Kraft pulp and papermaking properties of *Phanerochaete chrysosporium*-degraded aspen

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ABSTRACT Phanerochaete chrysosporium *was grown on glucose-supplemented aspen (*Populus tremuloides*) wood chips for 0, 10, 20, and 30 days. The biodegraded wood chips were then kraft digested for three different time schedules (1, 2, and 3 h) at two levels of effective alkali concentration (12% and 16%). Pulps prepared from chips fungally degraded for 30 days had significantly higher yields (3–6%) than the nondegraded control pulps at a given kappa number. The pulps of biodegraded wood also responded faster to beating than nondegraded wood pulp. Water-retention values and sedimentation volumes increased significantly with increasing duration of mycelial incubation. Handsheets prepared from pulps biodegraded for 20 and 30 days had higher tensile strength, burst, and fold properties than handsheets prepared from control pulps. Tear values decreased with increasing incubation time. In most cases, more than 90% of the variation in the tear and tensile strength properties of handsheets could be correlated to the duration of wood-chip incubation.*

KEYWORDS
Beating time
Biodegradation
Fungi
Kraft pulping
Microorganisms
Mycelium
Paper properties
Populus tremuloides
Pretreatment

Improvements in some papermaking properties of thermomechanical pulp (TMP) made from spruce wood chips pretreated with cellulaseless mutants of *Sporotrichum pulverulentum* and *Phlebia gigantia* were first reported by Eriksson *et al.* (*1, 2*). Their results showed that, at comparable freeness levels, preparation of TMP from biodegraded wood chips required about 23% less energy than nondegraded wood. Bar-Lev (*3*) reported similar results with spruce TMP treated with a wild strain of *Phanerochaete chrysosporium*.

Setliff *et al.* (*4*) used superior strains of lignophilic fungi in the pretreatment of aspen and spruce wood chips pulped by the refiner mechanical pulping (RMP) process. They found that increasing fungal incubation time reduced fiberizing energy. Pulp sheets from aspen wood chips pretreated with *Poria cinerascens* showed a 30% increase in burst index, a 39% increase in tensile strength, and a 35% increase in tear index. More recently, Myers *et al.* (*5*) pretreated aspen wood chips with *P. chrysosporium* and *Dichomitus squalens* in a solid-substrate reactor prior to producing RMP. At comparable freeness levels, paper produced from both fungal pretreatments had improved burst index, tensile index, and zero-span tensile. The opacity of the control paper and the test paper were similar. However, fungal pretreatment caused a decrease in sheet brightness and light-scattering coefficient.

Previous research in biopulping has focused on mechanical pulping processes. This study evaluates the kraft pulp and papermaking properties of aspen (*Populus tremuloides*) chips subjected to *P. chrysosporium* degradation.

Results and discussions

Pulp yield and kappa number

Aspen chips were subjected to fungal degradation by *P. chrysosporium* for 0, 10, 20, and 30 days. Each batch of chips was then kraft pulped for 1-, 2-, and 3-h periods. **Figures 1 and 2** show the effect of these treatments on pulp yield and kappa number (lignin content), respectively. Pulp yields increased with increasing fungal incubation time, while kappa number decreased. Pulp yield increased regardless of kraft cooking time.

Significant differences in pulp yields were observed for the wood chips that were fungally degraded for

20 or more days. Extrapolation of data after 3 h of kraft digestion showed respective increases in pulp yield of 2.8% and 4.2% for incubation times of 20 and 30 days. Under identical pulping conditions, kappa number decreased by 3% and 9%, respectively. Results also showed that fungally degraded wood chips could be kraft cooked to a given kappa number in less time than nondegraded wood chips. With but a few exceptions, there were no statistical differences ($P \leq 0.05$) in pulp yield and kappa number between the control pulp and the pulp made from 10-day-incubated wood chips.

