

BIOPULPING: SEVEN YEARS OF CONSORTIA RESEARCH

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ABSTRACT

This paper provides an overview and status report of a 7-year research effort conducted under the auspices of two sequential consortia involving the Forest Products Laboratory of the USDA Forest Service, the Universities of Wisconsin and Minnesota, and industry. The ultimate objective of the research is to evaluate the technical feasibility of biopulping, defined here as the treatment of wood with lignin-degrading fungi prior to pulping. Research to date has focused on mechanical pulping of loblolly pine and aspen (primarily on energy savings) and paper properties. Results have been promising. Pretreatment of wood chips with appropriate fungi results in significant energy savings during refining and improvement of paper strength properties. Optical properties are diminished, but they can be restored with peroxide bleaching. Current efforts are focused on engineering and scale-up for economic evaluations.

INTRODUCTION

Under the auspices of two sequential consortia, the Forest Products Laboratory (USDA Forest Service), the Universities of Wisconsin and Minnesota, and industry have been exploring biopulping—the use of lignin-degrading fungi to pretreat wood chips for pulping. The fungi open and “soften” the cell wall structure. As a result, mechanical pulping is less energy-intensive and the strength properties of the resultant pulp are improved. This report describes research directly related to fungal treatment with mechanical pulping; the overall program has also involved considerable effort on basic aspects of lignin and cellulose degradation by the fungi.

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As an industrial process, biopulping would entail large-scale “solid-state fermentation” of wood chips before they are pulped. Chips would be steamed briefly to reduce the natural microflora, then inoculated with a fungal suspension. The chips would then be incubated for 2 weeks or less, probably with forced aeration in the piles. The “softened” chips would then be pulped.

This kind of bioprocess is fairly alien to the industry at this point, although the Sandoz Cartapip process for decreasing the pitch content of chips (1) is very similar (the Sandoz Cartapip process does not require steaming or aeration). Ordinary composting, used commercially in many locations around the world, is also similar to the biopulping process.

Fungal delignification of wood for pulping was first seriously considered by industrial researchers of the West Virginia Pulp and Paper Company (now Westvaco) in the 1950s. The researchers wondered whether wood chips could be inoculated with a lignin-degrading fungus during transport and storage, and thereby become partially pulped. They published a survey of 72 lignin-degrading fungi, which summarized knowledge about fungal degradation of lignin (2). In the 1970s, Eriksson launched a fairly comprehensive investigation that demonstrated that fungal treatment could result in significant energy savings for mechanical pulping. That work is summarized in a number of publications on biomechanical pulping and in a U.S. patent (3). The researchers encountered difficulties in attempting to scale-up the process. The final focus of that work was on the development of strains of fungi with diminished ability to degrade cellulose.

Preliminary research on biopulping was conducted at the Forest Products Laboratory (FPL) in the 1970s. The work began in earnest in 1987 with the first Biopulping Consortium.

BIOPULPING CONSORTIUM I

The first Biopulping Consortium was conducted from 1987 to 1992. The idea for the consortium arose from a suggestion made at an industry liaison meeting at the FPL. Formally established in April 1987, the consortium consisted of the FPL, the Biotechnology Center of the University of Wisconsin-Madison, and nine pulp and paper and associated companies. The number of companies grew to 20 by April of 1990, and the University of Minnesota was subcontracted to collaborate in part of the research.

The overall objective of this 5-year research and education program was to evaluate the technical feasibility of using a fungal treatment for mechanical pulping to save energy and/or improve pulp and paper properties. In addition, we assumed that the fungal treatment would have a less negative impact on the environment than do chemical treatments. Research results have been published in a FPL Research Paper (4); key findings are described in the following sections.

Fungal Screening

Several hundred species of fungi cause the white-rot type of wood decay, in which all three structural components of wood-cellulose, lignin, and hemicelluloses-are decomposed. These microorganisms play a major role in the carbon cycle. Some of these fungi are relatively selective for lignin, and in that way their action mimics that of chemical pulping reagents. It is these selective lignin-degrading fungi that are useful in biopulping.

Much of the Consortium I research was devoted to screening and testing different species and strains of white-rot fungi. More than 400 species and strains were screened using a simple wood block decay assessment; the criteria were selectivity toward lignin and speed of decay. Most fungi were eliminated by this process. The eight to ten species that showed promise were further screened in actual biopulping runs; this process was considered necessary for final selection of species or strains for closer study.

Initial research focused on the fungus *Phanerochaete chrysosporium*, which has been extensively studied in many laboratories from the standpoint of lignin biodegradation. Late in Consortium I, we shifted our focus to *Ceriporiopsis subvermispora*. In contrast to *Phanerochaete*, *Ceriporiopsis* seldom has been studied from the standpoint of its biochemical activities; in fact, few studies have focused on the biology and physiology of this fungus. The fruiting bodies of *Ceriporiopsis* are inconspicuous; apparently, the fungus is not frequently encountered in nature.

We attempted to develop more efficient screening and less time-consuming methods than those afforded by actual biopulping runs. We had some success with refining in a PFI mill, where the measurement was the number of revolutions required for a given Canadian Standard Freeness (CSF). However, this technique proved to be unreliable for comparing different treatments (for example, effect of nutrient addition) with a given fungus. However, toward the end of Biopulping Consortium I, we found a promising and relatively rapid method that involves the use of Simon's stain. We also were able to increase the speed of the biopulping runs by decreasing the refining time; we decreased the refiner plate settings between passes, thereby reducing the number of passes. Tables I and II summarize screening results with single strains of five species of fungus on loblolly pine, which were first evaluated in decay tests and later in biopulping runs. As mentioned, *Ceriporiopsis subvermispora* was eventually chosen for additional study.

