8) and eucalyptus (9).

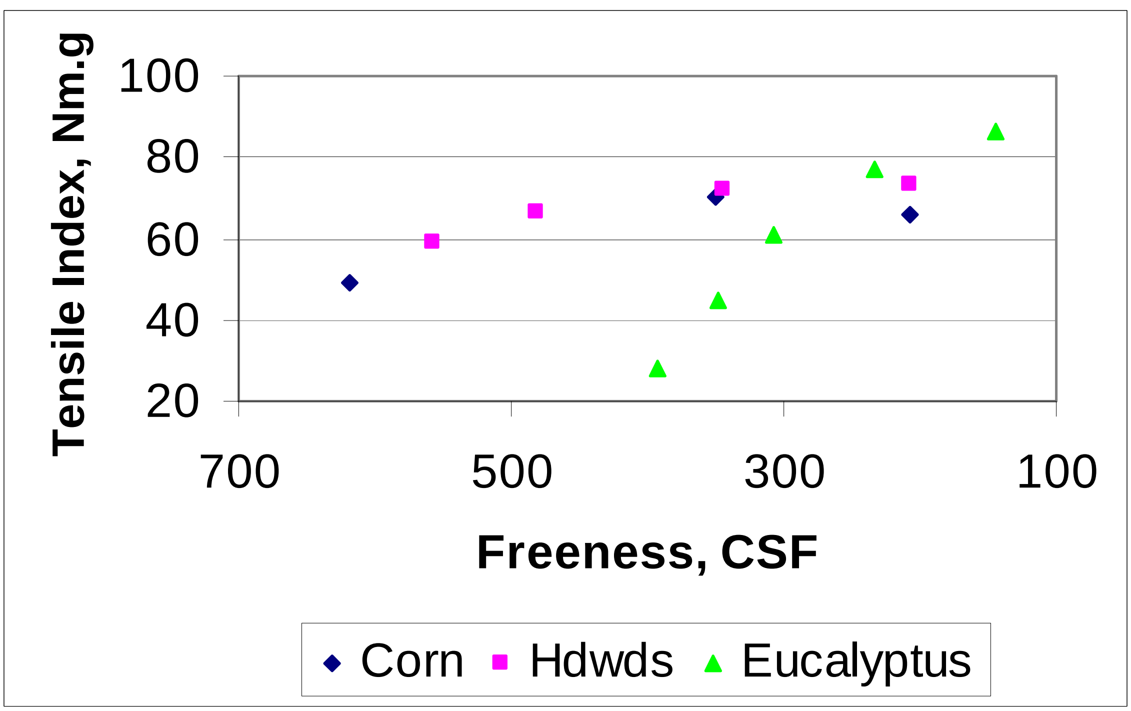


Figure 3. **Tearing strength response for corn stover pulps from the EAZP process, compared to mixed hardwoods (8) and eucalyptus (9).**