Pulps were compared at the same kappa number values. The results in **Fig. 3** show that the highest pulp yields and lowest kappa numbers were obtained using chips subjected to 30-day fungal degradation prior to kraft digestion. Extrapolation of data at kappa no. 77 shows that fungal pretreatment of aspen wood chips for 30, 20, and 10 days provides pulps with respective yield advantages of 5.7%, 3.3%, and 0.8% over the control pulp.

Two reasons may be proposed to explain the differences in pulp yields and kappa numbers for kraft pulps prepared from sound and fungally degraded wood chips.

- Enhanced penetration of cooking liquor: The biodegradation process results in loss of wood mass (4.0%, 12.7%, and 16.9% removal for incubation periods of 10, 20, and 30 days, respectively). The removal of woody mass prior to pulping may have left larger and/or additional pore structures in the fiber cell walls, thus enhancing access of the cooking liquor to the cell-wall components. Undoubtedly, the efficiency of the kraft pulping process was improved, since the initial delignification phase in kraft pulping process is diffusion controlled (*6*). This condition could explain, in part, the observed variations in kappa number obtained for biodegraded wood pulp.
- Increased holocellulose-to-lignin (H/L) ratio: The ligninase-producing fungi increase the H/L ratio of wood chips charged into the digester (*7*). The Klason lignin content for fungally degraded aspen chips over a 30-, 20-, and 10-day treatment period was reduced prior to kraft digestion by 5.5%, 4.3%, and 1.4%, respectively, compared with the Klason lignin content of sound aspen chips (*7*). These differences represented a higher total lignin charge to the digester for each cook. Thus it was expected that even if the lignin-removal rate was the same for the sound and fungally degraded wood chips, kappa numbers should be higher for pulps obtained for sound wood chips. The H/L ratios determined prior to kraft digestion of aspen chips were 3.9, 4.2, 4.8, and 5.0 for 0, 10, 20, and 30 days of fungal pretreatment, respectively. Therefore, a digester charge of *P. chrysosporium*-degraded aspen chips contained a higher proportion of carbohydrates than a digester charge of nondegraded wood chips.

From a material-balance perspective, the total pulp yield obtained from fungally degraded wood chips is not necessarily higher than the total pulp yield from nondegraded wood (*8*). Stoichiometrically, the proportion of chemical components in wood for sound and fungally degraded wood chips were not the same per unit digester charge.

Refining properties

Figure 4 shows that as incubation time increases, the time required to beat the pulp to a given freeness decreases. The rate of change in Canadian standard freeness (CSF) with beating time was fast for all pulps in the initial 15 min because of fibrillation. The rate became much slower after 25 min and decreased rapidly in the final 45 min. These results suggest a preponderance of fines and/or fibrillar materials at these stages of refining.

A faster rate of refining also was associated with fungal pretreatment in a similar study of red oak (*8*). In that study, the increased rate of refining was attributed to (a) enhanced swelling and flexibility of degraded pulp fibers and (b) differences in the relative amounts of holocellulose and lignin components in the pulp fibers. The swelling propensity of fungally degraded fibers may explain the fiber softening that was observed in the biodegraded aspen. This propensity may be due to the accessibility of water through bore holes and void spaces created by the removal of lignin in the cell walls. The prospect of larger voids or additional pore structures is suggested by the significant differences in weight loss (4.0%, 12.7%, and 16.9%) for glucose-supplemented aspen wood chips subjected to 10, 20, and 30 days of fungal degradation. In addition, pulps obtained from fungally degraded chips had a lower kappa number and a higher carbohydrate content than did pulps prepared from sound wood chips. As a rule, the lower the residual lignin content of a pulp, the faster the rate of refining.

