PEER REVIEWED

BIOTECHNOLOGY

New technology for papermaking: biopulping economics*

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ABSTRACT

Fungal pretreatment of wood chips prior to mechanical pulping (biopulping) reduces the electrical energy requirements during refining, potentially increases mill throughput, and improves paper strength. An economic analysis of a 600 tons/day thermomechanical pulp (TMP) mill indicates that, based on energy savings alone, the process is economically feasible, and results in an overall savings of about US$ 10 per ton of pulp. Increasing the mill throughput by 20% achieves additional savings of more than US$ 40 per ton of pulp. Replacement of TMP for kraft pulp results in additional savings. For any particular mill, the savings realized will depend on the specific conditions of the mill, utility costs, and current operations. The conclusion is that biopulping is feasible from both an engineering and economic standpoint.

Application:

Biopulping, the treatment of wood chips with a lignin-degrading fungus, reduces the electrical energy requirement for refining while producing a stronger pulp. We quantify the economic benefit of the energy savings, throughput increase, and stronger paper through an analysis of a 600 tons/day mill.

Biopulping is defined as the treatment of wood chips with lignin-degrading fungi prior to pulping. Previous work has demonstrated the efficacy of biopulping for mechanical pulping *(1, 2)*. In this work, it was found that the fungi alter the wood cell walls; this softens the chips and substantially reduces the electrical energy needs for pulping. The treatment also improves paper strength, reduces the pitch content, and reduces the environmental impact of pulping. All these factors increase the suitability of mechanical pulping for many applications. Furthermore, mechanical pulping, with its high yield, is viewed as a way of extending the raw materials.

To be commercialized, the technology must be feasible from both an engineering and economic standpoint. A series of scaleup trails have been previously described in the literature *(3)*. A companion paper describes the semicommercial scaleup trials performed at the USDA Forest Service, Forest Products Laboratory (FPL), with results similar to those obtained on the laboratory scale *(4)*. This paper deals with the economic feasibility of the process using an analysis of a 600 tons/day thermomechanical pulp (TMP) mill. For this analysis, three benefits of biopulping were considered: energy reduction, increased mill throughput, and improved strength properties. Economic values were assigned to each.

PROCESS OVERVIEW

Figure 1 is a conceptual overview of the biotreatment process in relation to existing woodyard operations. Wood is harvested and transported to the mill site for debarking, chipping, and screening. At this point, the first change in the normal operation is made. Chips are decontaminated by steaming, maintaining a high temperature for a sufficient time to decontaminate the wood chip surfaces and to allow the fungus to grow effectively. After decontamination, the chips are cooled sufficiently so that the fungus can be applied. The chips are then placed in piles that are ventilated to maintain the proper temperature, humidity, and moisture content for fungal growth and subsequent biopulping. The retention time in the pile is 1-4 weeks.

ANALYSIS PARAMETERS

This analysis is based on a 600-tons/day mill producing bleached TMP. **Table I** summarizes the cost assumptions for the analysis. Work by Ford and Sharman *(5)* serves as the basis for some of these values. Of course, many of these parameters are quite site specific and subject to variability. The values of kraft and TMP are market dependent and highly volatile. For example, during the past 16 years, the price of bleached chemithermomechanical pulp (BCTMP) has ranged from US$ 320 to US$ 830/ton, with the average being US$ 550/ton. In the same manner, the price of kraft pulp has also fluctuated, with an average of US$ 700/ton being used in this study *(6, 7)*.

The capital costs for biopulping will vary according to the land and equipment that are currently available and the type of system installed. In addition to the treatment equipment needed for biopulping, these costs include land, 10 days of chip inventory, and storage for the chips.

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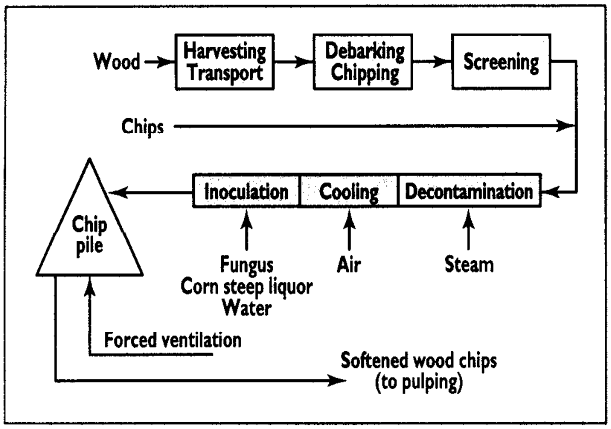