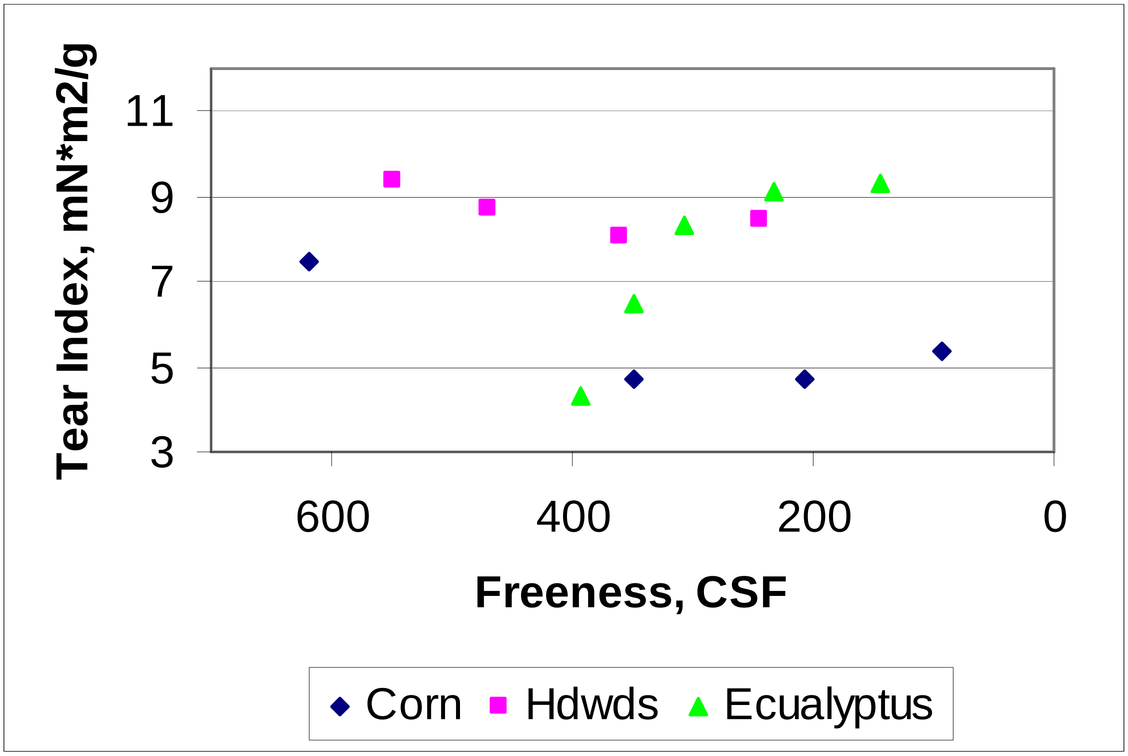


Figure 4. **Smoothness response for corn stover pulps from the EAZP process, compared to mixed hardwoods (8).**

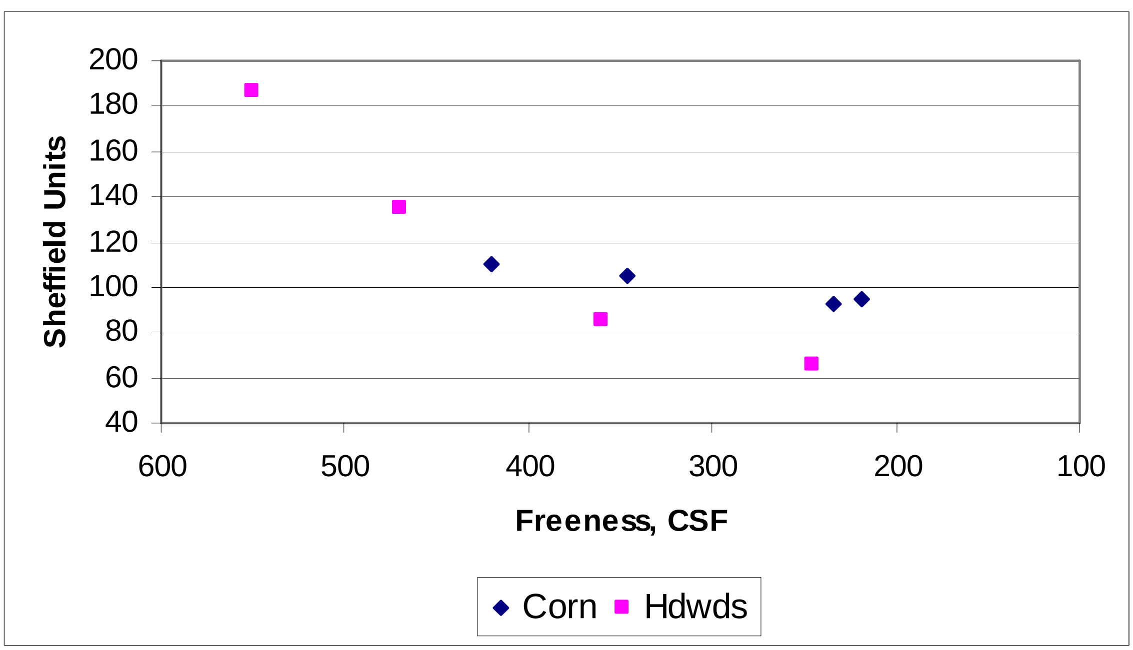
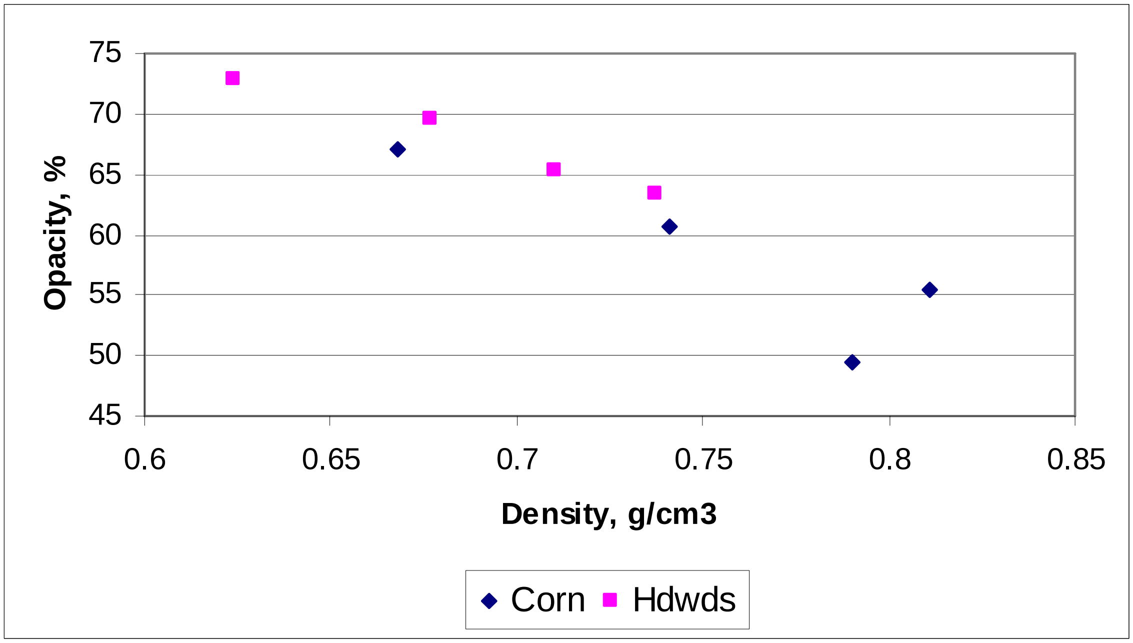