Biopulping Runs

More than 200 biopulping runs were completed during the course of Biopulping Consortium I. Many runs were part of the

Table I. Loss (Percent) Resulting From Fungal Decay on Loblolly Pine^a

Fungus	Wt.	Lig.	Gluc.	Xyl.	Man.
<i>P. chrysosporium</i>	24.5	20.9	26.1	19.1	31.4
<i>H. setulosa</i>	19.3	35.9	5.1	38.2	4.0
<i>Phlebia brevispora</i>	24.5	39.9	22.5	48.1	40.4
<i>Phlebia subserialis</i>	48.0	44.7	45.2	65.3	64.3
<i>C. subvermispora</i>	23.7	49.8	3.3	48.2	12.9

^aPercentage of loss based on noninoculated controls. Lignin determined by Klason method; wood sugars determined after acid hydrolysis. Lig. is lignin; gluc., glucose; xyl., xylase; and man., mannase.

Table II. Energy Savings and Change in Properties of Loblolly Pine Pulp Pretreated With Various Fungi^a

Fungus	Savings/Improvement (%)		
	Burst Energy	Tear index	Tensile index
<i>P. chrysosporium</i>	14	14	1
<i>H. setulosa</i>	26	12	32
<i>Phlebia brevispora</i>	28	-4	21
<i>Phlebia subserialis</i>	32	-29	9
<i>C. subvermispora</i>	42	32	67

^aPercentage of energy savings or strength improvements calculated on basis of untreated control values.

screening process; the purpose of most runs, however, was to evaluate the many interacting factors that influence fungal treatment. Biopulping runs involved incubating wood chips in bioreactors with the fungus, then mechanically refining the chips. Electrical power consumption was measured. Handsheets prepared from the resultant pulps were tested for strength and optical properties. Both aspen and loblolly pine chips were used for those studies.

Several bioreactor designs were examined before we decided to use the simple and inexpensive design shown in Figure 1. Chips (1500 g, dry weight basis) were introduced into each 21-L bioreactor with water (and additives, if any), and the loaded bioreactors were usually sterilized (by autoclaving in most runs). The chips were then inoculated with a fungus and incubated with forced aeration. Refining fungus-treated and control wood chips (controls treated in the same way without fungus) involved multiple passes in a 300-mm-diameter single-disk refiner (Andritz Sprout-Bauer, Muncie, PA) equipped with a watt-hour meter [see reference (4) and references cited therein]. Pulps were refined to CSF values just above and just below 100 ml. Handsheets (60 g/m²) were made with the two pulp samples and tested using TAPPI standard methods.

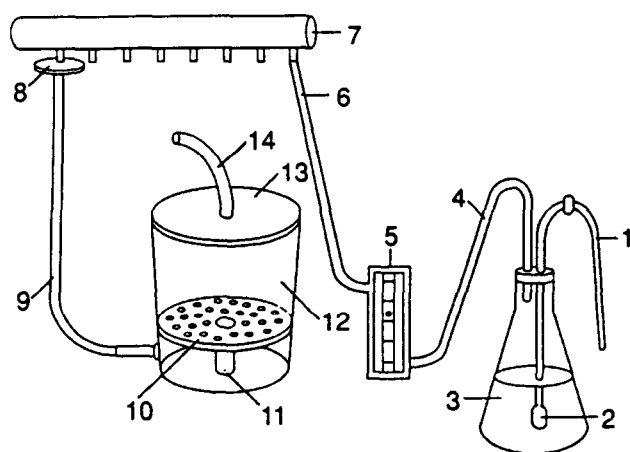


Fig. 1. Aerated static-bed bioreactor (ref. 14). Top of the 21-L vessel is sealed with a lid (13), which is vented to the atmosphere through an exit tube (14). Suspended above bottom of bioreactor (12) is a perforated polypropylene board (10) held in place by a stand (11). An 0.2- μm pore-size membrane filter (8) is connected by tubing (9) to base of bioreactor (12). The filter (8) receives input air supply from manifold (7) supplied through air line (6) connected to rotometer (5). Rotometer (5) receives air from air line (4) connected to humidifier (3), which passes incoming air through distilled water via fritted glass gas dispenser (2) connected through tubing (1) to regulated air supply.

Standard deviation values of the two handsheet sets were reviewed and the data with the higher values selected. We considered this to be the conservative approach. In some runs, the first refiner-pass effluent was collected and assayed for toxicity, biochemical oxygen demand, and chemical oxygen demand.

Factors Influencing Fungal Pretreatment

Many factors influence the efficacy of fungal treatment after a fungal strain has been chosen. Using biopulping runs, we examined a number of factors that were considered likely to be important; findings are summarized in the following paragraph.

Aspen was easier to pretreat than pine, and different batches of aspen chips gave similar results. Fresh chips, fresh chips stored frozen and then used later, and chips air-dried before use all gave similar results. We found that chips must be relatively free of contaminating indigenous microbes when *C. subvermispora* is used, whereas *P. chrysosporium* competes effectively with contaminants. Autoclaving and sterilization with methyl bromide were equally effective. Addition of nutrient nitrogen in various forms stimulated fungal activity and led to greater refiner energy savings in a given time of

incubation, but the nitrogen also promoted unacceptable losses in wood substance and damage to the cellulose. Treatment time was found, as expected, to be a trade-off between loss of wood substance and beneficial influence; 2-4 weeks was eventually chosen, and most runs were for 4 weeks; weight losses were below 10 percent. (As described below, a 2-week treatment time is now used.) The amount of inoculum was found to be critical up to a certain level, above which increases were without influence. Air flow rate through the chips in the bioreactors was important; 0.001 L/L min was too low, whereas 0.022 and 0.100 L/L min were equally effective. Temperature and chip moisture content were assumed to be critical; we simply used the optimum temperatures for the two fungi (39°C for *P. chrysosporium* and 27°C for *C. subvermispora*) and 55-60 percent chip moisture content (wet weight basis).

