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ORIGINAL ARTICLE

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# Industrial utilization of tobacco stalks II: preparation and characterization of tobacco pulp by steam explosion pulping

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**Abstract** Our previous paper showed tobacco stalks to posses the characteristics of a raw material for pulp and paper application. It contains the major biomass constituents and cell components common to wood species. In this study, preparation and characterization of tobacco stalk pulp by steam explosion (SE) pulping at two chemical pretreatments were attempted. Chemical pretreatment prior to SE pulping improved the brightness, yield, and strength properties of the resulting tobacco SE pulps in the order: 6% $Na_2SO_3$ + 1% NaOH > 6% $Na_2SO_3$ > control (untreated). The 6% $Na_2SO_3$ + 1% NaOH-impregnated tobacco stalks produced SE pulps of good fiber length distribution and considerable properties that compare well with pulps from other raw materials obtained from previous studies, and the nonimpregnated ones showed strength properties superior to those of their poplar counterpart. Prior to bleaching, pretreating the tobacco stalk SE pulps with two stages, 2% NaOH at 90°C, improved the initial pulp brightness by about 5 points. Two-stage 6% $H_2O_2$ bleaching gave a comparable effect with hypochlorite bleaching for both tobacco and poplar, giving a 29–34 brightness point increase for tobacco SE pulp and 61 for the poplar samples. The differences in the bleaching responses for untreated tobacco and poplar SE pulps were attributed to the differences in their lignin structure, as shown in the total yield of their respective nitrobenzene oxidation products and FT-IR spectra. Tobacco SE pulps contain more of the guaiacyl-type lignin and poplar the syringyl-type lignin.

**Key words** Steam explosion (SE) pulping · Tobacco SE pulp · Lignin · Characterization

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## Introduction

Population increases and economic growth will undoubtedly increase the demand for various forest products, resulting in competition with raw materials for the paper and pulp industries. At an average population annual rate of 3.2%, the global demand for pulp and paper is expected to reach 420 million metric tons by year 2010. Whether such projected demand can be met beyond year 2010 is an important question, and it is noteworthy that most of the resources of the major pulp suppliers in the world are now rapidly reaching a sustainable limit.[1] In light of the above concern, waste tobacco stalks may represent a potential material for pulp and paper industry as they contain comparable amounts of the major constituents common to wood species.[2] Added to this advantage is their availability as an agricultural residue in many parts of the world. At 45% moisture content, it is estimated that a global annual production of 26 million tons becomes available after every tobacco season.[3] Furthermore, tobacco plantations are mostly concentrated in places, especially in Asia, where forest cover is becoming increasingly sparse.[4]

During the 1960s tobacco stalks were processed into chemical pulps using conventional pulping processes, giving properties that compared well to those of wood species.[5] With today's increasing environmental concerns the need to explore the suitability of an environment-friendly technology using these abundant agricultural wastes is indisputable. Among the recently publicized nonconventional pulping, steam explosion (SE) seems to offer the greatest promise in the pulping industry, as it afford ultra-high yield and superior strength properties. The SE process consists of chemical impregnation of chips while cooking with saturated steam for a short period of time followed by rapid pressure release, atmospheric refining, and bleaching. This process was found suitable for hardwood and softwood.[6] It is generally recognized that chemical pretreatment is important for obtaining high yield and superior pulp properties.[7–10] In these studies, the authors showed that sulfite is essential for chip protection against oxidation, thus

preserving the high brightness level. To ensure good swelling of chips and to prevent acid hydrolysis and yield loss, a second chemical is usually added. These chemicals are usually NaOH, $Na_2CO_3$, $NaHCO_3$, and $MgCO_3$. In their study with *Eucalyptus*, Ahmed et al.[7] showed that NaOH as a second chemical to $Na_2SO_3$ caused a decrease in the yield and brightness with increasing concentration (up to 2%), but with much increased mechanical properties. From this study it seemed likely that an optimized combination of these two chemicals can give a good quality pulp. It is on this basis that the kind and concentration of the impregnation chemicals used in this study were set. To our knowledge, our SE pulping of tobacco stalks is the first attempt so far.

The objective of the present work was to prepare a utilizable tobacco pulp by SE pulping with nonchlorine bleaching. Effects of $Na_2SO_3$ and its combination with NaOH on the chemical, physical, and mechanical properties of tobacco SE pulps were evaluated and compared with other SE and mechanical pulps from previous studies. Nonimpregnated poplar and tobacco were also pulped by SE and served as controls.

## Materials and methods

### Materials

Flue-cured tobacco stalks (121 days) were provided by Japan Tobacco (JT). The stalks were cut into chunks of 4–5 cm length and air-dried until they attained approximately 10%–15% moisture content (MC). The samples were oven-dried at 105°C for 4 h and conditioned at 60°C before use. The dried poplar wood chips, a hardwood species, were obtained from the experimental stock of our laboratory.

