THE PULPING, BLEACHING AND PAPERMAKING CHARACTERISTICS OF REED (*ARUNDO DONAX*), COMPARED TO MIXED SOUTHERN HARDWOODS

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ABSTRACT

Chips from both mixed southern hardwoods and reed (*Arundo donax*) were pulped using a typical kraft process. Bleaching was carried out with a TCF sequence, and the bleached pulps were beaten in a PFI mill and tested for optical and physical properties. The air-dried reed chips required slightly more alkali than did the wet wood chips to reach a bleachable-grade Kappa number. Total and screened yields were moderately lower for the reed cooks. The brightness of the unbleached reed pulp was significantly higher than for the wood pulp. Bleachability for both pulps was similar. The bleached reed pulp was much easier to refine. Optical and physical properties for both beaten pulps were similar.

INTRODUCTION

Reed and reedy grasses have been of interest as a papermaking raw material for many years. This interest has been especially keen in countries like China, which has limited forest resources and requires longer-fibered pulps to reinforce short-fibered furnishes based mostly on cereal straws. Extensive laboratory- and mill-scale investigations have been carried out on common reed (*Phragmites communis*) (1-4) and reedy grasses such as elephant grass (*Miscanthus sinensis*) (5-6) and amur silver grass (*Miscanthus sacchariflorus*) (7-8). In general, these materials have been found to produce an acceptable yield of fibers with acceptable papermaking properties. In 1982, it was estimated that 1.4 million tons of the worldwide nonwood pulp production of 8 million tons was produced from reeds (9).

With the future of the wood-based fiber supply being debated worldwide, increasing interest is being shown in nonwood alternatives for papermaking. Even the United States, which has extensive forest resources, is looking at such alternatives. However, the use of nonwoods by an industry based almost entirely on wood faces significant technical and operational challenges. Some of the most important of these challenges are as follows:

- *Low Bulk Density* — straws and similar materials have a loose and fluffy structure, which makes them more costly to transport and store compared to wood chips
- *Difficulty in Processing* — fluffy, stringy materials like straw and bast cannot, in general, be processed in the feeding and cooking equipment used in modern wood pulp mills
- *Low Strength Properties* — while some nonwoods have strength properties equal to or better than wood pulps, many of the more available materials, like cereal straws, have inferior strength properties
- *Low Drainage Rates* — cereal straws and core materials from hemp and kenaf have drainage rates much lower than for wood pulps, causing production limitations

Bamboos and reeds, with bulk densities and physical/chemical characteristics similar to wood, are better able to meet these challenges than many other types of nonwoods. For this reason, interest in the United States has been increasing in the use of such materials. Unfortunately, many bamboos and reeds have proven difficult to establish in the growing conditions prevailing across the United States. One notable exception is the reed variety *Arundo donax*, commonly called “giant reed” or “Italian reed.” This perennial reed has been shown to have good growth characteristics in the United States, with some reports of yields up to 67 metric tons of dry material per hectare (10).

Studies on *Arundo donax* are not as plentiful as for other reeds and grasses. However, comparisons of its chemical and physical structure, compared to more common or wild reeds, date back more than thirty years (11). The bulk of older references are from forward-looking studies done in Europe, considering *Arundo donax* as a potential alternative to wood for papermaking (12-16). Most of these studies concluded that the growth, yield, and fiber characteristics of this particular reed make it one of the more promising nonwood raw materials.

More recent studies done in China have examined in more detail the chemical structure of *Arundo donax* (17-18), and its response to various pulping and bleaching processes (19-20).

It is assumed that the features which make *Arundo donax* most attractive to the United States pulp and paper industry are its high yield, its similarity to hardwoods, and its woody nature, which makes it possible to combine with wood chips in a “co-cooking” type of process. If *Arundo donax* is to find acceptance by the United States pulp and paper industry, additional studies must be done on cultivars being developed specifically for growth in that country. The purpose of this work is to determine a) how one such cultivar responds to a typical kraft pulping process; and b) how pulps produced in this manner compare with mixed southern hardwoods pulped by an identical process.