1. Overview of the biopulping process, showing how the biotreatment process fits into the wood-handling system of an existing mill

Assumption	Value
Utility and raw material costs	
Electricity, US$/kW·h	0.05
Steam, US$/10^6 Btu	2.00
Wood, US$/o.d. ton	60.00
Bleaching chemicals, US$/ton o.d. pulp	60.00
Kraft pulp, US$/ton o.d. pulp	700.00
TMP, US$/ton o.d. pulp	550.00
Biopulping costs	
Capital costs, US$ (for 600 tons/day of pulp)	5.7×10^6
Operating costs, US$/ton o.d. pulp	9.44
Process operations	
Production, days/year	350
Refining energy, kW·h/ton	2000
TMP yield, %	95
Treatment yield, %	98
Additional bleaching, %	15
TMP manufacturing costs	
Labor, US$/ton o.d. pulp	15.00
Maintenance and operational supplies, US$/ton o.d. pulp	30.00
Tax and insurance, US$/ton o.d. pulp	8.00
Overhead, US$/ton o.d. pulp	6.00

I. Cost assumptions for biopulping economic analysis

Overall, we envision a silo or other enclosed storage system with a capacity based on the treatment time. The number of silos used and the configuration of these silos would depend on the availability of the land and the layout of the mill and woodyard. Belt conveyors are probably the most likely candidate for moving the chips to and from the silos.

In addition, the silos need to be ventilated to remove the heat produced by the fungus. The ventilation would be provided by a series of blowers and preconditioning systems, with each silo serviced by several blowers. This allows a certain amount of redundancy in the design of the equipment. For greatest energy efficiency, especially in the northern climates, the air should be recovered from the top of the silos and the heat recovered.

For such a system, the total capital costs are estimated to be US$ 5.7 million (Table I). The additional operating cost for the treatment equipment, ventilation blowers, chip handling, and inoculum is estimated to be US$ 9.44 per ton of pulp produced. This value is dependent on the costs of electricity and steam. The mill is assumed to operate 350 days/year, with a 95% yield through the refining process. Additional operating parameters, including costs for the TMP operation, are given in Table I.

ECONOMIC BENEFITS CONSIDERED

The economic benefits of the biopulping process have been evaluated based on the process studies and engineering data obtained to date and are a result of the following effects.

Refiner energy savings

As previously discussed, energy savings at the refiner were used as the primary criterion for the effectiveness of biopulping. Thus, this aspect of the savings has been well quantified experimentally. For a 2 week process, the savings should be a minimum of 25% under the worst-case conditions of wood species and minimal process control, whereas up to nearly 40% can be achieved under some circumstances. In addition, utility rates can vary substantially with the time of day or magnitude of the peak usage. In these circumstances, the cost benefits of refiner load reduction could be even greater.

Process debottlenecking

The reduction in power requirement has an additional consequence that could be of great significance for some mills. Mills that are currently throughput-limited as a result of refiner capacity may assign substantial value to the debottlenecking effect that the fungal treatment will provide. Of course, even though the refiner is the rate-limiting step, additional capital may be needed to fully realize the throughput increases allowed by biopulping.

Furnish blend advantages

The biopulping process results in pulps that have improved strength properties. This is advantageous in situations where the product is a blend of mechanical pulps and kraft pulps. The kraft component is used to impart strength and is more expensive than the mechanical pulps. The improved strength of the biomechanical pulps would allow the required strength of the blend to be achieved with a lower percentage of kraft pulp. Of course, the exact blend in any application will need to be optimized to ensure that all product specifications are met. This aspect could also have a debottlenecking effect in mills that are kraft production-limited, because the total blended pulp rates can be greater for a given production rate of the kraft pulp component.

Other advantages

The biopulping process itself is benign environmentally. Only benign materials are used, and additional waste streams are not generated. Furthermore, the 2 week treatment with *C. subvermispora* significantly reduces the amount of pitch in the wood chips. Biopulping chip storage is carefully contained. These features are in addition to the substantial amount of energy that is conserved by the process. Other economic benefits could be realized, including the lower operating costs from an automatic system compared with a manual (bulldozer) system, better inventory control, and enclosed piles being less susceptible to environmental factors such as winter, rain, and wind.