### Steam explosion pulping

Two chemical impregnation treatments – with 6% $Na_2SO_3$ and 6% $Na_2SO_3$ + 1% NaOH – prior to SE were carried out for the tobacco stalks only. Dry samples of tobacco stalks (500 g) were placed separately in a polyethylene bag, mixed with the corresponding amount of the pretreatment chemicals at a 5:1 liquid/material ratio. The polyethylene bag containing the sample was submerged into a waterbath at 50°C for 24 h, after which the pretreatment solution was drained from the material. The residue was allowed to air-dry for 24 h. The pretreated air-dried samples were then placed in an SE vessel and steam-saturated at 200°C for 5 min, followed by instantaneous release to atmospheric pressure into the collecting vessel. The resulting pulps were washed with running water until there were no traces of black color in the wash water. They were then refined by a KRK High Consistency Refiner (Kumagai Riki Kogyo Co.) single disk with 305 mm diameter and with a clearance of 0.05 mm for 90 s. Refined pulps were then passed through a 14/1000 inch experimental flat screen (KRK, no. 2625) to separate the accept (passed through the screen) and reject (retained in the screen) pulps. Nonimpregnated samples of tobacco stalks and poplar wood chips were pretreated and steam-cooked in the same manner as the pretreated samples but without the addition of pretreatment chemicals during the impregnation stage. Cooking conditions were set after three preliminary trials.

### Hydrogen peroxide bleaching

The bleaching conditions used were set based on the results of the preliminary bleaching trials discussed elsewhere. Two-stage 6% $H_2O_2$ bleaching was carried out at 10% pulp consistency at 50°C for 2 h with 5% sodium silicate, 0.2% $MgSO_4$, and 4% NaOH added to the bleaching solution, all on an oven-dried basis. Prior to bleaching, all pulp samples were pretreated with two-stage 2% NaOH at 90°C for 1 h. For comparison, hypochlorite bleaching followed by one-stage $H_2O_2$ was done. The hypochlorite stage was carried out at 4% NaClO (on o.d. pulp) at pH 10 and 40°C for 2 h, and the same condition was adapted for the $H_2O_2$ stage as described above.

### Property evaluation of pulps

Optical and strength properties of the SE pulps were determined on a 1.2-g handsheet prepared in accordance with TAPPI standard procedures. Breaking length, tear index, and burst index were determined according to the methods described in TAPPI 494, 414, and 403, respectively, and folding endurance at a given load of 0.8 kg was based on TAPPI 511. Determinations of light-scattering coefficient and opacity were carried out following the methods described in TAPPI 425. Fiber length distribution was determined by an automated Kajaani FS 200 fiber length analyzer. The differences in the bleaching responses of SE pulps from untreated poplar wood chips and tobacco stalks were evaluated based on their lignin composition using nitrobenzene oxidation[11] and Fourier transform infrared (FT-IR) spectroscopy.[8,12] Scanning electron microscopy (SEM) was carried out to characterize the morphology of the fibers. Other chemical analyses were based on standard TAPPI procedures.

## Results and discussion

### Bleaching responses of tobacco SE pulp

One of the disadvantages of SE pulping compared with conventional processes is its low initial pulp brightness due to the retention of practically all the original lignin on the resulting SE pulp. This often poses a dilemma, especially for applications where high brightness is a major criterion. For this reason, several preliminary bleaching trials were conducted prior to the actual bleaching to improve the initial brightness and to set the bleaching conditions for tobacco SE pulp that should not negatively affect the other

**Table 1.** Brightness and yield responses of 6% $Na_2SO_3$ + 1% NaOH-pretreated tobacco SE pulps during the preliminary bleaching trials

| Condition | Yield (% on o.d. pulp) | Brightness (% ISO) | Brightness (point increase) |
|---|---|---|---|
| After SE treatment | 64.0[b] | 17.6 | – |
| After two-stage 2% NaOH | | | |
| 50°C, 2h | 88.0 | 20.5 | 2.9 |
| 90°C, 1h | 87.5 | 22.7 | 5.1 |
| After $H_2O_2$[a] bleaching | | | |
| 6% | 95.5 | 27.8 | 10.2 |
| 8% | 95.0 | 30.3 | 12.7 |
| 10% | 93.0 | 33.0 | 15.4 |
| 12% | 92.5 | 33.4 | 15.8 |

[a] Percent charges based on 100g o.d. pulp
[b] Based on o.d. tobacco stalk material

