COMMERCIALIZATION OF BIOPULPING FOR MECHANICAL PULPING

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ABSTRACT

Biopulping is defined as the treatment of wood chips with lignin-degrading fungi prior to pulping. Fungal pretreatment prior to mechanical pulping reduces electrical energy requirements during refining or increases mill throughput, improves paper strength, reduces the pitch content, and reduces the environmental impact of pulping. Our recent work involved scaling up the biopulping process towards the industrial level, investigating both the engineering and economic feasibility. We envision the process to be done in either a chip-pile or silo-based system for which several factors need to be considered: the degree of decontamination, a hospitable environment for the fungus, and the overall process economics. Currently, treatment of the chips with low-pressure steam is sufficient for decontamination and a simple, forced ventilation system maintains the proper temperature, humidity, and moisture conditions, thus promoting uniform growth of the fungus. The pilot-scale trial resulted in the successful treatment of 4 tons of wood chips (dry weight basis) With results comparable to those on a laboratory. Larger, 40-ton trials were also successful, with energy savings and paper properties comparable with the laboratory scale.

INTRODUCTION

Mechanical pulping accounts for about 25% of the wood pulp production in the world today. This volume is expected to increase in the future as raw materials become more difficult to obtain. Mechanical pulping, with its high yield, is viewed as a way to extend these resources. However, mechanical pulping is electrical energy-intensive and yields paper with lower strength compared with chemical pulping. Biopulping, which uses natural wood decay organisms, has the potential to overcome these problems. Fungi alter the lignin in the wood cell walls, which has the effect of "softening" the chips. This substantially reduces the electrical energy needed for mechanical pulping and leads to improvements in the paper strength properties. The fungal pretreatment is a natural process; therefore, no adverse environmental consequences are foreseen.

The overall conclusion of the Biopulping Consortium at the USDA-Forest Service, Forest Products Laboratory (FPL) was that biopulping works. Through the use of the proper lignin-degrading fungus, at least 30% electrical energy can be saved in mechanical pulping and paper strength properties are improved [1-4]. In addition, the fungal pretreatment for mechanical pulping has less environmental impact than chemical pretreatments [5].

PROCESS OVERVIEW

Based on the results of previous work and discussions with mill personnel, we envision a fungal treatment system that fits into existing mill operations with minimal disturbance. Figure 1 is a conceptual overview of the biotreatment process in relation to existing wood yard operations. Wood is harvested and transported to the mill site for debarking, chipping, and screening. Chips are decontaminated by steaming, maintaining a high temperature for a sufficient time to decontaminate the wood chip surfaces, and then cooled so that the fungus can be applied. The chips are then placed in piles that can be ventilated to maintain the proper temperature, humidity, and moisture content for fungal growth and subsequent biopulping. The retention time in the pile is 1 to 4 weeks.

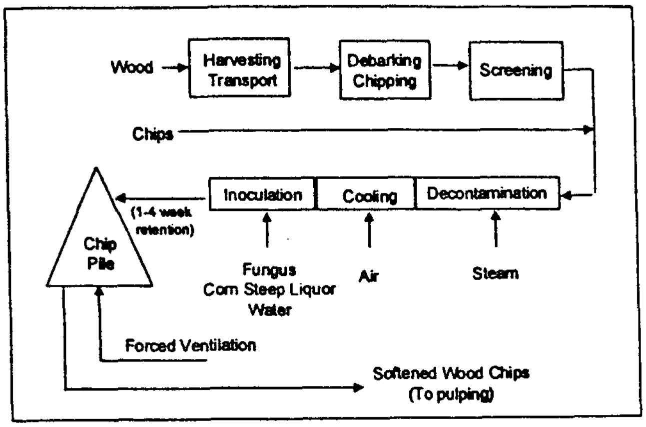

Figure 1. Overview of the biopulping process showing how th biotreatment process fits into an existing mill's wood-handling system.

Although Figure 1 shows a basic concept for the process, several variations can be easily envisioned. For those mills that purchase chips rather than logs, the chips can be fed directly into the decontamination. The process of decontamination, cooling, and inoculation could be done in screw conveyers (described later) or on conveyer belts. If sufficient silo or other indoor capacity is available, the entire process could be enclosed, thus minimizing the adverse effect of the environment on the process.