ECONOMIC SCENARIOS

These advantages must be compared with the costs of implementing and operating the biopulping process. A preliminary assessment was conducted for a 2 week treatment and a flat-pile geometry operating in a northern climate. A southern climate scenario would show somewhat lower costs because of reductions in containment and air-handling requirements. **Table II** summarizes the three scenarios investigated in this assessment. Each scenario assumed a base TMP production of 600 tons/day. In scenario 3, the TMP was blended with equal parts of kraft pulp for a total production of 1200 tons/day. For all three scenarios, biopulping resulted in an energy reduction at the refiner of 30%. For scenario 2, a 20% increase in throughput was realized. For scenario 3, a 10% throughput increase was achieved, with the additional TMP production reducing the amount of kraft needed.

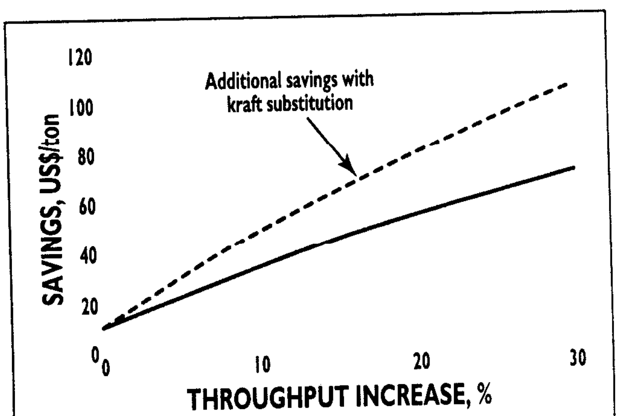
Table III shows the economic analysis for scenario 1, where a 30% energy reduction was realized. Comparing the base case with scenario 1, the annual energy costs decreased from US$ 21.00 million to US$ 14.70 million. After taking into account the additional costs for the wood and biopulping treatment, an annual savings of US$ 2.14 million was achieved. This is a savings of US$ 10.21 per ton of pulp produced. Under different scenarios and assumptions for utility costs, equipment needs, and operating costs, the net savings can reach more than US$ 26 per ton of pulp produced, with an estimated capital investment of US$ 5.7 million. Simple rates of return can range from 25% to 95%, resulting in a payback of 1.0-3.9 years. Using typical values for the parameters of the analysis, a savings of US$ 10.21 per ton of pulp can be expected after the cost of capital with a simple payback of 2.66 years.

		SCENARIO	
[illegible]	[illegible]	[illegible]	3
Base process capacity, tons/day	600	600	1200
TMP production, tons/day	600	600	600
Kraft pulp requirements, tons/day	0	0	600
Energy savings per unit weight, %	30	30	30
Production increase, %	0	20	10
TMP substitution for kraft, %	0	0	5

II. Process capacities and biopulping effects for economic scenarios

		SCENARIO	
Parameter	Base	1	2
TMP production, tons/day	600	600	720
Biopulping capital costs, 10^6 US$	-	5.7	6.8
Manufacturing costs			
Energy, 10^6 US$/year	21.00	14.70	17.64
Wood, 10^6 US$/year	13.26	13.55	16.26
Bleaching chemicals, 10^6 US$/year	12.60	14.49	17.39
Biopulping treatment, 10^6 US$/year	-	1.98	2.38
Other, 10^6 US$/year	12.39	12.39	14.87
Total, 10^6 US$/year	59.25	57.11	68.53
Product value, 10^6 US$/year	115.50	115.50	138.60
Marginal profit, 10^6 US$/year	-	2.14	13.82
Simple payback period, years	-	2.66	0.49
Savings, US$/ton	-	10.21	54.85

III. Economic analysis for scenarios 1 and 2



2. Effect of debottlenecking the process through biopulping for a 600 tons/day TMP plant. The solid line shows the savings per ton as a function of the throughput increase. The dotted line demonstrates the additional savings that can be realized when the added TMP production is used as a replacement for kraft pulp.