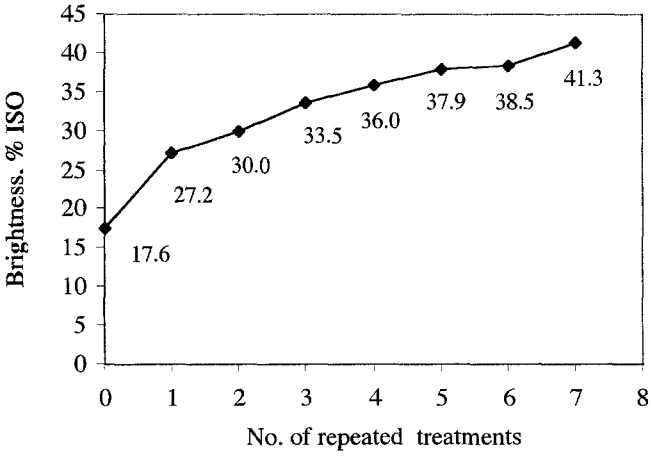


**Fig. 1.** Brightness responses of tobacco SE pulp pretreated with 6% $Na_2SO_3$ + 1% NaOH to repeated hydrogen peroxide bleaching

**Table 2.** Chemical constituents of the bleaching solution at different chemical charges

| Chemical constituents | Chemical charges (% on o.d. pulp) | | | |
|---|---|---|---|---|
| | T1 | T2 | T3 | T4 |
| $H_2O_2$ | 6 | 8 | 10 | 12 |
| Sodium silicate | 5 | 7 | 9 | 11 |
| NaOH | 4 | 6 | 8 | 10 |
| $MgSO_4$ | 0.2 | 0.3 | 0.4 | 0.5 |

pulp properties. For this purpose, only the tobacco SE pulp pretreated with 6% $Na_2SO_3$ + 1% NaOH was used. Three preliminary studies were carried out: NaOH pretreatment; repeated 3% $H_2O_2$ bleaching; and two-stage $H_2O_2$ bleaching at different $H_2O_2$ concentrations.

First, the effect of two-stage 2% NaOH bleaching at different temperatures and times (50°C and 90°C at 2h and 1h, respectively) on the initial brightness of the pulp was evaluated. As shown in Table 1, pretreating the pulp with 2% NaOH at a high temperature (90°C) for a short time (1h) improved the initial brightness of the pulp to about 2.2 points better than at 50°C for a long time (2h) without drastically affecting the pulp yield. Using the 90°C 1h NaOH pretreated pulps, bleaching responses with time were then evaluated by conducting a test with 2h 3% $H_2O_2$ repeated bleaching at 50°C. The repeated treatment was carried out to seven stages, and the bleaching solution containing 3% sodium silicate, 0.1% $MgSO_4$, and 3% NaOH (all based on o.d. pulp) was changed after each stage without interstage washing. The process was carried out at 10% consistency and pH 11.5. The results are shown in Fig. 1. The data revealed that pulp brightness progressively increased by 10 points after the first stage (2h), 3 points after the second stage (4h) and third stage (6h), and about 1–2 points thereafter. This means that prolonging the bleaching time beyond 6h does not significantly increase the brightness of the tobacco SE pulp. Without altering the temperature, consistency, and pH at 50°C, 10%, and pH 11.5, respectively, and using the 2-h two-stage conditions, we then further evaluated the effect of $H_2O_2$ concentration on the brightness and yield of the SE pulp with the treatment conditions shown in Table 2.

The results in Table 1 show that increasing the $H_2O_2$ concentration did not markedly improve the pulp brightness or decrease the yield. On the basis of brightness and yield, and depending on the target final brightness for the pulp, this result implies that at the present bleaching conditions, 3%–6% is a reasonable $H_2O_2$ range for tobacco SE pulp. Based on these results, final conditions for the experiment were set as described in the methodology.

## Characteristics of tobacco stalk and poplar SE pulps

The SE pulp yields of tobacco and poplar, presented as shot, accept, and reject yields are shown in Fig. 2. Shot yield is defined in this experiment as the exploded yield after washing without further refining the pulps. Accept yield is the yield of refined pulp that passed through the experimental flat screen; it represents the utilizable pulp. Reject pulps are the pulps retained on the above-specified screen. The result shows that poplar gave a remarkably higher shot yield than any of the tobacco SE pulps. How-

**Table 3.** Characteristics of bleached tobacco and poplar SE pulps

| Pulp properties | Untreated SE pulps | | Pretreated tobacco SE pulps | |
|---|---|---|---|---|
| | Poplar wood chips | Tobacco stalks | 6% $Na_2SO_3$ | 6% $Na_2SO_3$ + 1% NaOH |
| Before bleaching | | | | |
| Kappa number | 151.6 | 178.1 | 146.4 | 137.6 |
| Brightness (% ISO) | 12.0 | 11.3 | 15.3 | 17.6 |
| After two-stage $H_2O_2$ | | | | |
| Yield[a] | 88.3 | 84.2 | 85.2 | 87.7 |
| Kappa number | 33.7 | 129 | 128.8 | 127.1 |
| Brightness (point increase) | 61.3 | 28.8 | 33.0 | 33.8 |
| Alpha cellulose | n.d. | 78.3 | 82.3 | 82.3 |
| Fiber LWA (mm) | 0.47 | 0.82 | 0.86 | 0.93 |
| After NaClO | | | | |
| Yield[a] | 84.5 | 74.5 | 74.2 | 73.7 |
| Brightness, point increase | 59.9 | 28.4 | 33.8 | 34.5 |
| Alpha cellulose | n.d. | 79.2 | 77.8 | 74.3 |
| Fiber LWA (mm) | 0.35 | 0.69 | 0.71 | 0.76 |