Figure 5. Opacity response for corn stover pulps from the EAZP process, compared to mixed hardwoods (8).



Simplified Pulping & Bleaching of Pithy Nonwoods:
Trials on Cornstalks and Bagasse

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OUTLINE

- Why Cornstalks and Bagasse
- Our experiences with cornstalk pulping
- A new approach
- Experimental (Cornstalks)
- Results (Cornstalks)
- Work on Bagasse
- Conclusions and future work

Why Cornstalks/Bagasse?

- Agricultural residues
- Large quantities available
- Favorable physical/chemical makeup
- Suitable as hardwood substitute

There Are Special Challenges!

- Cornstalks/bagasse have a high content of pith – parenchyma and fines
- Pith consumes huge amounts of pulping and bleaching chemicals
- Pith reduces drainage rate during washing, dewatering, papermaking
- Usually requires mechanical depithing prior to pulping

What is Needed

- A simplified process that lends itself to “mini-mills” located in the supply area
- A process that deals with pith without expensive mechanical de-pithing
- A process that preserves drainage rate

Our Experiences in Pulping Non-Depithed Cornstalks, With TCF Bleaching

1. Soda Pulping with TCF Bleaching

	Brightness, % ISO	Freeness, CSF
Pulping, 20 % NaOH, 140 C, 90 minutes	25-30	400-450
Bleaching, Q-P-P	68-75	350-400
Bleaching, Q-Pp-P	82-84	280-360
Bleaching, Q-Pp-Q-P	**84-88**	**270-300**

2. Soda-AQ Pulping with TCF Bleaching

	Brightness, % ISO	Freeness, CSF
Pulping, 11 % NaOH, 0.1 % AQ, 140 C, 60 minutes	14-25	360-423
Bleaching, Q-P-P	**78-82**	**280-332**

The Deficiencies

- "Traditional" pulping and bleaching approaches do not remove or passivate pith
- The pith breaks up in the bleaching sequence (especially acid stages), reducing freeness significantly

A New Approach --
The E-A-Z-P Process…
US Patent Number 6,302,997

Attributes

- A simple, 2- or 3-stage process (3- or 4-stage including screening)
- Requires no raw material depithing
- Produces bright, free-draining pulp with good papermaking properties

Two Key Concepts

- ***Lowered pulping intensity*** – many processes tend to "overcook" cereal straws, actually reducing lignin removal
- ***In-process treatment of pith*** – deals with pith and parenchyma chemically in the process, rather than using mechanical depithing of the raw material