Global Analysis of Data

At the end of Biopulping Consortium I, we analyzed all the runs statistically in a global (exploratory) manner (4). We treated *P. chrysosporium*/aspen, *C. subvermispora*/aspen, and *C. subvermispora*/pine as three separate sets of data, with all runs of these combinations included. We felt that the large number of runs and the consistency of the results were strong arguments for a global analysis, even though the many runs did not fit into an overall experimental statistical design. In general, the variables examined in the separate groups of runs did not differentially affect the measured properties. The data in the global analysis were plotted as notched box plots (5), so that any statistically significant differences (± 0.95 confidence level) between the untreated controls and biopulped chips could be observed, as could differences between different treatments. The global analysis greatly simplified our overall interpretation of a large amount of data.

With aspen, comparison of several fungal species in terms of refiner energy consumption clearly illustrated the potential of *C. subvermispora* and the less impressive efficacy of *P. chrysosporium* (Fig. 2). As mentioned, *C. subvermispora* has also been proven to be very effective on pine; *P. chrysosporium* is relatively ineffective on this species. Figure 2 shows energy consumption for aspen wood chips treated with eight different fungi.

Density of handsheets from aspen pulp was decreased somewhat by treatment of chips with *P. chrysosporium* and *C. subvermispora*; treatment did not affect density in the case of pine (Fig. 3). Burst and tensile indices of handsheets from aspen pulp were increased significantly by chip treatment with either fungus; neither fungus affected burst and tensile indices of handsheets from pine pulp (Figs. 4 and 5). Zero span tensile strength of handsheets was not affected by either fungus on either wood species (data not shown). Tear index (single-ply test) was significantly increased by chip treatment with either

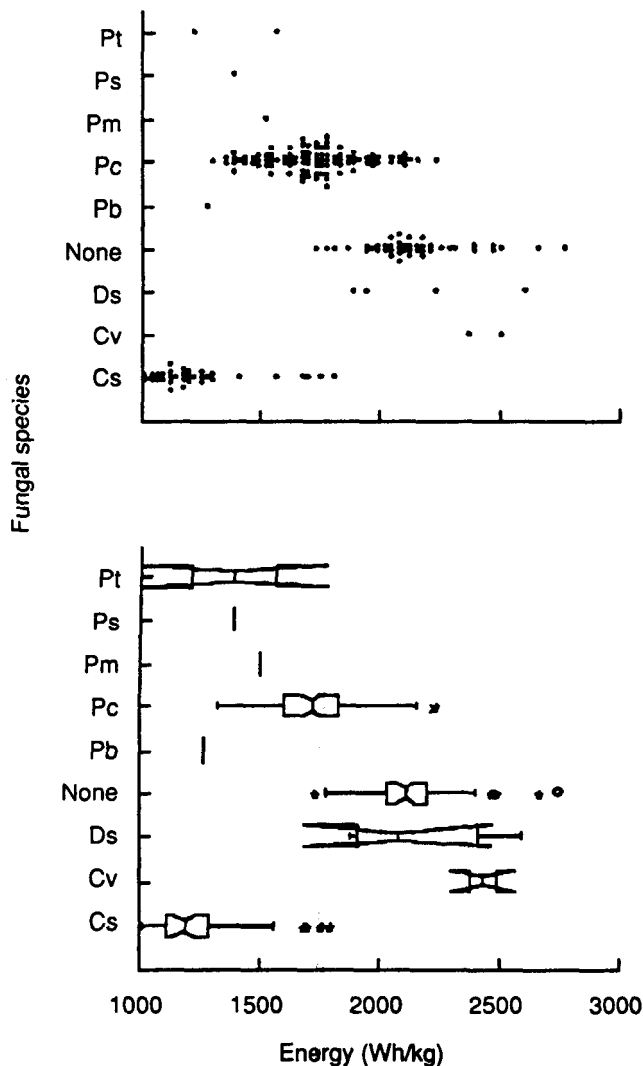


Fig. 2. Refiner energy consumption of aspen chips treated with different fungi. Pt is *Phlebia tremellosa*; Ps, *P. subserialis*; Pm, *Pholiota mutabilis*; Pc, *Phanerochaete chrysosporium*; Pb, *P. brevispora*; Ds, *Dichomitus squalens*; C, *Coriolus versicolor*, and Cs. *Ceriporiopsis subvermispora*.

fungus. For pine, tear index was examined in only handsheets from pulp treated with *C. subvermispora*; this property increased significantly (Fig. 6). Handsheet brightness was significantly decreased by treatment with either fungus, on both wood species (Fig. 7). Treatment with *C. subvermispora* decreased scattering coefficient on both species; *P. chrysosporium* decreased this property on aspen (data not shown).

Additional results of the global analysis were published in detail in the final report of Biopulping Consortium I (4).