LWA, Length weighted average
[a] Percent on o.d. NaOH pretreated pulp

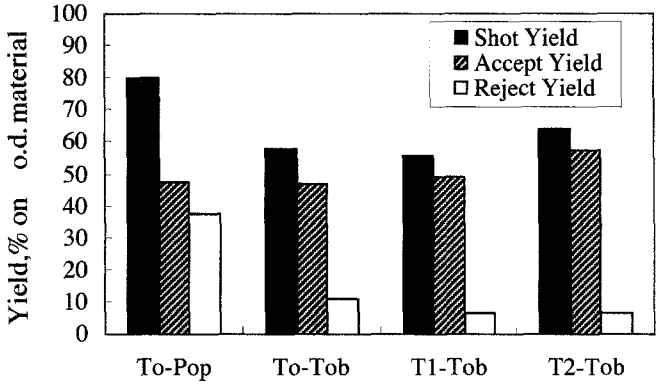


**Fig. 2.** Yield characteristics of tobacco stalk and poplar wood SE pulps. *To-Pop*, nonimpregnated poplar; *To-Tob*, nonimpregnated tobacco stalks; *T1-Tob*, 6% $Na_2SO_3$; *T2-Tob*, 6% $Na_2SO_3$ + 1% NaOH

ever, as noted, tobacco stalks gave a low reject yield, making their accept yields comparable to that of poplar, suggesting that tobacco is better pulped by SE than poplar. It is worth mentioning that reject pulps can be refined several times until all pulps pass through the standard sieve, but it would entail more refining energy.

In our previous paper[2] it is shown that tobacco stalk contains about 41.3% $\alpha$-cellulose, 32% hemicellulose, 21% lignin, and 13% hot water extractives, not to mention the other extractives, which were found to be present in relatively higher than concentrations in hardwood. It is therefore likely that the low shot yield of tobacco stalks (60% on o.d material) indicates that about 40% of the components, presumably more hemicelluloses and extractives, were removed during the pretreatment and high-temperature steam cooking of the SE process.

The characteristics of bleached tobacco and poplar SE pulps are shown in Table 3. The 6% $Na_2SO_3$ + 1% NaOH impregnated samples showed better performance in terms of yield, kappa number, and brightness index than the nonimpregnated samples and those pretreated with 6% $Na_2SO_3$ alone with either of the two bleaching processes. At 6% $H_2O_2$ and 50°C, tobacco SE samples did not show increase in brightness as marked as that observed in poplar, giving only 29-, 33-, and 34-point increases for the untreated, 6% $Na_2SO_3$-treated, and 6% $Na_2SO_3$ + 1% NaOH-treated specimens, respectively, in contrast to poplar which had a 61-point brightness increase. This finding indicates that $H_2O_2$-bleached tobacco SE pulps have narrower range of application than the poplar pulps. As noted, hypochlorite bleaching did not seem to improve the final brightness and, worse, it negatively affected the $\alpha$-cellulose content and the fiber length of the SE pulps.

It is interesting to note here that although untreated poplar SE pulp had almost the same initial brightness index as the tobacco SE pulps, it allowed a brightness increase of 60–61 points after NaClO and $H_2O_2$ bleaching, respectively, almost twofold that of the tobacco samples (33.8–34.5 points) impregnated with 6% $Na_2SO_3$ alone or in combination with 1% NaOH. To understand the marked differences in the bleaching responses between untreated tobacco stalk and poplar, alkaline nitrobenzene oxidation (NBO) analysis and FT-IR spectroscopy were performed. It is obvious in Table 4 that the total NBO product for both tobacco and poplar decreased after the SE treatment, suggesting that noncondensed-type lignin was preferentially delignified or condensed by SE pulping (or both). Furthermore, after SE treatment the syringaldehyde/vanillin (S/V) molar ratio of tobacco decreased whereas that of poplar remained almost unchanged, indicating that poplar SE pulp retained more of the syringyl-type lignin and tobacco more of the guaiacyl-type lignin. This result was in agreement with their respective FT-IR spectra shown in Fig. 3. For tobacco SE pulps (Fig. 3a–c) the ratio of their respective absorption at 1322.4 $cm^{-1}$ (C-O stretch vibrations of syringyl) to that at 1509.5 $cm^{-1}$ (aromatic skeletal vibrations in associated