SCALE-UP EQUIPMENT AND METHODS

Recent efforts have focused on bringing the successful laboratory-scale procedures up to the industrial level. Our laboratory process treats approximately 1.5 kg of chips (dry weight basis) at one time. Commercial processes need to treat about 200 to 2,000 tons or more per day of wood chips processed, representing a 10^5 increase in scale. This gap is currently being bridged through a series of experiments to bring the process scale to this level. The goals of these scale-up studies are two-fold: (1) demonstrate that chips can be decontaminated and inoculated on a continuous basis rather than a batch process, and (2) demonstrate that the process scales as expected from an engineering standpoint.

In our reactor scale-up studies, we investigated two types of reactor systems: tubular reactors and chip piles. The tubular reactors have an advantage in obtaining the necessary engineering and kinetic data for scaling up the process. The one-dimensional nature of the system is easy to analyze and model. The reactor also allows for well-controlled air flow in the system with air flow patterns that are well known. Heat loss from the system is easily controlled with exterior insulation, thus achieving conditions that would be experienced in the center of large chip piles. Details on the configurations of these reactors and the chip piles have been published [1, 6].

On **a** large scale, decontamination and inoculation must be done on a continuous basis and not batchwise as had been done in the laboratory trials. To achieve this, we built a treatment system based on two screw conveyers that transport the chips and act as treatment chambers. Figure 2 is an overview of the continuous process equipment used in 4- and 40-ton trials. Steam is injected into the first screw conveyer, which heats and decontaminates the chip surface. A surge bin is located between the two conveyers to act as a buffer. From the bottom of the surge bin, a second screw conveyer removes the chips, which are subsequently cooled with filtered air. In the second half of the second screw conveyer, the inoculum suspension containing fungus, unsterilized corn steep liquor, and water is applied and mixed with the chips through the tumbling action. From the screw conveyer, the chips fall into the pile or reactor for a 2-week incubation. In the first scale-up trial, 4 tons of spruce wood chips were inoculated and incubated at a throughput of approximately 0.5 tons per hour. The first successful outdoor trial with the biopulping fungus *C. subvermispora* had 40 tons of spruce treated at a throughput of about 2 tons per hour (dry weight basis) continuously for over 20 hours. During the 2 weeks, the chip pile was maintained within the temperature growth range for the fungus, despite the outdoor exposure to ambient conditions.

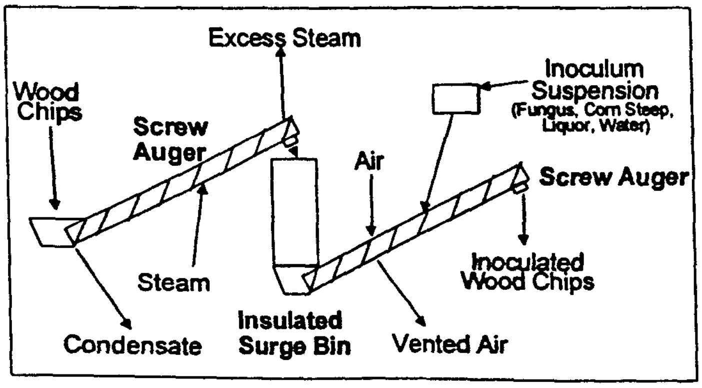

Figure 2. Continuous treatment system to decontaminate and inoculate wood chips. Wood chips are steamed in the first screw conveyor before being placed into a surge bin. The second screw conveyor then picks up th chips, cools them, and applies the inoculum.

In previous work [1-4], most of the energy savings and paper properties were evaluated through Refiner Mechanical Pulping (RMP) in a 30-cm atmospheric laboratory refiner. For the 4- and 40-ton trials, Thermo-Mechanical Pulping (TMP) was done at FPL. In addition, samples were sent to two laboratories—Andritz Sprout-Bauer in Springfield, Ohio, and Herty Foundation in Savannah, Georgia-for independent confirmation of our results. At Herty Foundation, primary refining was done in a 30-cm pressurized refiner. At Andritz Sprout-Bauer, a 91-cm pressurized refiner was used. The remaining two or three refining stages were done at atmospheric pressure. For the second 40-ton trial, the chips were refined in a commercial TMP mill, with a pressurized primary stage and an atmospheric secondary stage.