Water-retention value and sedimentation volume of pulps

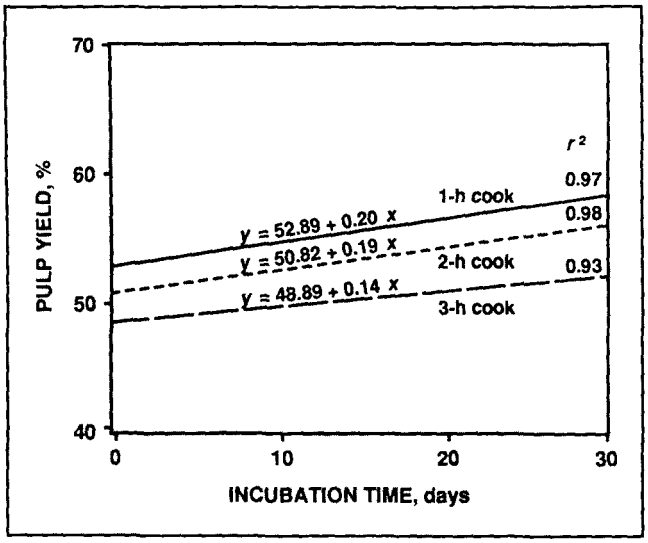
P. chrysosporium pretreatment of aspen wood chips significantly altered the water-retention value (WRV) and sedimentation volume of aspen wood pulp fibers. This is especially apparent after 20 or more days of fungal incubation, as seen in **Fig. 5**. Control pulp fibers averaged 102% WRV, while fungally degraded wood pulp ranged from 106% to 137% WRV. These results indicate that the fungally degraded aspen fibers were more hydrophilic than the nondegraded fibers.

Statistical evaluation of data showed that the 4% difference in WRV between control and 10-day degraded aspen fibers was not significant ($P \leq 0.05$). In the case of sedimentation volumes of pulp fibers, however, the difference between sound and fungally degraded chips was significant even at the 10-day level. Average sedimentation volumes of 242 mL/g and 412 mL/g were obtained from aspen pulp prepared from wood chips fungally degraded for 0 and 30 days, respectively.

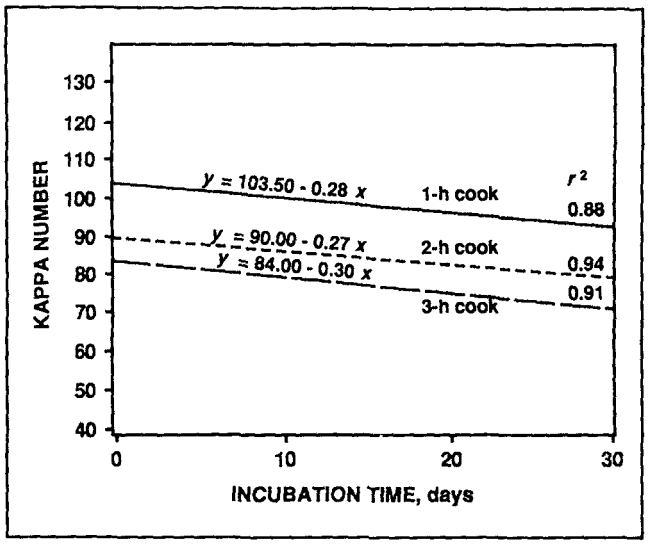
Fiber size distribution

Bauer-McNett classification studies on selected pulps showed significant differences in the distribution of fines and fibers for the control pulp and for pulps subjected to 20 or more days of fungal pretreatment. The results of these studies are presented in **Fig. 6**. The control and 10-day degraded pulps retained more material on the 0.8333-mm screen than did the 20- and 30-day degraded pulps. However, the proportion of pulp fibers retained on the 0.208-mm and 0.104-mm