**Table 4.** Nitrobenzene oxidation products of untreated tobacco stalk and poplar SE pulps

| Nitrobenzene oxidation products (% on lignin) | Tobacco stalk | | Poplar wood | |
|---|---|---|---|---|
| | Original material | Untreated SE pulp | Original material | Untreated SE pulp |
| Vanillin | 13.24 | 11.35 | 15.34 | 8.17 |
| Syringaldehyde | 15.26 | 8.14 | 35.23 | 18.23 |
| Vanillic acid | 1.49 | 0.29 | 1.02 | 0.61 |
| Syringic acid | 1.78 | 0.29 | 1.89 | 1.12 |
| *P*-Hydroxybenzaldehyde | 0.68 | 1.80 | n.d. | n.d. |
| *P*-Hydroxybenzoic acid | n.d. | n.d. | n.d. | n.d. |
| Yield | 32.45 | 21.87 | 53.48 | 28.13 |
| S/V molar ratio | 1.16 | 0.72 | 2.29 | 2.23 |

n.d., not done; S/V, syringaldehyde/vanillin ratio

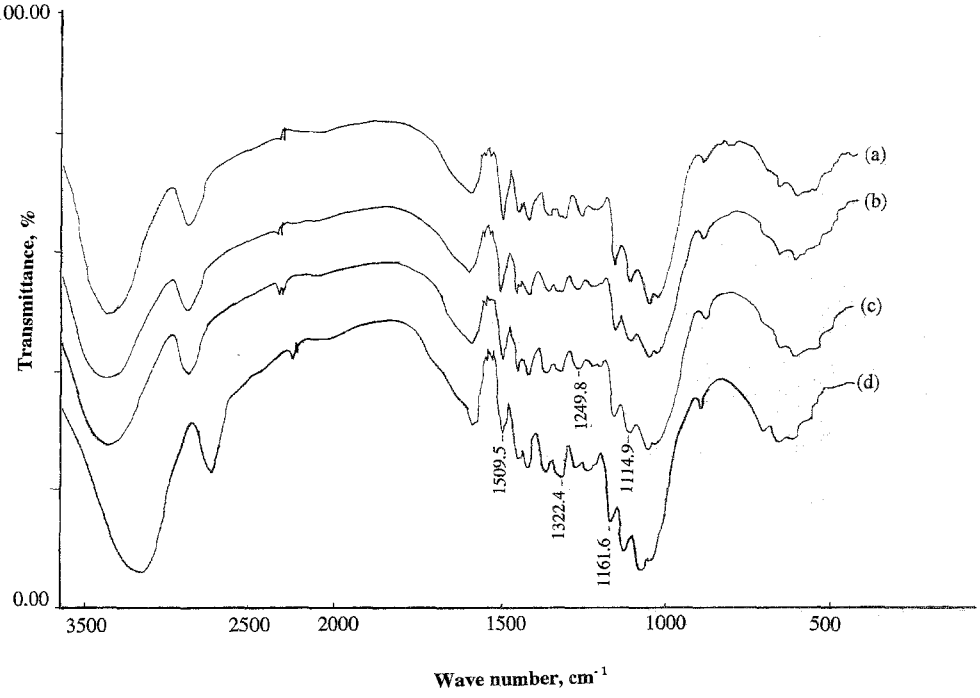


**Fig. 3.** Fourier transform infrared (FT-IR) spectra of tobacco stalk and poplar SE pulps: untreated tobacco stalk (a); 6% $Na_2SO_3$ pretreated tobacco stalk (b); 6% $Na_2SO_3$ + 1% NaOH pretreated tobacco stalk (c); untreated poplar wood (d)

lignin) is lower than the ratios of their absorptions at 1249.8 $cm^{-1}$ (C-O guaiacyl stretch vibrations) to that at 1509.5 $cm^{-1}$. In contrast, in poplar SE pulp (Fig. 3d) the ratios of the absorptions at 1322.4 $cm^{-1}$ and 1249.8 $cm^{-1}$ to that at 1509.5 $cm^{-1}$ were observed to be higher in the latter. Furthermore, in poplar, the absorption intensity at 1161.6 $cm^{-1}$ (C-H guaiacyl stretching) is weaker than that at 1114.9 $cm^{-1}$ (C-H-syringyl stretching), and almost the same intensities were observed for tobacco SE pulps. The results obtained from both NBO analysis and FT-IR investigation strongly suggest differences in the lignin structures of poplar and tobacco. Because syringyl-type lignin is more susceptible to bleaching than guaiacyl-type lignin, the results therefore explain the better bleachability of poplar wood than tobacco SE pulps regardless of the chemical pretreatment used.

In terms of fiber length distribution, tobacco pulps gave longer fibers than did poplar in either of the bleaching sequences, being observed longer in pulps pretreated with 6% $Na_2SO_3$ + 1% NaOH (Table 3). This result parallels those obtained in a previous study[7] wherein the authors showed longer fibers after $Na_2SO_3$ + NaOH treatment than in any of the chemically pretreated samples of *Eucalyptus*. Both results prove the swelling and softening effects of NaOH in facilitating liberation of fibers from the wood matrix during high-temperature decompression treatment of the SE process, thus preserving the fiber lengths of the pulps. This was observed by scanning election microscopy (SEM) of the unbleached samples shown in Fig. 4. On careful examination of these micrographs, the fibers of the untreated tobacco (Fig. 4A) and poplar (Fig. 4D) SE pulps are partly damaged. Most of the fibers in the untreated pulps are broken and deformed compared to the pretreated tobacco samples (Fig. 4B,C), which showed longer, smoother fibers.