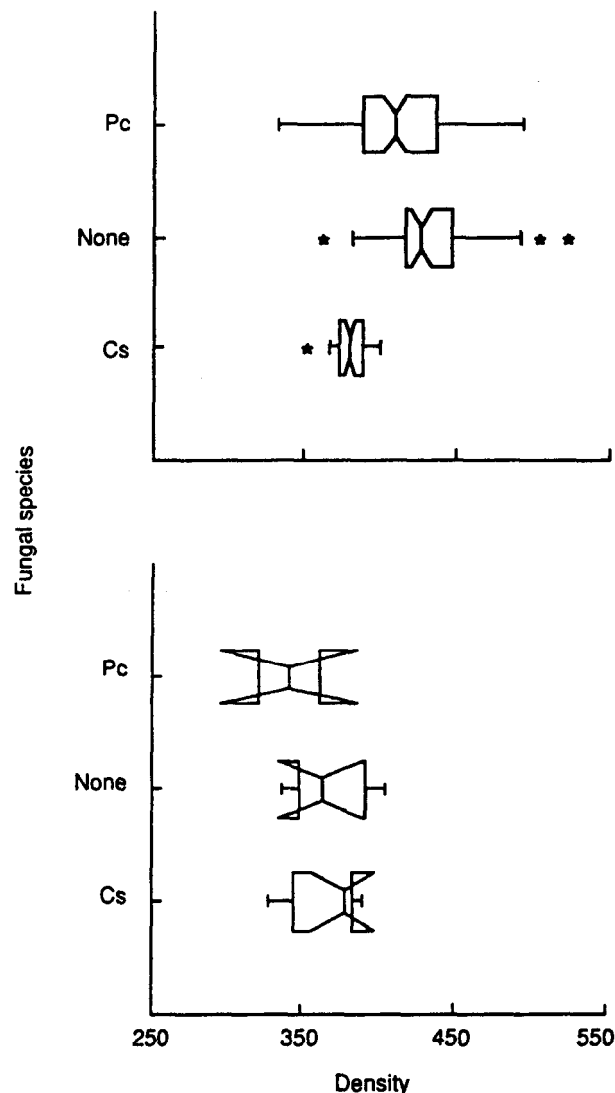


Fig. 3. Density of handsheets made from aspen (top) and pine (bottom) treated with *P. chrysosporium* or *C. subvermispora*.

Bleaching Studies

Fungal treatment of chips reduced the brightness of the resultant pulps. Consequently, the bleachability and brightness stability of aspen “bio-refiner mechanical pulps” (BRMPs) were investigated. The BRMPs were compared to untreated aspen refiner mechanical pulp (RMP) and other mechanical pulps: chemithermo-mechanical pulp (CTMP), thermo-mechanical pulp (TMP), and groundwood (GW) pulp (6). *Phanerochaete chrysosporium* was used for the treatments reported here; subsequent experiments demonstrated that aspen chips treated with *C. subvermispora* respond similarly to bleaching.

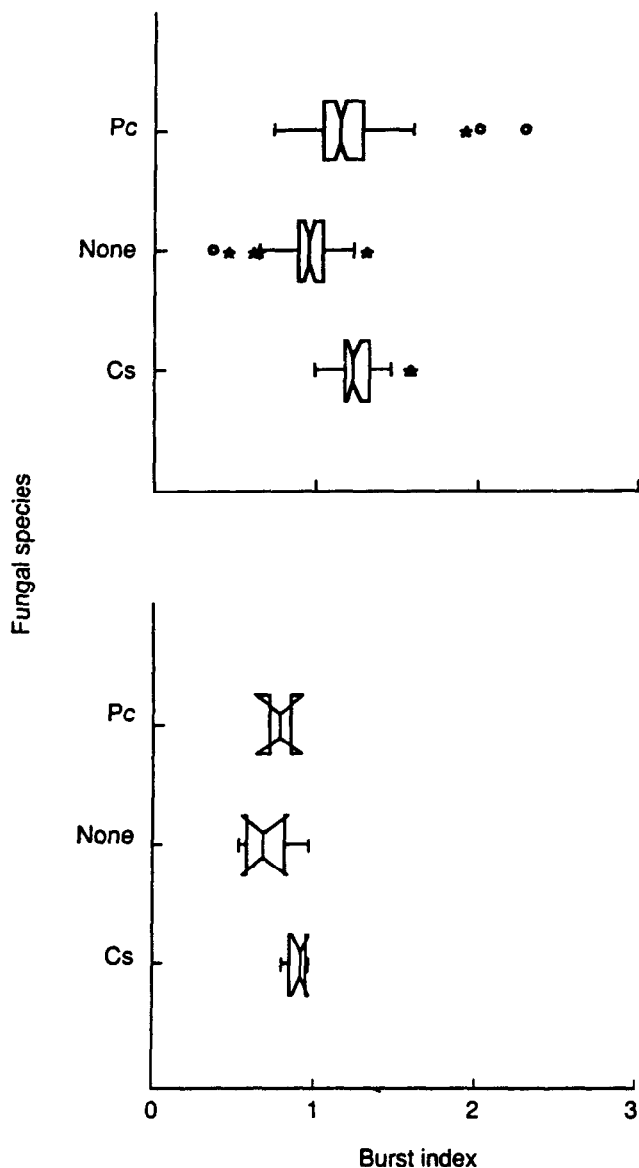


Fig. 4. Burst index for handsheets made from aspen (top) and pine (bottom) treated with *P. chrysosporium* or *C. subvermispora*.