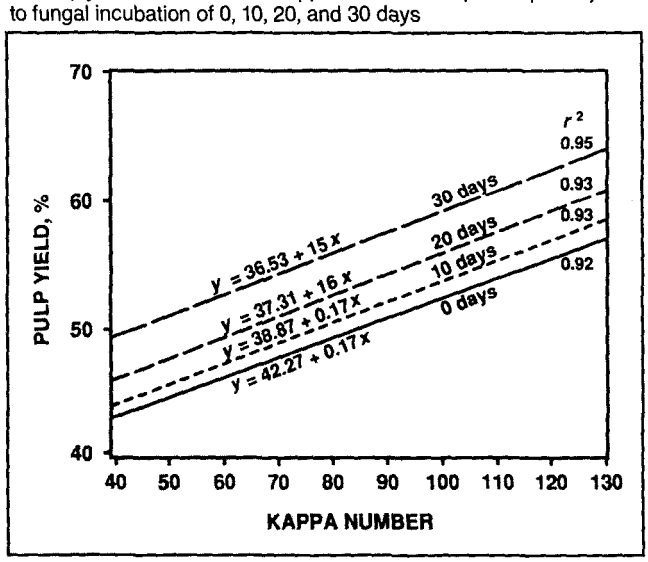
1. Pulp yield as a function of fungal incubation time for kraft cooks of 1-, 2-, and 3-h duration



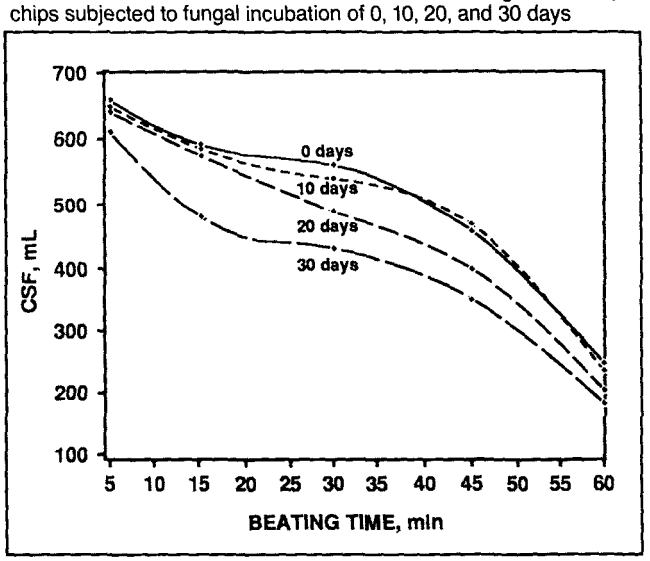
2. Kappa number as a function of fungal incubation time for kraft cooks of 1-, 2-, and 3-h duration



3. Pulp yield as a function of kappa number for aspen chips subjected to fungal incubation of 0, 10, 20, and 30 days



4. Canadian standard freeness as a function of beating time for aspen chips subjected to fungal incubation of 0, 10, 20, and 30 days



screens was higher for the 20- and 30-day degraded pulps. The increase in fines associated with fungally degraded wood pulp suggests that some adjustments in paper machine drainage may be required to maintain machine operations.