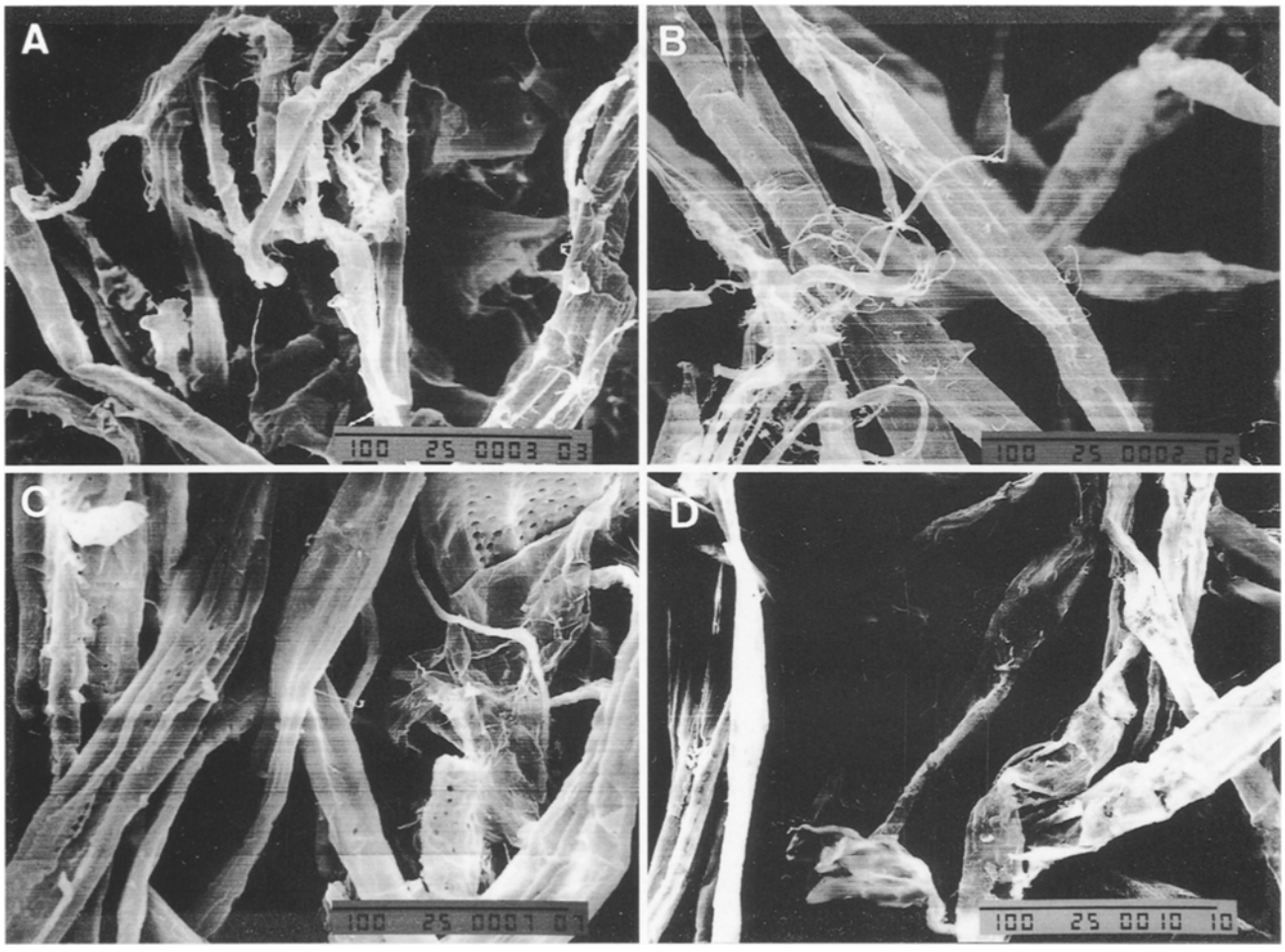


**Fig. 4.** Scanning electron photographs of tobacco stalk and poplar SE pulps. **A** Untreated tobacco stalk. **B** 6% $Na_2SO_3$ pretreated tobacco stalk. **C** 6% $Na_2SO_3$ + 1% NaOH pretreated tobacco stalk. **D** Untreated poplar wood. Bar 100$\mu$m