EXPERIMENTAL

Arundo donax chips, from a cultivar developed for high yields in the Southern United States, were supplied with an average length of one inch. The chips were not crushed or compacted prior to use. No attempt was made to remove the residual husk from the chips. To simulate the drying which the chips, harvested at one time in the fall, experience during storage, the chips were allowed to air dry thoroughly prior to use.

Mixed southern hardwood chips were obtained from a southern mill in a pre-screened, wet state.

Pulping was conducted in a 10-liter batch digester equipped with sidearm liquor circulation and electric heating. Pulping conditions are shown in Table 1.

After cooking, the chips were passed through a twin-disk refiner with a plate gap of 0.025" in order to complete the defibration. The refined material was then passed through a slotted flat screen with 0.010-inch slots. Screen accepts were centrifuged, fluffed, and measured for total weight, consistency, and OD weight. Screen rejects were oven-dried and weighed.

The selection of the bleaching sequence received careful consideration. It was decided to utilize a sequence that would allow a final brightness in the mid-80's (ISO), yet would not employ any chlorine-based bleaching agents. It was also desired to make the sequence fairly harsh, to insure that the reed fiber could tolerate such conditions.

Table 1. Pulping conditions

Furnish	**100 % HWD, Bl.** **100 % Reed, Unbl.**	**100 % Reed, Bl.**
Active alkali, %	18	19.2
Sulfidity, %	25	25
Liquor-to-fiber ratio	4:1	6:1
Maximum temperature, C	170	170
Time to max. temp, min.	60	60
H-factor	1000	1000

Based on these requirements, a Q-P-P sequence was selected: acid chelation, followed by two stages of pressurized peroxide bleaching.

Acid chelation was carried out in a heat-sealed plastic bag immersed in a heated water bath. The bag was kneaded periodically. The conditions used in the chelation stage were as follows:

- pH 5 (adjusted with sulfuric acid)
- DTPA 0.5 %on OD fiber
- Consistency 4 %
- Temperature 55 C
- Time 30 minutes

After chelation, the pulp was washed thoroughly with distilled water.

Pressurized peroxide bleaching was carried out in a Teflon-lined, 2-liter bomb placed on a rotating rack in a hot-air oven. The pulp and chemicals were mixed briefly in a kitchen-type mixer, then placed into the bomb. Conditions used in each of the two peroxide stages were as follows:

- H_20_2 4 % on OD fiber
- NaOH 4 % on OD fiber
- DTMPA 0.2 % on OD fiber
- $MgSO_4$ 0.5 % on OD fiber
- Na_2SiO_3 0.5 % on OD fiber
- Consistency 12 %
- Temperature 105 C
- Time 90 minutes

Refining was carried out in a PFI mill, according to TAPPI procedures. 1.2-gram (OD) standard handsheets were made, conditioned, and tested according to TAPPI standards.

RESULTS AND DISCUSSION

Pulping

The results of pulping hardwood and dry reed chips are shown in Table 2. Unlike for the wet reed chips, the dry reed chips required slightly more alkali to produce a Kappa number in the same range as for the hardwood. The reed chips had a moderately lower total and screened yield compared to the hardwood. Screened reject rates were comparable.

Table 2. Pulping Results

Furnish	**100 % HWD**	**100 % Reed**
Kappa Number	18.3	19.8
Total Yield, % of raw material	43.8	41.0
Screened Yield, % of raw material	43.6	40.8
Screened Rejects, % of total pulp	0.35	0.61
Brightness, % ISO	18.8	35.3
Freeness, CSF	720	645
Kajaani Fiber Length Length-weighted average, mm P-fraction, %	 1.38 34.4	 1.33 29.8
Unrefined Breaking Length, km	3.15	4.25
Unrefined Tear Index, $mN*m^2/g$	2.22	7.30
Unrefined Burst Index, $kPa*m^2/g$	0.616	3.96

Overall, both pulps looked very similar, with the exception that the reed pulp was much brighter. Fiber length and fines content for both pulps were very similar.

The unrefined strength data show that the reed fibers were better able to form bonds without refining. This behavior was most likely due to the more slender nature of the reed fibers, which permits easier collapse and comformability during sheetmaking.

Bleaching

The results of the first stage of pressurized peroxide bleaching are shown in Table 3.