LARGE-SCALE EXPERIMENTAL RESULTS

From the many experiments, our key engineering findings included the degree of decontamination necessary for the fungus to grow, the cooling and inoculation of the chips, the heat generation in the pile, the compression of the chips during the incubation, and the air flow for cooling through the pile [6]. As we went up in scale, we achieved the same results as far as energy savings and paper properties are concerned. For RMP, as the process scale increased from the bioreactors (1.5 kg) to the large trials, the energy savings for RMP (at 100 Canadian Standard Freeness (CSF)) improved from 24% to over 30% in our larger outdoor trials. In addition to the scale, there were some differences between the trials. First of all, the 40-ton trials were held outdoors and were strongly affected by the ambient temperature, which ranged from -4°C to 16°C for the first trial and from 16°C to 32°C for the second On the other hand, the bioreactors were at a constant temperature of 27°. The indoor 4-ton trial was also enclosed and experienced little effect of the ambient temperature. The outdoor trial was exposed to the elements including rain and wind which could have had an effect on the growth of the biopulping fungus. Other operational differences between the smaller indoor trials and the outdoor trial may have also contributed to the differences.

For TMP at the 40-ton scale, energy savings were 31% at 100 CSF, according to the refining trials done at Andritz Sprout-Bauer and Herty Foundation. This is consistent with previous TMP results at the bioreactor scale. After the first fiberization step, the treated chips had a lower CSF with less energy input. With each subsequent refining pass, the energy needed for the treated pulp samples was significantly less than that needed for control Similar percentage energy savings were achieved at all levels of freeness. For the TMP at all process scales, we saw improvements in the strength properties. Figure 3 shows the tensile index as a function of the refining scale. For the treated chips, an improvement in the tensile index is seen at all refining scales.

Often, mills blend the TMP with groundwood and kraft pulp to produce paper with the desired characteristics. We performed such blending studies at the laboratory scale and confirmed our findings on a pilot paper machine. Strength properties improved even when blending the TMP and groundwood with 40 to 50% softwood kraft. Figure 4 shows the tensile index for control and treated pulps as a function of the amount of kraft pulp. The same tensile strength as the control with 50% kraft can be obtained with 10% less kraft (40%) when biotreated TMP is used. In Figure 5, a similar result can be seen for the tear index. Thus, biotreated pulp allows the substitution of less-expensive TMP for kraft

As has been the case throughout biopulping research, a darkening of the chips occurs, resulting in a loss of brightness of the paper (Figure 6), but bleaching will regain most of this *lost* brightness. Figure 6 also shows the resulting brightness of the paper after bleaching and blending with 50% kraft pulp. However, additional optimization of the bleaching steps for biopulping still needs to be done. Also, other fungi, such as *Phlebia subserialis,* are being investigated. These fungi may not darken the wood as much as *C. subvermispora* while still giving energy and improving paper strength.

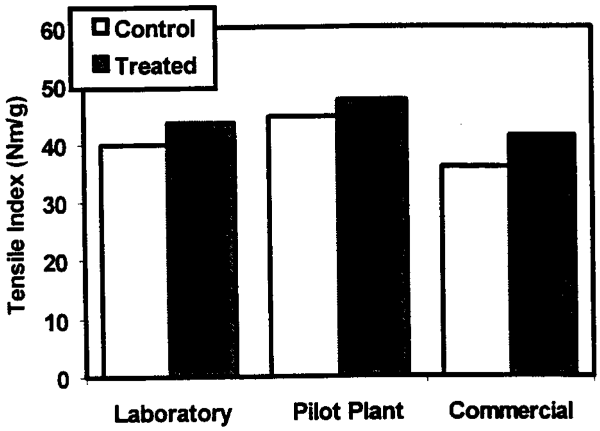

Figure 3. Tensile Index of pulp at different refining scales. All chips were treated in 50-ton outdoor piles.