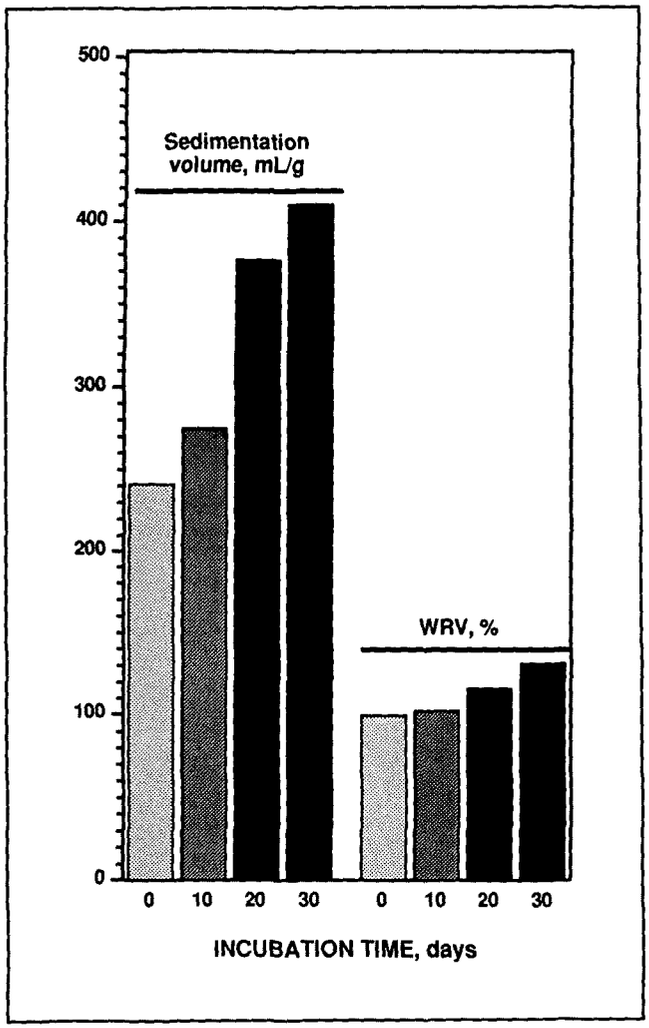
Pulp brightness and opacity

The GE brightness of unbleached handsheets was measured and tabulated. The results in **Fig. 7** show that pulp brightness decreases with increasing fungal incubation time. For example, after 3-h digestion at 16% effective alkali (E.A.) concentration (as Na_2O), pulp brightness was reduced by 35%, 54%, and 62% after 10-, 20-, and 30-day fungal pretreatments, respectively. Under similar conditions, but at 12% E.A., pulp brightness reductions were 45%, 58%, and 58% with respect to the control. Handsheet opacity was not affected by pretreatment with *P. chrysosporium*, as seen in **Fig. 8**.