Strength properties of $H_2O_2$-bleached tobacco SE pulps

Determination of the physicomechanical properties of tobacco SE pulps were determined on 1.2-g handsheets. The effects of the impregnating chemicals on the strength properties of the $H_2O_2$-bleached tobacco SE pulps at different Canadian Standard Freeness (Csf) levels are presented in Figs. 5, 6, 7, and 8. Generally, 6% $Na_2SO_3$ + 1% NaOH-pretreated tobacco SE pulps consistently showed higher strength than the other samples at all Csf levels. The influence of impregnating chemicals on the breaking length and burst index of the SE pulps are shown in Figs. 5 and 6, respectively. For both properties, the pretreated and untreated pulps show a decreasing trend with increasing Csf value. An opposite trend was observed in terms of the tear index, as shown in Fig. 7. As demonstrated in Fig. 7, tobacco SE pulps pretreated with 6% $Na_2SO_3$ + 1% NaOH showed a consistently higher tear index at all Csf levels than both 6% $Na_2SO_3$ and nonimpregnated pulps. It can be recalled from Table 3 that 6% $Na_2SO_3$ + 1% NaOH-pretreated pulps gave longer fiber length than the other treatments, confirming the dependence of the tear index on fiber length, as shown in previous studies.[7] The folding strength of the tobacco SE pulps, at a given load of 0.8kg, is given in Fig. 8. Again, the 6% $Na_2SO_3$ + 1% NaOH-pretreated pulps showed markedly higher folding endurance (550 times) than those pretreated with 6% $Na_2SO_3$ alone (240 times). Nonimpregnated samples gave only 202 times.

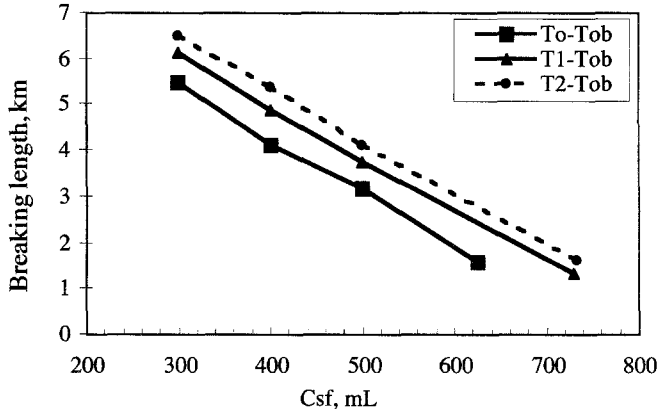


**Fig. 5.** Breaking length of tobacco SE pulps as affected by impregnating chemicals at different Csf levels. *To-Tob*, nonimpregnated tobacco stalks; *T1-Tob*, 6% $Na_2SO_3$; *T2-Tob*, 6% $Na_2SO_3$ + 1% NaOH

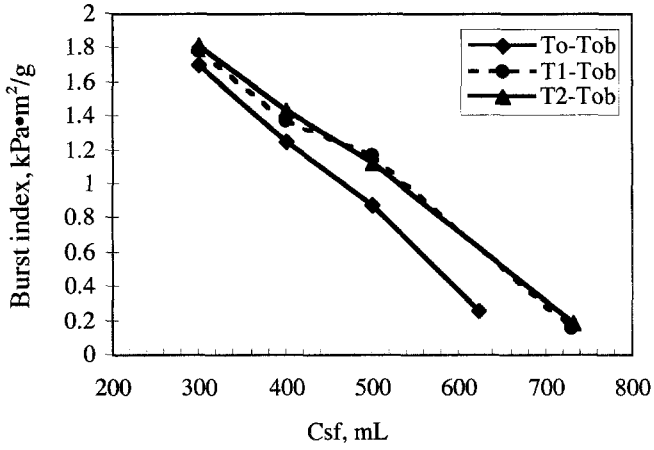


**Fig. 6.** Burst index of tobacco SE pulps as affected by pretreatment chemicals at different Csf levels. Symbols are the same as in Fig. 5

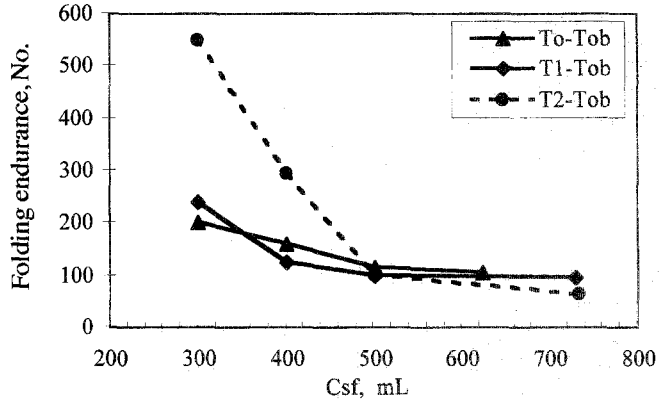


**Fig. 8.** Folding endurance of tobacco SE pulps as affected by impregnating chemicals at different Csf levels. Symbols are the same as in Fig. 5