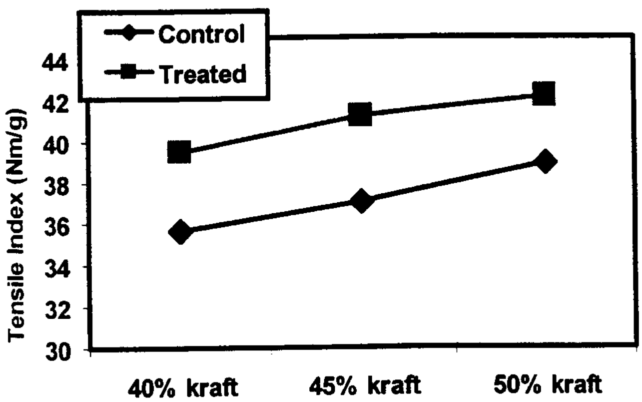

Figure 4. Tensile Index of TMP pulp blended with different levels of kraft pulp.

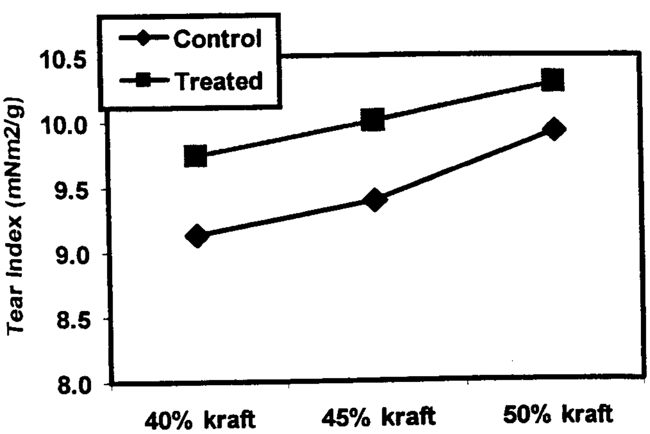

Figure 5. Tear Index of TMP pulps blended with different levels of softwood kraft.

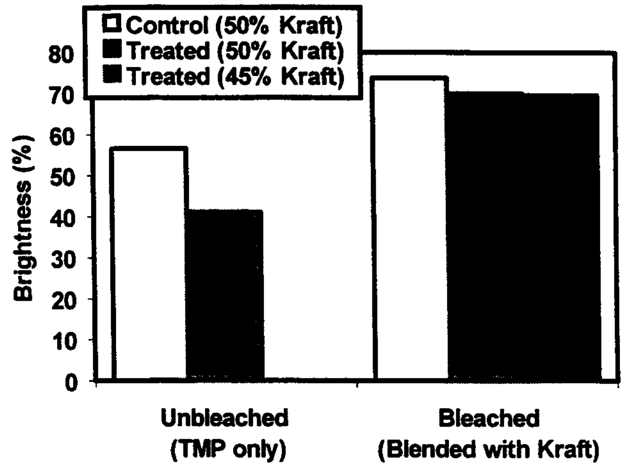

Figure 6. Brightness of unbleached and bleached and blended TMP pulps.

COMMERCIALIZATION ISSUES

All this work is leading to the large-scale treatment of wood chips with a lignin-degrading fungus. In a related development, huge-scale treatment of wood chips with a fungus is being done with the Cartapip™ process developed by the Sandoz Chemicals Co. (now Clariant Corp.) [7]. The Cartapip™ process removes pitch and controls unwanted colored microorganisms that consume bleach chemicals. It differs from our biopulping process in that the Cartapip™ fungus does not attack lignin nor does it reduce electrical energy during biopulping. Also, decontamination of the chips and ventilation of the piles are not practiced with Cartapip™ although these steps would probably lead to better control of the process. The fact that the Cartapip™ process is commercial indicates that mills are able and willing to insert a biotechnological step into their existing operations.

Several issues need to be considered in making the final scale-up to the industrial levels, which can range from 200 to 2,000 tons (dry) or more of chips being processed on a daily basis. The larger scale with a 2-week treatment time would require the routine storage of 28,000 tons of wood for a 2,000 ton per day plant Although some mills do store and manage inventories in these ranges, others may need to make changes in their wood yard operations to take advantage of this technology. Chip rotation has to be controlled with a first-in, first-out policy to maintain a consistent furnish to the pulp mill-as is usually the case.