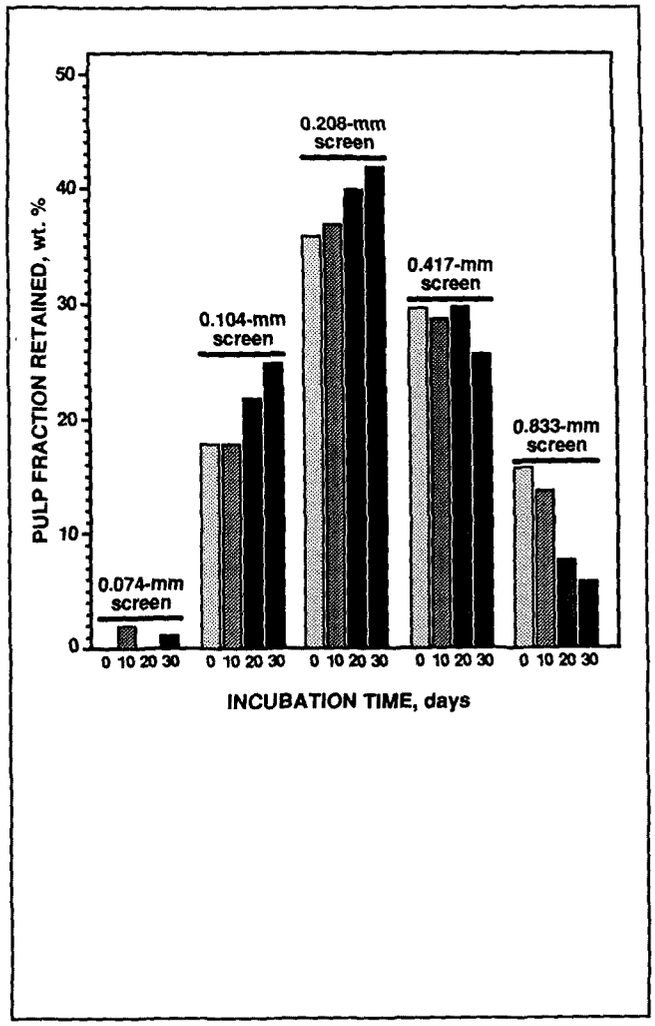
Handsheet properties

Handsheet properties were linearly related to fungal incubation time for each E.A. concentration, cooking time, and beating time. **Figures 9 and 10** show that, in most cases, more than 90% of the variation in handsheet tensile and tear properties could be accounted for by fungal incubation time. Figure 9 reveals that, under typical kraft cooking conditions (3 h, 16% E.A., 173°C), 30-day pretreatment of aspen chips with *P. chrysosporium* should increase tensile strength by about 21%. Burst and fold properties exhibited the same trends. The tensile-strength improvement for pulps obtained from fungally degraded wood can be associated with the WRV of fungally degraded pulp fibers (Fig. 5). The increase in WRV—and thus the flexibility—of degraded pulp fibers enhanced fibrillation during refining.

5. Sedimentation volume and WRV as functions of fungal incubation time



6. Pulp fractions retained on various screens following fungal incubation of 0, 10, 20, and 30 days



Tear strength, however, progressively decreased with increasing fungal incubation time. Figure 10 shows that this is especially dramatic at beating times of 30 min or more. This may be due to increased cohesion and stiffness, resulting in the concentration of tearing force into a smaller area in the sheet. Increased cohesion and stiffness are suggested because of the reduced fiber length and the fines generation that occur at this stage of beating. The loss in tear strength was expected because of the inverse relationship between tear and tensile or burst properties of handsheets. These results agreed with those reported in kraft pulping of fungally degraded red oak (*8*).

Summary and conclusion

P. chrysosporium pretreatment of aspen chips increased kraft pulp yields. At an equivalent kappa number, pulp yield increased by about 6% for pulps prepared from wood chips that had been fungally degraded for 30 days. Aspen pulps prepared from wood biodegraded for a 30-day period refined the fastest, followed respectively by pulps from 20-, 10-, and 0-day fungal pretreatments. Higher tensile strength, burst, and fold properties were obtained for handsheets prepared from 20- and 30-day fungally degraded wood compared with handsheets prepared from control pulps. There were distinct reductions in tear and brightness for the handsheets prepared from fungally degraded wood. However, fungal pretreatment had no effect on sheet opacity.