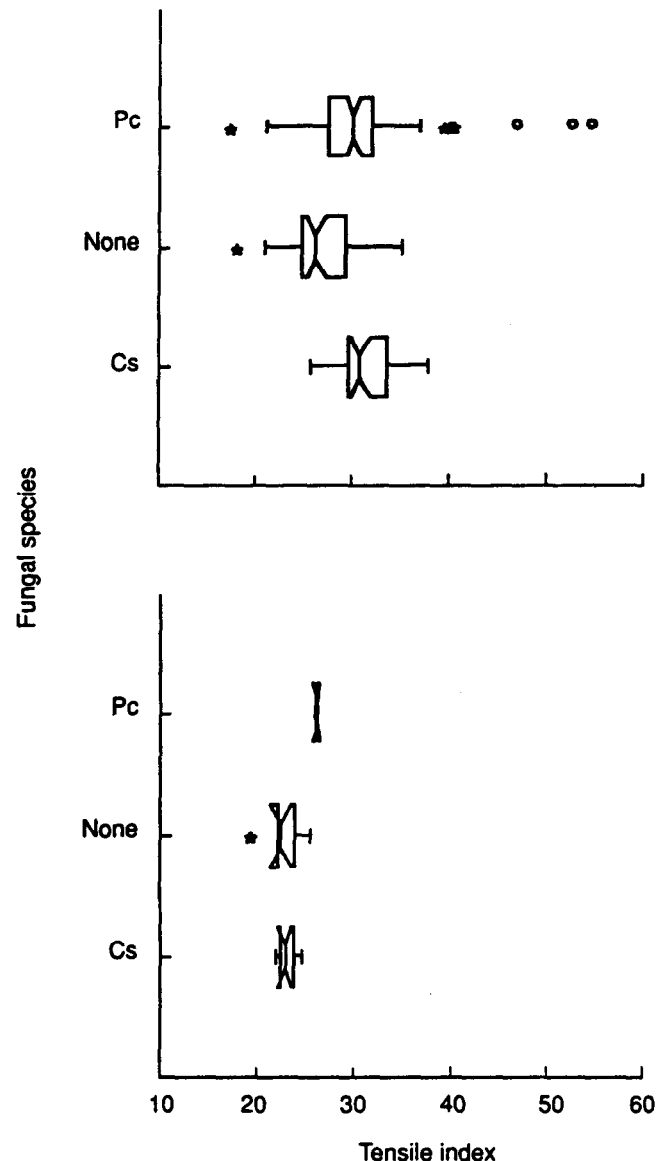


Fig. 5. Tensile index for handsheets made from aspen (top) and pine (bottom) treated with *P. chrysosporium* or *C. subvermispora*.

Either alkaline hydrogen peroxide or sodium hydrosulfite readily increased the brightness of aspen BRMP (Table III); fungal treatment enhanced the bleachability of the pulps. The BRMPs increased more brightness points than did the untreated pulps. However, because the initial brightness values of the BRMP were lower than those of the corresponding untreated mechanical pulps, the brightness values of bleached pulps were not as high as those of untreated pulps, at a given chemical charge. Aspen BRMP was readily bleached to 60 percent Elrepho brightness with 1 percent sodium hydrosulfite—a brightness suitable for newsprint; brightness values approaching 80 percent were achieved with a two-step bleach sequence.

Opacity and scattering coefficients are also summarized in Table III (6). The optical properties of both bleached and unbleached BRMP were superior to those of CTMP, the GW pulp displayed the best opacity and light-scattering coefficient, followed by RMP and TMP. Shortened incubation time for fungal treatment and alternate asepsis methods resulted in 80 percent brightness for BRMP with a single-step 4percent hydrogen peroxide charge.

Brightness stability was evaluated by subjecting handsheets to accelerated thermal-and photo-aging tests (6). The stability of BRMP was slightly lower than that of RMP but slightly higher than that of CTMP (6).

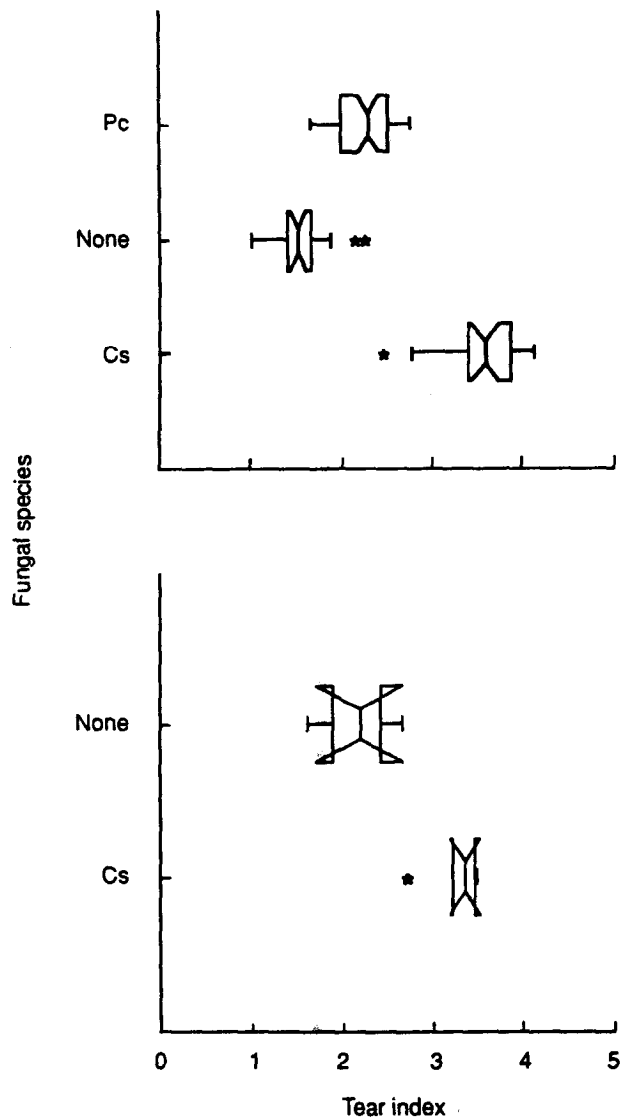


Fig. 6. Tear index (single-ply tear) for handsheets made from aspen (top) and pine (bottom) treated with *P. chrysosporium* or *C. subvermispora*.