E – Alkaline Extraction

- Milder than a typical soda or soda-AQ cook
- Typical conditions
  - NaOH charge = 12-14 % on OD
  - Temperature = 115-118 C
  - Time = 60 minutes
  - Liquor:Fiber = 8:1
- Kappa = 18-20

A - Acid Chelation

- Can use nitric, sulfuric, or acetic acids
- Typical conditions
  - Acid charge = 5 % on OD
  - DTPA (chelant) charge = 0.5 % on OD
  - Consistency = 10-15 %
  - Temperature = 60 C
  - Time = 30-60 minutes

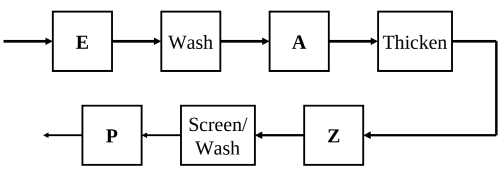
Z – Ozone Treatment

- Typical conditions
  - Ozone consumption = 0.7 – 1 % on OD
  - Consistency = 3 %
  - pH = 1.5
  - Temperature = 30 C
  - Time = 10 minutes

P = Pressurized Peroxide Bleaching

- Typical conditions
  - Peroxide charge = 4 % on OD
  - NaOH charge = 5 % on OD
  - DTMPA (chelant) charge = 0.2 % on OD
  - MgSO4 and Silicate charge = 0.5 % on OD
  - Consistency = 10-12 %
  - Temperature = 105 C
  - Time = 90 minutes

Basic Process Flowsheet



Experimental Methods

Raw Material

- Corn stover from Iowa, aged 1 year
- Composition = 70 % stalk, 30 % leaves and husks
- Prior to pulping, soaked in hot water (130 F) for 30 minutes, then drained

E Stage

- Carried out in Paprican-designed “finger reactor”
- Good for emulating screw-type digester
- Cooked fiber passed through disk refiner, 0.035-inch gap
- Washed

A Stage

- Carried out in sealed plastic bags placed into a heated water bath
- Nitric acid used
- Kneaded periodically

Dewatering Stage

- Acid-treated fiber centrifuged in fine-mesh poly bag for 5 minutes
- Discharge consistency = 35 %
- Z stage followed immediately

Z Stage

- Centrifuged pulp diluted to 3 % consistency with distilled water
- Acid added
- Put into modified blender with non-cutting rotor and gas sparger into mixing zone
- Ozone gas of known flow rate and concentration injected into blender; excess taken off top and bubbled into kill solution
- Reacted for 10 minutes

Screening/Washing Stage

- Z stage pulp diluted with distilled water to approximately 0.5 % consistency
- Screened through vibrating flat screen with 0.010-inch slot
- Accepts dewatered to 35 % consistency

P Stage

- Carried out in 3-liter bombs placed into heated oven on rotating rack
- Chemicals mixed in using industrial-style kitchen mixer

Cornstalks: Results

Results by Stage

	Kappa	Brightness % ISO	Freeness CSF	% Yield
E	20.1	29.2	---	57.9
A	19.4	40.2	---	94.7
Z	6.5	56.1	587	75.3
Screening	---	---	---	98.7
P	1.3	87.4	619	93.2

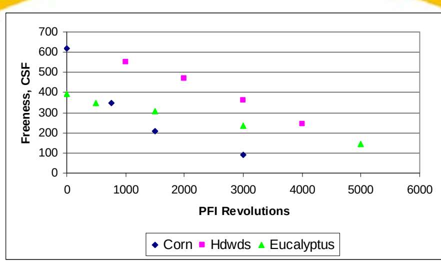
Overall Yield = 38.0 %

Bleached Fiber Properties

	Cornstalk	Mixed Hardwoods	Eucalyptus
Avg. Length, mm (Length-wtd)	1.09	1-1.07	0.65
Coarseness, mg/10m	1.06	1.23	0.95
Fines, % of total fibers (by number)	41.3	57.8	---

>Hdwds = NCSU kraft study data, mixed southern hardwoods
> Eucalyptus = N.I.S.T. data, Study 8496

Refining Response



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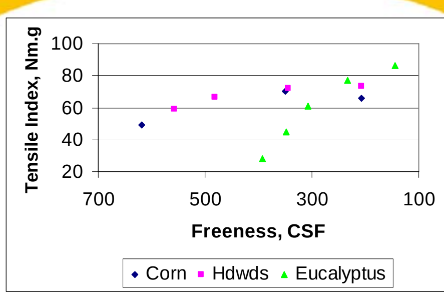
Tensile Strength