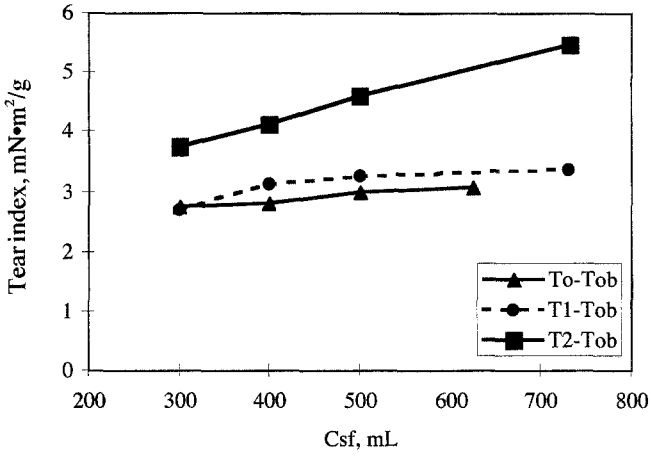


**Fig. 7.** Tear index of tobacco SE pulps as affected by impregnating chemicals at different Csf levels. Symbols are the same as in Fig. 5

**Table 5.** Mechanical and optical characteristics of bleached, untreated tobacco stalk and poplar wood SE pulps

| Pulp characteristics | Tobacco stalk | Poplar wood |
|---|---|---|
| Csf (ml) | 654 | 656 |
| Density (g/cm$^3$) | 0.5 | 0.4 |
| Bulk (cm$^3$/g) | 2.0 | 2.8 |
| Breaking length (km) | 3.2 | 0.4 |
| Burst index (kPa·m$^2$/g) | 0.3 | 0.1 |
| Tear index (mN·m$^2$/g) | 3.1 | 1.3 |
| Brightness, ISO (%) | 40.1 | 73.33 |
| Opacity, ISO (%) | 87.6 | 90.3 |
| LSC, ISO (cm$^2$/g) | 345.2 | 603.83 |

LSC, Light scattering coefficient

### Tobacco SE pulps compared with other SE and mechanical pulp materials

When untreated poplar and tobacco stalk SE pulps are compared, the latter had lower brightness but markedly higher strength properties (Table 5). This result can be directly related to the amount of the residual lignin and fiber length of the respective pulps, being higher and longer, respectively, in tobacco SE pulps (as shown in the previous section).

As shown in Figs. 5, 6, 7, and 8, at 300 Csf tobacco SE pulps pretreated with 6% $Na_2SO_3$ + 1% NaOH gave considerable strength properties that compare well with other SE and mechanically prepared pulps from previous studies at varied experimental conditions. Using the same impregnating chemicals and at the same Csf level of 300 ml, tobacco stalks had a breaking length (6.5 km) (Fig. 5) and brightness (51.4, % ISO) (Table 3) comparable to that of kenaf,[9] a much favored nonwood fiber used in pulp and paper applications. In another case, although tobacco SE pulp yield (63.95%) is lower than that of SE aspen pulp (89.13%)[10,13] and chemimechanical (CM) reed pulp (74.4%),[14] at the 300 Csf level it shows superior breaking length (6.5 km) and comparable burst index (1.81 kPa·m$^2$/g) (Fig. 6) when compared with the above-mentioned pulps, which were refined at the 100 Csf level. It is general knowledge that further beating of the pulp increases the surface area of the individual fibers, thereby improving the fiber-to-fiber bonding and resulting in much improved strength of the fibers. This therefore implies that further beating to a Csf level of 100 ml (similar to that resulting with aspen and reed pulps) may further improve the above properties of the tobacco SE pulps. In terms of tear index (Fig. 7), tobacco SE pulps pretreated with 6% $Na_2SO_3$ + 1% NaOH gave 3.75 mN·m$^2$/g, which compared well with bagasse mechanically prepared pulps.[15]

## Conclusions

With the present pulping and bleaching conditions, tobacco stalks produced SE pulps of considerable properties. A combination of 6% $Na_2SO_3$ and 1% NaOH as pretreatment chemicals fared well in tobacco stalks. At about 64% yield, tobacco SE pulp of 300 ml Csf has the following physical properties: breaking length 6.5 km; tear index 3.75 mN·m$^2$/g; burst index 1.81 kPa·m$^2$/g; and brightness 51.4% ISO.

Two-stage hydrogen peroxide bleaching with 2% NaOH as pretreatment can bring about a 34-point increase in brightness, although it may not be bright enough for fine paper applications. For applications where high brightness is not such an important criterion, the results presented here indicate the potential of tobacco stalk SE pulp for use in the pulp and paper industry. Furthermore, it is inviting to consider the annual huge, readily available supply of tobacco stalks, currently agricultural waste, as a competitive, alternate raw material for pulp and paper manufacture where wood and other well-studied nonwood fibers are now in use. For optimum utilization of this tobacco stalk material, other pulping and bleaching processes and more detailed analysis of the tobacco stalk lignin and other inherent residual chemical constituents of the pulp and the material per se is recommended.

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