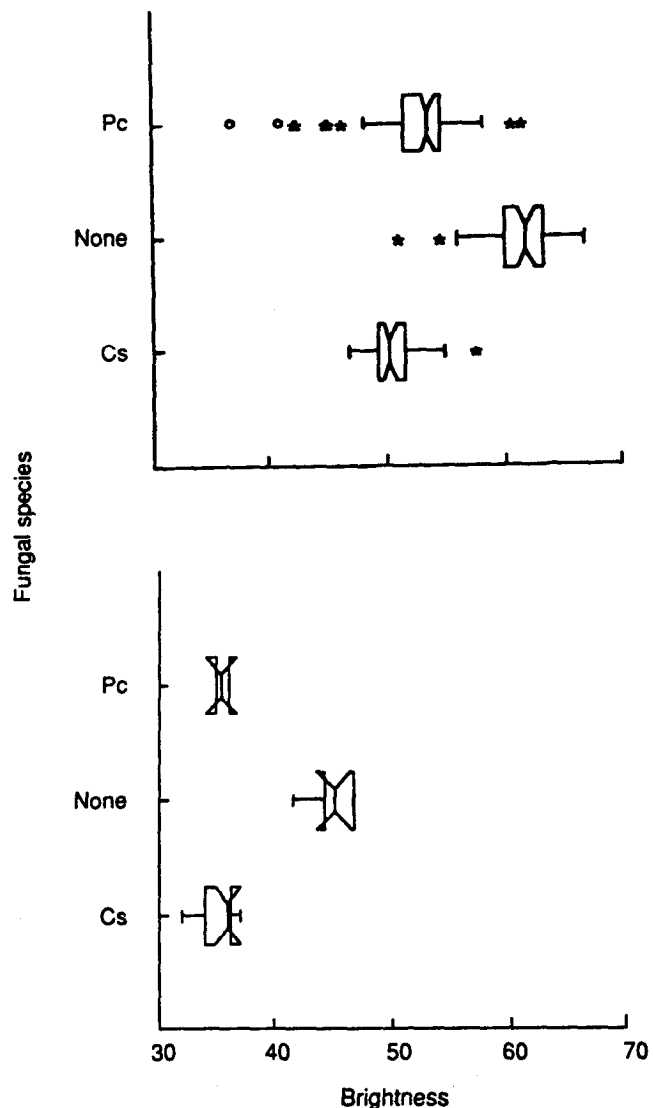


Fig. 7. Brightness of handsheets made from aspen (top) and pine (bottom) treated with *P. chrysosporium* or *C. subvermispora*.

Biopulping Effluents

Samples of wastewater from the fast refiner pass of aspen chips treated with either *C. subvermispora* or *P. chrysosporium* were analyzed for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and Microtox toxicity (7). Results showed that fungal treatments substantially decreased toxicity but generally increased BOD and COD as a result of the release of soluble degradation products (Table IV).

Engineering and Economics

The engineering and economics studies related to Biopulping Consortium I are summarized in the Ph.D. thesis of Wall (8). The approach to eventual scale-up involves an iterative process, which includes process simulation and laboratory studies. In Biopulping Consortium I, engineering and economics studies were used to obtain data required for process simulation and to gain a better understanding of process variables that affect biopulping efficacy. Process simulation was used to integrate information determined experimentally and to make predictions concerning operation at laboratory scale.

Table III. Optical Properties of Aspen Pulps

Pulp	Bright. (%)	Opacity (%)	Scatt. coeff. (m ² /kg)
GW			
Unbleached	63.1	97.0	81.3
1.5% H ₂ O ₂	80.8	90.8	70.7
1% Na ₂ S ₂ O ₄	71.9	94.2	78.3
CTMP			
Unbleached	62.0	88.7	42.1
3% H ₂ O ₂	78.3	77.0	37.2
1% Na ₂ S ₂ O ₄	66.3	84.2	41.5
TMP			
Unbleached	60.2	94.2	59.4
3% H ₂ O ₂	78.6	87.2	56.2
1% Na ₂ S ₂ O ₄	66.9	91.2	60.0
RMP (control)			
Unbleached	62.2	94.2	62.9
2% H ₂ O ₂	80.0	87.5	64.0
1% Na ₂ S ₂ O ₄	71.2	91.2	70.9
BRMP			
Unbleached	51.8	94.8	50.1
3% H ₂ O ₂	76.0	84.8	53.5
1% Na ₂ S ₂ O ₄	59.3	90.0	51.1

Early in the biopulping research, Harpole et al. (9) conducted an economics evaluation based on a thermomechanical process model. Results indicated that a 25-percent reduction in pulping energy by fungal treatment would save \$21 (U.S. dollars) per air-dry ton (adt) of pulp (\$33 with 40 percent

Table IV. Effect of Treatment on Biopulping Effluents^a

Effluent sample	BOD (g/kg pulp)	COD (g/kg pulp)	Toxicity (100/EC ₅₀)
Control	40	73	19
Phanerochaete	16	75	5
<i>Ceriporiopsis</i>	39	100	4

^aEffluents from first refiner pass of untreated and treated aspen chips.

energy savings). The capitalized value of the energy savings was estimated to be about \$250,000 for each percentage of energy saved, at an electricity cost of \$0.035/kW-h. Thus, a sizeable capital expenditure for the biotreatment could be accommodated. Later, an economic model based on mass and energy balances was made for a controlled aerated static bed process and a chip pile-based system (10). The controlled aerated static bed process does not appear to be economically attractive (return on investment is 15 percent); the chip pile-based system promises a greater return.