Another concern is the variation in the fungal treatment in different parts of the piles. As temperatures in the pile vary, so does the efficacy of the biopulping process [6]. Near the edges of the piles, contamination with other microorganisms may increase competition and reduce the biopulping efficacy. In larger piles, where the surface-to-volume ratio is quite low, the outer chips represent only a small fraction of the pile. Furthermore, untreated chips in large industrial piles often heat to more than 50°C because of indigenous microbial growth, leading to variation of the chip quality throughout the pile, with the hotter center of the pile being more affected by this growth. Furthermore, some indigenous organisms also degrade the cellulose in the wood, leading to pulp quality reductions and variation [8]. With biopulping, this suite of naturally-occuring organisms is replaced with a single lignin-targeted fungus that is grown under controlled conditions. The single organism, together with the better control of chip-pile conditions, should lead to a number of quality improvements including a reduction in the pitch content of the wood chips by *C. subvermispora*

On an industrial scale, suitable equipment is available for this technology. For example, chip steaming and decontamination could be easily accomplished in a presteaming vessel similar to that used for Kamyr digesters [9] or in a vertical, pressurized steaming bin. Cooling and inoculation will likely take place at atmospheric pressure. Air conveying will naturally cool the chips during transport, thus requiring the inoculation to be done at the end of the conveying system and before being incubated. Mills using other conveying methods-such as belts or screw conveyers—may require the addition of some type of ventilation. In our pilot-scale work, the cooling and inoculation of the chips were done through ventilation in a screw conveyer. Pile ventilation strategies are given in [6].

Currently, it is estimated that losses of approximately 1% per month of wood occur in outside chip storage systems [8]. This loss is mainly due to the blowing of fines, respiration of the living wood cells, and microorganism activity. The blowing of fines and sawdust as well as microorganism growth can also cause environmental difficulties in the vicinity of the chip piles. Thus, indoor storage should also be considered as an option for incorporating a biopuiping operation into a mill. Enclosing the chip storage operation will significantly reduce blowing dust and other environmental concerns. Furthermore, better control of the environment for the growth of the fungus would be maintained throughout the year. Enclosing the chip storage would also allow the recovery of the heat produced by the fungus for use in conditioning the incoming air. The geometry of the enclosed storage would also tend to reduce the blower costs. These factors could result in substantial energy savings, especially during the winter months in northern climates.

CONCLUSIONS

Our engineering analysis indicates that the biopulping process is technologically feasible and economically beneficial. Previous work on a laboratory-scale basis has culminated in successful larger scale trials. On the pilot scale, methods for the surface decontamination of wood chips, cooling, fungal inoculation, and controlling temperature and moisture content throughout the chip bed have been developed. Our 4- and 40-ton trials in which the decontamination of chips, subsequent cooling, and inoculation occurred sequentially in screw conveyers have given results similar to or better than those obtained in the laboratory. With this information, a complete process flowsheet has been established for the commercial operation of the process. Based on the electrical energy savings alone, the process appears to be economically feasible. The additional benefits—increased throughput and stronger paper—improve the economic picture for this.

A large amount of effort has gone into this research during the past 10 years to bring this technology to commercialization. However, many questions remain unanswered. The most important basic question is the molecular mechanism of biopulping. An understanding of the mechanism will facilitate the optimization of the process for both mechanical and chemical pulping. Furthermore, most of the work has focused on the use of the biotreatment for mechanical pulping and some work has been done for sulfite pulping. The use of biopulping as a pretreatment for the kraft process is still an open research issue. Finally, the use of this technology for other substrates—nonwoody plants such as kenaf, straw, and corn stalks—will be investigated in the future.

ACKNOWLEDGMENTS

We wish to thank Rick Bergman, the staff of the Engineering Mechanics Laboratory, the staff of the Research Facilities Engineering, and the staff of the Pilot Plant at FPL. This work was financially supported by the U.S. Forest Service, the Biopulping Consortium, the Energy Center of Wisconsin, the Wisconsin Alumni Research Foundation, the University of Wisconsin University—Industry Relations Board, and Weaver Industries.

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Oral Presentations
Vol. A

ISBN 1-896742-34-3

PRINTED IN CANADA