Table 3. Bleaching Results, First Stage of Pressurized Peroxide Bleaching

	Hardwood	**Reed**
Starting Brightness, % ISO	18.8	35.3
Starting Kappa Number	18.3	19.8
Final Brightness, % ISO	64.3	73.5
Final Kappa Number	10.0	4.6
pH, initial./final	11.6 / 9.5	11.6 / 10.8
Yield, %	93.0	96.7
% of Peroxide Consumed	99.9	95.8

The hardwood pulp, with a much lower brightness, began the sequence with a significant disadvantage compared to the reed pulp. Nonetheless, both pulps responded very strongly to the bleaching, with brightness values increasing by up to 45 points. As expected, the hardwood pulp consumed more peroxide and had a lower bleaching yield compared to the reed pulp. It was interesting that less delignification occurred for the hardwood pulp, even though the starting Kappa numbers for both pulps were similar.

Results for the second stage of bleaching are shown in Table 4.

Table 4. Bleaching Results, Second Stage of Pressurized Peroxide Bleaching

	Hardwood	Reed
Starting Brightness, % ISO	64.3	73.5
Starting Kappa Number	10.0	4.6
Final Brightness, % ISO	88.3	85.1
Final Kappa Number	4.1	3.0
pH, initial./final	12.2 / 12.0	12.2 / 12.1
Yield, %	96.1	94.0
Total Pulped/Bleached Yield, %	39.0	36.7
% of Peroxide Consumed	84.9	79.3
Pulp Freeness, ml CSF	716	665

Again, the hardwood pulp consumed more peroxide than the reed pulp, reaching a final brightness of 88.3 % ISO, a few points higher than for the reed. Overall, both pulps had good bleachability, with the reed pulp requiring less peroxide due to its higher initial brightness.

Both pulps were quite clean, with very little evidence of dirts or shives. Freeness values were comparable to and typical for high-quality pulps with little pulping and bleaching damage.

Refining and Handsheet Testing

Tables 5 and 6 contain testing data for the handsheets produced from both bleached pulps after refining in a PFI mill. It should be noted that the PFI refining for the reed pulp did not proceed as desired. There was a limited amount of bleached pulp available for refining, and two samples were overbeaten because it was not anticipated that the pulp would refine so easily. It was necessary to accept points over a much lower freeness range (below 250 CSF) in order to generate the refining curve. While this occurrence limits some specific conclusions from being drawn, a general comparison of the two raw materials is still possible.

Table 5. Handsheet Properties of Bleached Reed Pulp, 85.1 % ISO

PFI Revolutions	0	200	500	1000
Freeness, ml CSF	665	330	224	103
Basis Weight, g/m^2		65.0	65.0	63.5
Caliper, mils		3.82	3.60	3.40
Apparent Density, g/cm^3		0.670	0.711	0.735
Bulk, cm^3/g		1.49	1.41	1.36
TAPPI Opacity, %		72.8	70.1	66.1
Scattering coefficient, cm^2/g		388	427	240
Gurley Porosity, seconds		27	176	835
Sheffield Smoothness		164	70.2	58
Tear Strength, gf		67.4	55.2	41.3
Tear Index, $mN*m^2/g$		10.2	8.33	6.38
Bursting Strength, psig		36.2	48.6	55.0
Burst Index, $kPa*m^2/g$		3.84	5.15	5.97
Tensile Breaking Length, km		6.86	7.52	7.89

Table 6. Handsheet Properties of Bleached Mixed Southern Hardwood Pulp, 85 % ISO

PFI Revolutions	0	250	500	1000
Freeness, ml CSF	624	497	470	287
Basis Weight, g/m^2	63.9	66.2	63.7	66.5
Caliper, mils	4.67	4.38	4.45	3.75
Apparent Density, g/cm^3	0.538	0.594	0.563	0.699
Bulk, cm^3/g	1.86	1.68	1.78	1.43
TAPPI Opacity, %	80.6	76.8	75.7	71.2
Scattering coefficient, cm^2/g	560	371	440	309
Gurley Porosity, seconds	0.9	2.6	3.0	49
Sheffield Smoothness	265	228	225	116
Tear Strength, gf	41.9	57.9	64.0	64.3
Tear Index, mN*m^2/g	6.47	8.59	9.86	9.48
Bursting Strength, psig	16.6	27.4	35.4	56.0
Burst Index, kPa*m^2/g	1.79	2.85	3.83	5.80
Tensile Breaking Length, km	4.28	5.25	5.92	7.73

