ENERGY SAVINGS IN BIOMECHANICAL PULPING *

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Biological agents are currently being investigated as alternatives to chemicals in pulping wood. Recently we reported that a biomechanical pulping process that uses white-rot fungi to treat aspen chips prior to refiner mechanical pulping can increase paper strength properties. Here we show that fungal treatments can substantially reduce the energy required for refiner mechanical pulping of both aspen and loblolly pine chips. Fungal species and treatment conditions affected the amount of energy savings. Several fungi reduced the energy required for pulping by over 20%. The maximum savings with aspen or loblolly pine were 47 and 68%, respectively. Energy consumption analyses showed that over the range of treatments tested (1) most energy was saved during initial chip fiberization and (2) neither chip weight nor lignin loss correlated with the amount of energy saved. Some treatments resulting in minimal chip weight loss (< 5%) saved the most energy. With aspen, the treatments that saved the most energy did not necessarily result in the highest paper sheet strength properties. With loblolly pine, energy was saved with several treatments, but paper strength was not changed.

Keywords
Lignin biodegradation, biotechnology, biopulping, white-rot fungi, mechanical pulps, Cerioporiopsis subvermispora, Dichomitus squalens, Phanerochaete chrysosporium, Phlebia brevispora, Phlebia subsequeralis, Phlebia tremellosa, Pholiota mutabilis, Trametes versicolor.

Introduction

Mechanical pulping processes that incorporate thermal or chemical treatments, such as thermomechanical pulping (TMP), chemirefinermechanical pulping (CRMP), and chemithermo-mechanical pulping (CTMP), are increasing in popularity (3,8,15,20). These processes require lower capital investment and give higher pulp yield than chemical pulping, and they produce stronger sheets than either stone ground wood (SGW) pulping or refiner mechanical pulping (RMP) (3,8,18). The major disadvantage of mechanical pulping processes is that they require substantial energy to fiberize the chips and subsequently refine the pulps (3,4,12,21).

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Attempts to save energy in mechanical pulping processes with either thermal or chemical treatments have met with little success. Energy can be saved by increasing the saturated steam pressure in refiners, which softens lignin, but this results in a lignin-encased fiber, which drastically reduces sheet strength (10,11,13). Chemical pretreatments of chips increase sheet strength (3,8,22), but they can reduce pulp yield, decrease desirable sheet optical properties (light scattering and opacity), produce dilute waste liquor streams that require treatment, and often increase (instead of decrease) the overall energy requirement (1,4,8,9,14,22).

The disadvantages of thermal and chemical treatments have prompted interest in evaluating the potential of biological treatments. The biopulping processes under investigation are generally based on the concept of using lignin-degrading fungi such as Phanerochaete chrysosporium to selectively remove lignin (2,5–7,16,17,19).

Recently, we obtained promising results with a nonoptimized bench-scale biomechanical pulping process that uses white-rot basidiomycetes to treat aspen chips prior to mechanical pulping (16). Handsheets produced from aspen chips treated in rotating drum (16) or stationary tray bioreactors for four weeks showed substantial increases in burst, tensile, and tear strength indexes. Maximal strength improvement was gained with less than 5% chip weight loss, showing that the process does not require bulk removal of lignin or other major wood polymers. Here we report the energy savings for mechanical pulping by fungal pretreatment of both aspen and loblolly pine chips.

Results and discussion

Fungal species and wood effects. We compared the energy requirement for mechanical pulping of chips treated for four weeks with fungi in either stationary or rotating bioreactors. The efficacy of the individual fungal treatments were dependent on the type of wood tested. The percentage of energy saved in producing 100-ml Canadian standard freeness (CSF) pulp ranged from insignificant for aspen treated with Trametes versicolor to as much as 47% far aspen treated with Phlebia brevispora and 68% for loblolly pine treated with Cerioporiopsis subvermispora (Fig. 1). Substantial energy savings were also obtained for aspen treated with Phlebia subserialis (42%), Phanerochaete chrysosporium (38%), Pholiota mutabilis (37%), or Phlebia tremellosa (35%) and loblolly pine treated with Phlebia brevispora (35%), Dichomitus squalens (32%), or Phlebia subserialis (24%).