Parameter	SCENARIO Base	3
Total production, tons/day	1200	1200
TMP production, tons/day	600	660
Kraft pulp requirements, tons/day	600	540
Biopulping capital costs, 10^6 US$	-	6.3
Manufacturing costs		
Energy, 10^6 US$/year	21.00	16.17
Wood, 10^6 US$/year	13.26	14.90
Bleaching chemicals, 10^6 US$/year	12.60	15.94
Biopulping treatment, 10^6 US$/year	-	2.18
Kraft pulp, 10^6 US$/year	147.00	132.30
Other, 10^6 US$/year	12.39	13.63
Total, 10^6 US$/year	206.25	195.12
Product value, 10^6 US$/year	262.50	262.50
Marginal profit, 10^6 US$/year	-	11.13
Simple payback period, years	-	0.56
Savings, US$/ton	-	48.19

IV. Economic analysis for scenario 3

It is important to remember that this assessment considers only the economic benefit of energy savings.The additional advantages of debottlenecking can be considerable. Mills that are refiner limited can experience throughput increases of up to 30% from the reduction in refining energy by running the refiners to a constant total power load.

Table III also shows the analysis when a throughput increase is achieved. In scenario 2, production increased by 20% to 720 tons/day. Comparing this with the base case, the annual energy costs decreased from US$ 21.00 million to US$ 17.64 million, even with the increased production. As a result of the greater production, the other costs increased proportionally, but the total annual product value increased by more than US$ 23 million. The total additional profit achieved through biopulping was US$ 13.82 million, which translates to more than US$ 50/ton and a payback of about 6 months.

Figure 2 shows the savings as a function of the throughput increase.The savings are from the increase in the production using the same capital. The solid line shows the savings as a function of the throughput increase. Even a modest throughput increase of 10%, coupled with the energy savings of 30%, results in a payback of less than 1 year.At a 20% throughput increase, the savings are more than US$ 50 per ton of pulp. Even if additional capital expenditures are needed, throughput increases of 20% result in a payback of less than 1 year. These values depend on the value of the product, in this case TMP, which has ranged from less than US$ 400 per ton of pulp to more than US$ 800 per ton of pulp in the past 15 years *(6, 7)*. An average value of US$ 550 per ton of pulp was used in this analysis.

Many mills blend mechanical pulps and kraft pulps to achieve the desired optical and strength properties. The biotreated pulp, being stronger, may require less kraft pulp to meet the product specifications. **Table IV** summarizes the economic analysis for scenario 3 in which a mill is blending TMP with purchased kraft. There was a 10% increase in the TMP production; this was used to replace kraft in the product. The total energy costs decreased from US$ 21.00 million to US$ 16.17 million; kraft costs decreased by almost US$ 15 million/year. Overall, US$ 11.13 million was saved per year; this is equivalent to US$ 48.19 per ton of TMP produced. The payback period of this technology is slightly more than 6 months for this scenario. Figure 2 also shows the effect of additional kraft substitution on the savings for incorporating biopulping into the mill. The dotted line represents the total savings on a per ton basis that are realized when the additional TMP is used as a substitution for kraft. As shown, for a 10% increase in production, an additional savings of US$ 13/ton is achieved through this substitution.

CONCLUSIONS

Our economic analyses indicate that the biopulping process is technologically feasible and economically beneficial. Under the assumptions detailed here, savings of about US$ 10 per ton of pulp were obtained. Even greater benefits can be realized when the other benefits of biopulping, such as increased throughput and substitution for kraft, are considered. Throughput increases brought the simple payback period of the process to less than 1 year. Substituting this increased production for kraft pulp in blended products resulted in additional savings. As this analysis shows, biopulping can produce substantial economic savings for TMP producers.

This preliminary analysis is subject to appropriate qualifications. The capital costs are subject to some variability, in particular the costs associated with integrating the new facility into an existing site. The additional advantages of biopulping, including the environmental benefits and pitch reduction, have not been quantified in this paper. Finally, much of this analysis is site specific; the results depend on the operating conditions at the particular mill that is considering incorporating biopulping into its operations. **TJ**

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We thank David F. Shipley of the Energy Center of Wisconsin, Gary Myers of the Forest Products Laboratory, and Rick Bergman of the University of Wisconsin for reviewing this manuscript prior to publication, and we thank Jean Livingston for *editing the final manuscript. We also thank T. Kent Kirk and MaSood Akhtar for their help and advice. Many others played an important role in this research, including Eric Horn, Michael Lentz, Rick Bergman, the staff of the Engineering Mechanics Laboratory, the staff of Research Facilities Engineering, and the staff of the pilot plant. This work was financially supported by the USDA Forest Service, the Biopulping Consortium, the Energy Center of Wisconsin, the Wisconsin Alumni Research Foundation, and the University of Wisconsin University–Industry Relations Board.*

Received for review April 21, 1997.
Revised Aug. 20, 1997.
Accepted Sept. 13, 1997.

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