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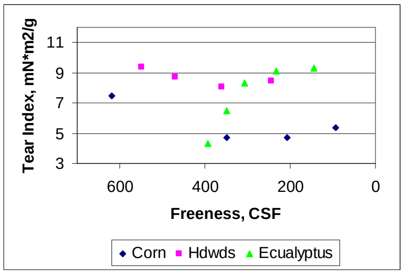
Tearing Strength



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Work on Bagasse

Strategy

- Compare several processes, final brightness 82-85 % ISO
  - Soda-AQ pulping + DED bleaching
  - Soda-AQ pulping + AZP bleaching
  - EAZP pulping/bleaching

Bagasse vs. Cornstalks

- Similar fiber length, wall thickness
- Slightly higher lignin content
- Higher pith content (30 % vs. 21 %)
- Much darker in color

Experimental

- Whole (non-depithed) bagasse obtained from mill in Australia
- Air-dried to ensure stability
- Soaking, pulping, A-Z-P treatments done as described previously
- D-E-D bleaching done in sealed plastic bags at medium consistency

Soda-AQ Pulping Conditions

- Various NaOH charges
- AQ used at 0.1 % on OD
- Liquor-to-fiber ratio = 4:1
- Max. temperature = 165 C
- H-factor = 1200

Soda-AQ Pulping Results

% NaOH	**16**	**18**	**20**	**22**
Kappa	32.9	28.8	17.7	15.8
Total Yield, %	55.1	48.3	53.1	51.3
Screened Yield, %	43.5	41.0	51.3	49.9
% Rejects on OD Pulp	21.1	15.2	3.5	2.7
Freeness, CSF	585	513	640	544
End pH	10.2	10.4	10.8	10.9

D-E-D Bleaching Results

	Cook	**D**	**E**	**D**
% CLO2	---	1.8	---	1.4
Kappa	17.7	---	1.1	0.6
% Yield	51.3	---	*93-95 (est.)*	98.0
Brightness, %	23.3	---	47.1	82.7
Freeness	640	---	---	536

Estimated Total Yield = 47 – 48 %

EAZP – E stage

- 15 % NaOH on OD
- 120 C
- 90 minutes
- Followed by refining
- Necessary to screen after refining

EAZP Results

	E	Scr	A	Z	P
Kappa	26.5	--	--	10.5	2.8
% Yield	47.0	92.5	--	96.6	88.8
Brightness, %	12.5	--	--	48.2	82.8
Freeness, CSF	523	--	--	397	448

Overall Yield = 37.3 %

Soda-AQ – A-Z-P Results

	Cook	A	Z	P
Kappa	17.7	---	7.4	1.6
% Yield	51.3	---	89.9	96.8
Brightness, %	23.3	---	41.5	78.3
Freeness	640	---	355	488

Overall Yield = 44.6 %

Overall Comparison

Process	Kappa	% Yield	% Brightness	Freeness
Soda-AQ – D-E-D	0.6	47 - 48	82.7	536
Soda-AQ - AZP	1.6	44.6	78.3	488
EAZP	2.8	37.3	82.8	448

Conclusions

- Using corn stalks, the EAZP process produced pulps with freeness values superior to those for soda-AQ pulping followed by TCF bleaching
- The Z stage of the EAZP process produced a significant drop in yield and a concurrent improvement in drainage; it is believed that this effect was due to the attack and removal of pith

Conclusions

- Bleached cornstalk pulps produced using the EAZP process had tensile strength, smoothness, and opacity properties similar to those for hardwoods.
- Tearing strength was inferior to hardwoods
- The EAZP cornstalk pulps were easier to refine than hardwood pulps

Conclusions

- Using the same conditions as for cornstalks, on bagasse the EAZP process was able to produce final pulp brightness similar to that for soda-AQ pulping followed by DED bleaching
- However, yield and freeness values were inferior

Future Work

- Need to repeat bagasse EAZP trials, using
  - TCF bleaching
  - E stage Kappa number in the 18-20 range
  - Bagasse that has not been dried
  - Bagasse that has been washed
  - AQ in the E stage
- Need to investigate the nature of bagasse pith, vs. cornstalk pith