The chip pile-based system is illustrated in Figure 8 (10). Calculations included ductwork to provide aeration, pipes for steam to presteam the chips on the conveyor, and a sprayer to apply inoculum to the chips on the conveyor. Calculations were based on 25 percent energy savings, 300 ton/day mill, 2-week treatment time, 95 percent yield, and 0.59 VVM aeration. Operating costs included steam, inoculum, and electricity for aeration. Capital costs included costs for fans, ductwork and steampipe system, inoculum tanks, and humidification. An approximate value of \$500,000 was chosen for the total capital investment, a conservative estimate.

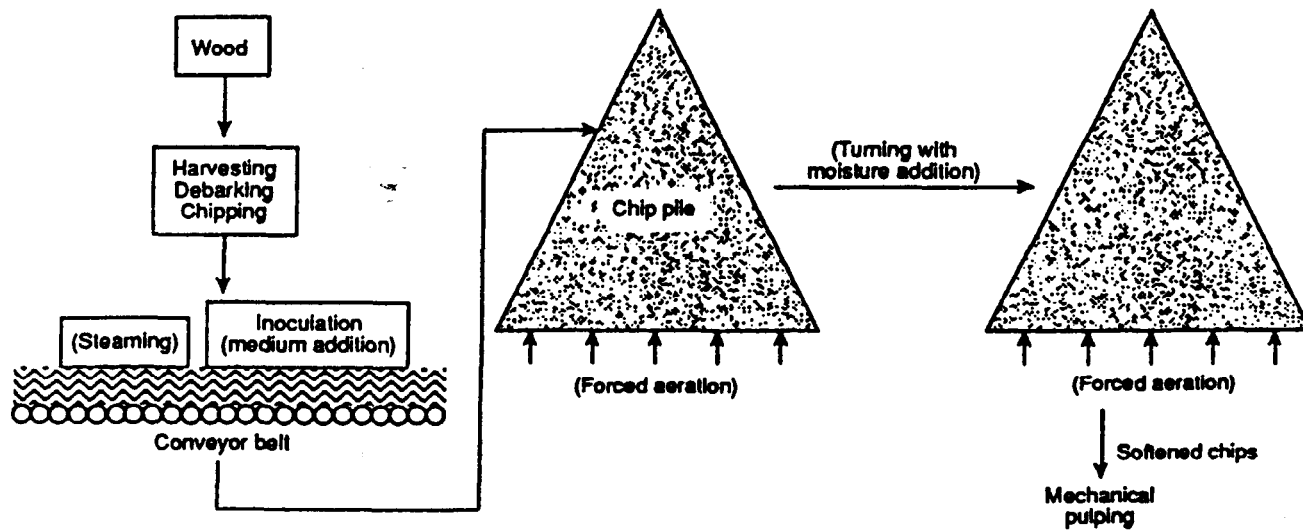


Fig. 8. Process flowsheet for chip pile-based system. Processes in parentheses are optional.

Table V. Economic Feasibility of Chip Pile-Based System^{a,b}

Item	U. S. dollars		
	Case1	Case2	Case3
Installed equipment costs	500,000	500,000	500,000
Working capital investment	206,750	206,750	206,750
Total capital investment	706,750	706,750	706,750
Utility costs	2.46	2.46	2.46
Inoculum costs	3.00	5.00	10.00
Labor	0.76	0.76	0.76
Yield losses	2.46	2.46	2.46
Depreciation	0.76	0.76	0.76
Total operating costs	9.35	11.35	16.35
Pretreatment value	23.49	23.49	23.49
Gross Profit	14.14	12.14	7.14
Pretax ROI	217%	180%	106%

^a*P. chrysosporium* on aspen; 300 metric ton/day; 14-day treatment; 95-percent yield; 0.59 VVM air.

^bOperating costs are expressed in dollars Per air-dry ton.

Table V shows the results of calculations for three cases based on three different costs of the inoculum, which is a major cost element. In any event, the calculated pretax return on investment (ROI) is 106 to 217 percent, making the system economically attractive (8).

BIOPULPING CONSORTIUM II

At the end of the first consortium, several of the participating companies wanted to continue the research. Biopulping Consortium II was established in April of 1992 as a 3-year program. The primary objective of this consortium is to evaluate further the parameters that affect scale-up. We have focused the work on loblolly pine and *Ceriporiopsis subvermispota*. We have continued fungal screening studies and are working to reduce the cost of *Ceriporiopsis* inoculum. Results to date that have been publicly disclosed are summarized briefly in the following discussion.

Bioreactors have been constructed to mimic chip piles; they are instrumented to provide exact data on heat build-up and rate of fungal action. These data should enable us to design a chip pile-based system that allows control of the treatment process.

The fungal screening work has focused on strains of *Ceriporiopsis subvermispota*. We have found-and are now using- strains that result in more than 30 percent energy saved in 2 weeks; in some runs, the energy saved is close to

40 percent. We have also found that Simon's stain is a promising screening procedure. This reagent is a differential stain consisting of a mixture of a high molecular weight orange dye and a low molecular weight blue dye. The orange dye binds to the fibers much more strongly than the blue dye; thus, it displaces the blue dye in parts of the cell walls in which the fiber is accessible to the orange dye (Yu et al.; manuscript in preparation). This reagent therefore stains pulp orange where the walls have undergone internal delamination, fibrillation, or damage. Successful fungal treatment followed by brief refining causes aspen and pine wood to stain orange to a much greater extent than similarly prepared control fibers. We have found that the intensity of the orange dye in coarse refiner pulp correlates well with the relative efficacy of fungal treatment, as determined by refiner energy savings in full biopulping runs (Akhtar et al.; unpublished results).