Experimental

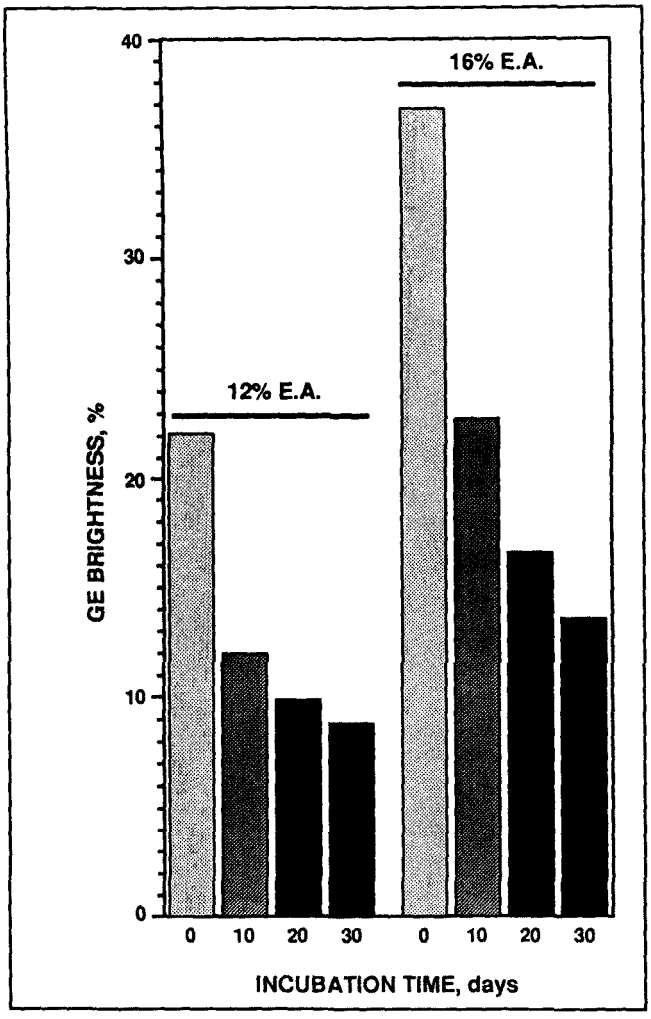
Wood and fungi preparation

Twenty aspen trees were randomly harvested in October 1986. All trees had clear upright stems, were free of apparent deformations, and showed no signs of bacterial or fungal infection. The trees were felled and cut into bolts, debarked, chipped, and screened at a local sawmill. The wood chips were inoculated with rye spawn of isolate BKM 1767 of *P. chrysosporium* and incubated according to procedures described by Oriaran *et al.* (*7*). The glucose-supplemented aspen chips were incubated with fungi for periods of 0, 10, 20, and 30 days prior to pulp evaluation studies.

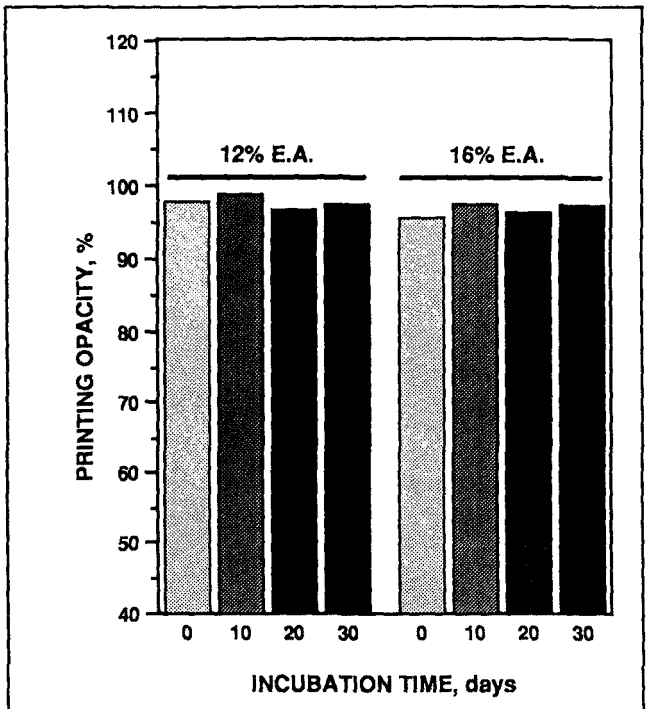
Pulp preparation

Individual batches of nondegraded and fungally degraded wood chips (500 g o.d. weight) were charged into

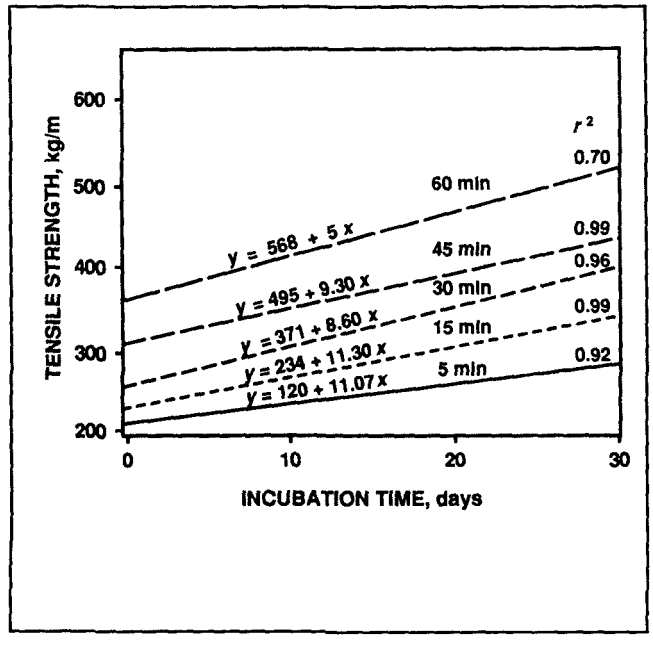
7. GE brightness as a function of fungal incubation time for chips kraft digested at 12% and 16% E.A.