Figures 1-3 show data for opacity, air porosity, and smoothness plotted as a function of handsheet apparent density. Although the overlap of the two data sets was less than desired, it could clearly be seen that the reed data for opacity and smoothness lie on a line plotted through the same data for the hardwoods. Although there could be some deviation between the two at lower densities, the linear nature of the relationship tended to indicate little difference between the two pulps with respect to opacity and smoothness. It was harder to analyze the porosity data. The reed data were clearly in the same range as the hardwood at a density of 0.7 g/cm^3, but it could only be speculated as to the manner in which the hardwood porosity data might increase sharply at higher densities.

Figure 4 shows the data for tear index plotted as a function of freeness. In the overlap region of 300 CSF, tear values for both pulps were comparable. The trend of both data sets showed little difference in tearing strength.

Figures 5 and 6 show the data for tensile breaking length and burst index plotted as a function of freeness. If the relationships are considered linear, there was no significant difference between the two pulps.

CONCLUSIONS

1. Although the *Arundo donax* (reed) chips required slightly more alkali to reach a given Kappa number, in general the reed responded to kraft pulping in a manner very similar to mixed southern hardwood chips.
2. Pulping yield, both total and screened, was moderately lower for the reed than for the mixed hardwoods.
3. At about the same Kappa number, the unbleached reed pulp was significantly brighter than the unbleached hardwood pulp.
4. The reed and hardwood pulps had very similar fiber length distributions, fines contents, and freeness values.
5. With no refining, the unbleached reed pulp had significantly higher strength properties than the hardwood pulp.
6. Both the reed and hardwood pulps exhibited a good response to bleaching with pressurized hydrogen peroxide.
7. Because of its higher initial brightness, the reed pulp required less hydrogen peroxide to reach final brightness.
8. The bleached reed pulp was significantly easier to refine than the hardwood pulp.
9. The optical and physical properties of handsheets for the reed and hardwood pulps were very similar.

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Fig. 1 Opacity vs. Apparent Density for Reed (❍) and Hardwood (■) Bleached Pulps

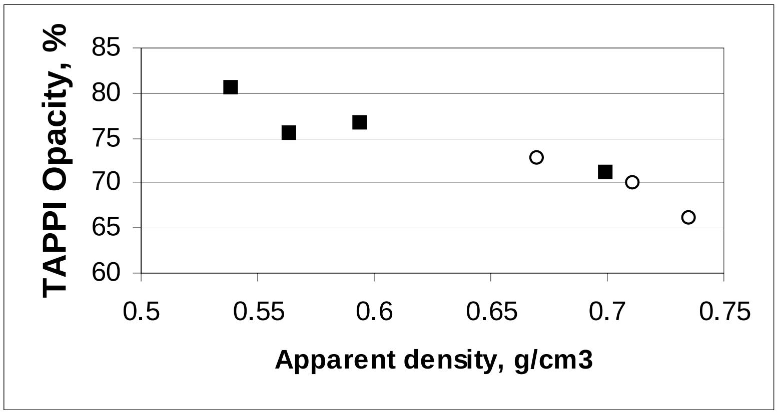

Fig. 2 Porosity vs. Apparent Density for Reed (❍) and Hardwood (■) Bleached Pulps

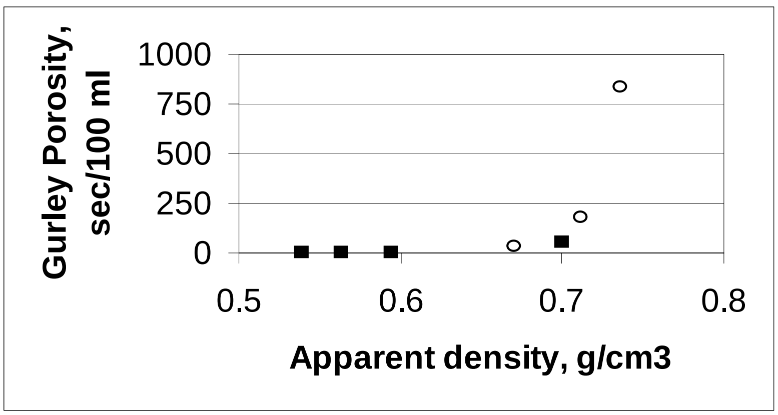

Fig. 3 Smoothness vs. Apparent Density for Reed (❍) and Hardwood (■) Bleached Pulps