Chip movement effects. Comparisons of two fungi on aspen chips in both rotating drums and stationary trays showed that fungal pretreatment was sensitive to chip movement. With movement, energy savings increased 3.8-fold (to 38%) with P. chrysosporium and decreased 2.7-fold (to 7%) with Dichomitus squalens (Fig. 1).
Energy-saving stage. Comparison of the patterns for energy consumption during pulping of fungal-treated chips (Fig. 1) with that of nontreated chips showed that the treatments facilitated wood fiber separation (Fig. 2). The bulk of the energy savings occurred early in pulping when the chips were fiberized into the first coarse pulp (300- to 700-ml CSF). After fiberization, the energy required to refine the pulps to a given CSF was similar for untreated and treated chips (nearly parallel refining lines for the different fungal treatments; Fig. 2). The only exception was the treatment of loblolly pine with *C. subvermispora*, which gave significant energy savings both during fiberization and subsequent refining (Fig. 2). The energy consumption patterns indicate that the coarser the pulp used in papermaking, the more energy saved.

Relationship of chip degradation to energy savings. To determine the basis for energy savings, we investigated the effects of the fungal treatments shown in Fig. 1 on both chip weight loss and Klason lignin loss (Fig. 3). Little degradation of either aspen or loblolly pine chips was required for maximal energy savings. Treatments resulting in minimal chip weight loss (< 5%) were capable of giving substantial energy savings. Over the range of fungi and treatment conditions tested, no definitive correlations occurred between the extent of energy savings and either bulk weight or Klason lignin loss. Treatment of loblolly pine chips typically resulted in energy savings equivalent to those obtained with aspen, but at much lower lignin loss. Although treatment efficacy is apparently not due to bulk lignin loss, we cannot rule out limited lignin modification, such as a decrease in the degree of lignin polymerization, or lignin degradation in a limited specific zone.

Relationship of paper Strength to energy savings. Using handsheets produced from chips treated with the test fungi, we investigated whether or not fungal treatments that resulted in energy savings also resulted in increased sheet strength. Certain fungal treatments of aspen, including *P. tremellosa* in a stationary wire tray and *P. chrysosporium* in a rotating drum, resulted in high relative energy savings as well as high relative burst, tensile, and tear indexes (e.g., burst index shown in Fig. 4). However, over the range of fungi and conditions tested for aspen, the extent of energy savings for a given treatment did not correlate with the level of improvement for burst, tensile, and tear indexes (e.g., burst index shown in Fig. 4). For loblolly pine, substantial energy savings occurred with no significant change in strength (e.g., burst index shown in Fig. 4).

Conclusions

Our observations show that certain high-yield fungal treatments of both aspen and loblolly pine chips can result in substantial energy savings during mechanical pulping. Most energy is saved during chip fiberization. Fungal species, wood type, and chip movement during treatment can all markedly affect the amount of energy saved. Neither strength improvements nor energy
savings depended on bulk loss of chip weight or Klason lignin content. Treatments resulting in
the highest energy savings did not necessarily result in the highest strength properties. Certain
fast-growing fungal species within the genera *Cerioporiopus*, *Phanerochaete*, and *Phlebia* showed
the most promise for further research.

Further research is required to (1) determine the chemical-physical and biochemical basis for
energy savings and strength increase in both hardwoods and softwoods, (2) apply this knowledge
in developing more efficient screening methods, and (3) use these methods to optimize both
energy savings and strength properties for a given fungal treatment.

**Experimental procedures**

*Fungi, chip medium, bioreactors, and treatment conditions.* The following white-rot fungi,
maintained on potato dextrose agar (Difco Laboratories, Detroit, MI.) slants, were used (#
indicates strain): *Cerioporiopsis subvermispora* (Pil.) Gilbn. et Ryv. #FP-90031-Sp, *Dichomitus
squalens* (Karst.) Reid #TON-427, *Phanerochaete chrysosporium* Burds. (syn. *Sporotrichum
pulverulentum*) #BKM-F-1767 (BKM), *Phlebia brevispora* Nakas. #HHB-7099, *Phlebia
subserialis* (Bourd. et Galz.) Donk #RLG-6074, *Phlebia (Merulius) tremellosa* (Schrad.:Fr.)
Nakas. et Burds. #RAB-25, *Pholiota mutabilis* (Schaeff.:Fr.) Kumm. #OKM-2994, and
*Trametes* (syn. *Coriolus*) *versicolor* (L.:Fr.) Pilát #MAD-697. The fresh, standard, industrial-
type 19-mm white aspen (*Populus tremuloides* Michx.) chips used for inoculum and treatments,
nutrient supplements (minus glucuronic and salicylic acids), inoculation method, aeration with
humidified air, and drum rotation schedule (1 rev·h⁻¹; initial rotation schedule as for
*P. chrysosporium*) were described previously (16). The bioreactors consisted of rotating
stainless-steel nonperforated drum bioreactors, otherwise identical to the perforated drum
bioreactors described previously (16), or stationary stainless-steel stationary wire trays (570 by
480 by 60 mm) placed within sterile autoclavable polypropylene bags. All fungi were incubated
at 27.5 ± 1°C except for *P. chrysosporium*, which was incubated at 39 ± 1°C.