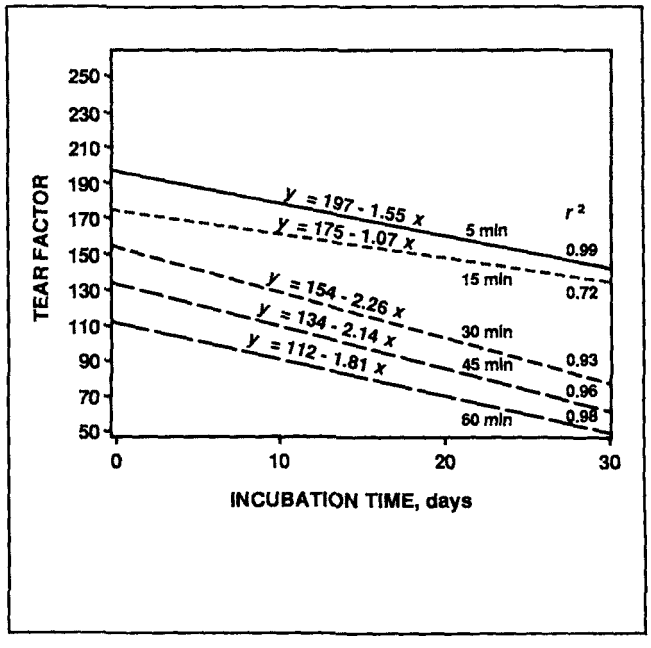
8. Printing opacity as a function of fungal incubation time for chips kraft digested at 12% and 16% E.A.



9. Tensile strength as a function of fungal incubation time for aspen chips refined for 5, 15, 30, 45, and 60 min



10. Tear factor as a function of fungal incubation time for aspen chips refined for 5, 15, 30, 45, and 60 min



an M/K laboratory digester and kraft digested for three different time regimes (1, 2, and 3 h) and at two levels of E.A. (12% and 16%). Time at temperature and E.A. were varied to produce pulps with a range of yields, kappa numbers, and papermaking characteristics. Pulp yields were determined based on the oven-dry weight of wood chips initially charged to the digester. The residual carbohydrate in the pulp was assumed to be equal to one hundred less the percent lignin in pulp. In making this assumption, minor constituents in pulps such as resins and residual metal salts were neglected. A total of 96 cooks were prepared from control and biodegraded aspen chips using a 2 × 3 × 4 (E.A., cooking time, and fungal incubation time) full-factorial design, with four replications per treatment (*9*).

Pulp and handsheet evaluation

Pulps were evaluated for kappa number (TAPPI Test Method T 236 om-85), WRV (*10*), Bauer-McNett fiber classification (*11*), and pulp refinability (TAPPI Test Method T 200 om-85). Pulp samples were withdrawn from the Valley beater after beating intervals of 5, 15, 30, 45, and 60 min for CSF testing (TAPPI Test Method T 227 om-85) and handsheet formation (TAPPI Test Method T 205 om-88). Handsheets were conditioned and tested for tensile, tear, burst, MIT fold, brightness, and opacity. Simple linear regression was used to relate measured handsheet strength values to incubation time. Means separation was achieved via the Student-Newman-Keuls procedure using the Statistical Analysis Systems (*12*).□

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