Our approach to reducing the cost of the inoculum has been to augment the inoculum with low-cost nutrients, reducing the amount of inoculum required. The nutrients stimulate initial fungal growth and establishment in the chips. We have already been able to reduce the amount of inoculum from 3 kg (dry weight basis) per ton (dry weight basis) to 3 g/ton by adding corn steep liquor to the mycelial suspension. The actual cost of *Ceriporiopsis* inoculum is not known at this point. *Ceriporiopsis* does not produce spores suitable for use as inoculum. Thus, more fragile mycelial suspensions must be used, which raises the costs of packaging, transportation, and storage. On the other hand, producing the inoculum at the mill site should be possible, which would eliminate packaging, transportation, and storage.

MECHANISM OF FUNGAL ACTION IN BIOPULPING

During both consortia, we have conducted limited studies aimed at understanding the fundamental mechanism of biopulping. Electron microscopy of cell walls before and after fungal treatment has indicated that the normally rigid wood cell wall structure becomes swollen in biopulping, with localized areas of thinning or fragmentation (Fig. 9) (11). These changes are fully in accord with the results recently obtained with Simon's stain.

Thus, we have visible evidence for alterations in the cell wall during fungal treatment, and we assume that these changes are related to the efficacy of the fungal treatment. But what are the specific changes in the cell wall components at the molecular level, and what enzymes bring them about? As this report has indicated, we have assumed from the outset that degradation and alteration of the lignin plays a major role. Analyses show that the lignin is selectively removed during fungal treatment (4), but that is to be expected because the fungi were selected for that trait. We do not really know how relevant lignin is to the mechanism. Indeed, some of the earliest work in Biopulping Consortium I failed to establish a relationship between refiner

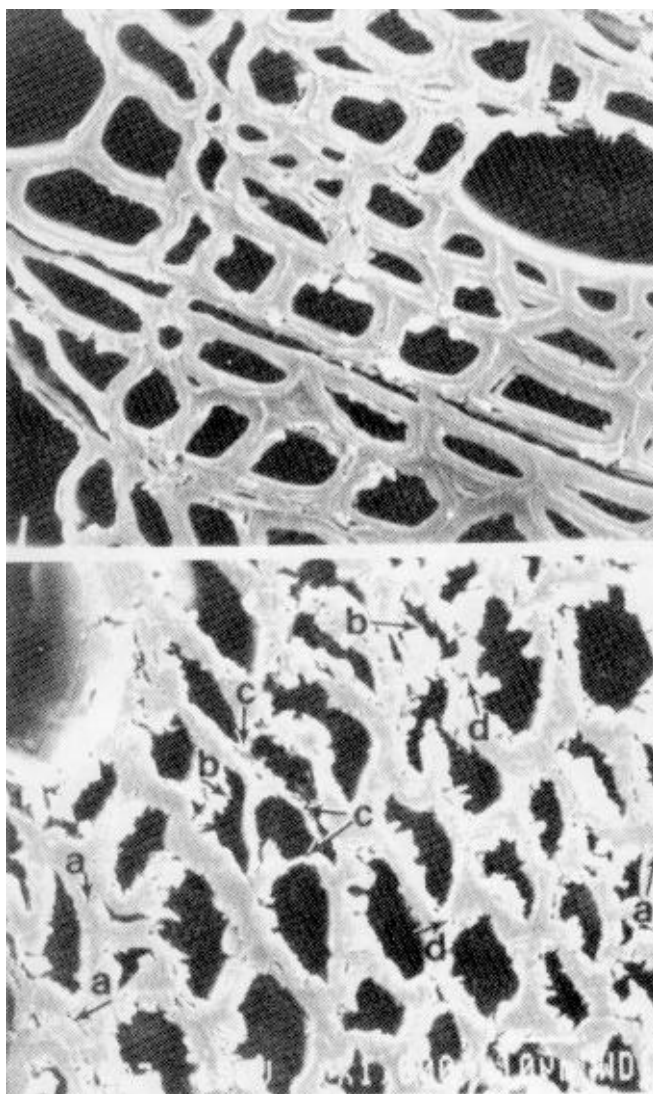


Fig. 9. The normally rigid wood cell wall structure within an aspen chip (top) was modified by the model 3-week fungal treatment used in the bench-scale biomechanical pulping process. Modifications (bottom) included cell wall swelling (a), enzymatic softening or relaxing resulting in the partial collapse of the tubelike cell structure (b), and localized areas of wall thinning (c) or fragmentation (d). (1,000x)

energy savings and selectivity for lignin removal among different fungi (12). Alterations in the lignin could occur without actual removal of the lignin. However, we did not see any differences in the UV spectra of "extractive lignins" prepared from fungus-treated and control chips (unpublished results), as might have been expected from earlier work (13). In any event, we have not chosen to focus our limited resources on the question of the molecular mechanism of biopulping, and our investigations have been only cursory. As biopulping approaches commercial realization,

the question of mechanism will become increasingly important since it holds the key to rational approaches to improvements in fungal strains and in the process itself.

PROSPECTS FOR COMMERCIALIZATION

At this point in our investigations, it would appear that biomechanical pulping has a good chance of commercial success. Three recent developments have led to this optimism: (a) the discovery of *Ceriporiopsis subvermispora* as a superior biopulping fungus, equally effective on pine and aspen; (b) the demonstration that brief atmospheric steaming of wood chips reduces the natural microflora sufficiently for *Ceriporiopsis* to take over, and (c) the discovery that inoculum levels of *Ceriporiopsis* can be drastically reduced by including corn steep liquor in the mycelial suspension. The need at this point is to demonstrate methods for controlling temperature, aeration, and moisture in chip piles so that the fungal treatment is effective. Current research is focused on this aspect of biopulping.

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Proceedings

1994

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