*Refining energy measurements.* Energy was measured by fiberizing chips and refining
pulps (approximately 1 to 5 kg oven-dry weight) over a 30- to 250-s interval in a Sprout-Waldron
model D 2202 *single, rotating, 305-mm-diameter disk mechanical refiner* operated at
atmospheric pressure. The energy consumed was measured using an Ohio Semitronics, Inc.
model WH 30-11195 integrating watt meter that was attached to the power supply side of the
driving 44.8 kW electric motor. Automated data acquisition was performed by an AT&T PC
6300 computer using Lotus Measure (Lotus Corp.). Values for pulping and refining energy are
reported as kW·h·kg⁻¹ (oven-dry) with the idling (without chip or pulp load) energy subtracted.

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Chip fiberization, pulp refining, handsheet production and testing, and chemical analysis. Previously described methods (16) were used for the following procedures (standard TAPPI method numbers given where applicable): production of pulps (45 to 150 ml CSF) in a single, rotating, 305-mm disk mechanical refiner operated at atmospheric pressure; preparation of 60 g·m⁻² handsheets (T205); determination of conditioned handsheet burst strength index (T403); and chemical determination of chip Klason lignin content. Dry weight loss and lignin loss caused by fungal treatment were determined on preweighed chip samples taken from six nylon mesh bags placed within the bioreactors before autoclaving. Three bags were recovered immediately prior to inoculation and the other three bags after completing the fungal treatment. Values for handsheet properties made from 100-ml CSF pulps were interpolated from a linear regression performed on a series of three or four pulps refined for each treatment. Note: values for each pulp series gave the near linear relationships typically observed for nontreated chips.

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Literature cited

Running title

Biomechanical pulping

Figure captions

Fig. 1. Energy savings for refiner mechanical pulping of fungal-treated aspen or loblolly pine chips to 100-ml CSF pulp. Prior to pulping, chips were treated for 4 weeks with different white-rot fungi in either stationary Wire tray (**) or rotating drum (***) bioreactors. Untreated aspen or loblolly pine chips required 2.45 or 2.25 kW·h·kg⁻¹ (ovendry) to produce 100-ml CSF pulp.

Fig. 2. Pattern for energy consumption in the production of refiner mechanical pulps of a given CSF from aspen or loblolly pine chips in a single, 305-mm-diameter disc, Sprout-Waldron refiner. Chips were either untreated (●) or treated with white-rot fungi (○; separate lines represent individual fungal treatments). Dashed line shows interpolated values used in Fig. 1.

Fig. 3. Relationship between weight loss or Klason lignin loss from fungal-treated aspen (■) or loblolly pine (○) chips and energy savings in the production of a 100-ml CSF pulp. The individual fungal treatments are those listed in Fig. 1.

Fig. 4. Relationship between energy savings for pulping and change in relative burst index (kPa·m²·kg⁻¹) for handsheets produced from fungal-treated and pulped aspen (‖) or loblolly pine (○) chips. The individual fungal treatments are those listed in Fig. 1. Treatments that maximized energy savings and burst strength index for aspen chips were (a) *P. tremellosa* in stationary tray and (b) *P. chrysosporium* in rotating drum bioreactor. Burst index values for sheets produced from untreated aspen and loblolly pine chips were 0.82 and 0.65 kPa·m²·kg⁻¹.
Fig. 3.

Weight

Energy savings (%) vs. Chip component loss (%)

Klason lignin

Energy savings (%) vs. Chip component loss (%)