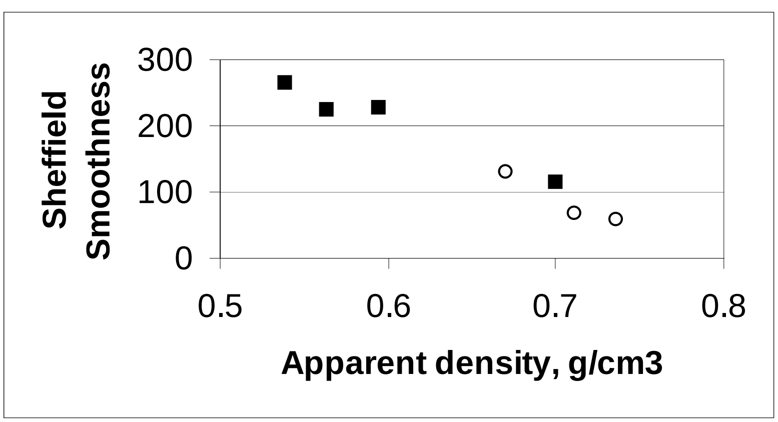

Fig. 4 Tearing Strength vs. Freeness for Reed (❍) and Hardwood (■) Bleached Pulps

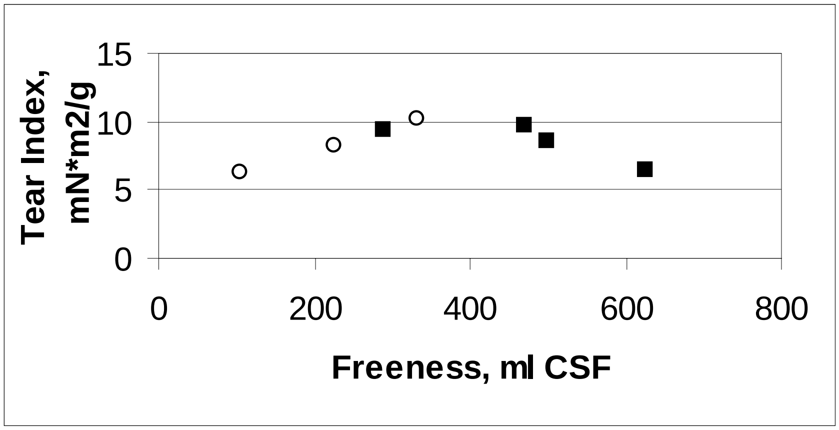

Fig. 5 Tensile Strength vs. Freeness for Reed (❍) and Hardwood (■) Bleached Pulps

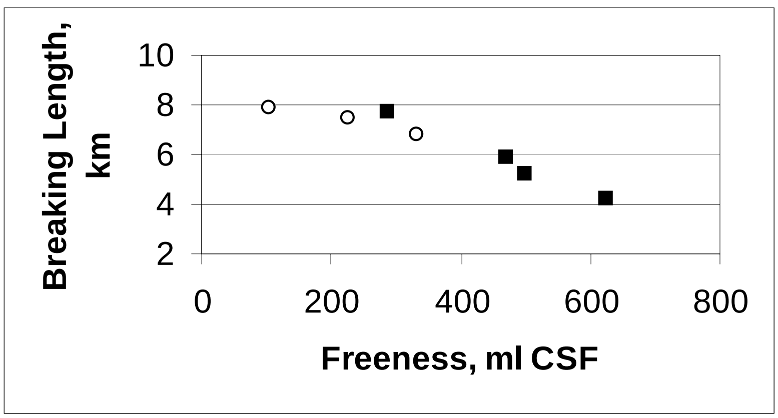

Fig. 6 Bursting Strength vs. Freeness for Reed (❍) and Hardwood (■) Bleached Pulps