BIOMECHANICAL PULPING OF EUCALYPTUS WOOD CHIPS

André Ferraz[1], Anderson Guerra[1], Régis Mendonça[2] and Paulo César Pavan[3]
1. Escola de Engenharia de Lorena, Universidade de São Paulo, CP 116, 12602-810 Lorena, SP, Brasil.
2. Centro de Biotecnologia, Facultad de Ciencias Forestales, Universidad de Concepción, Concepción, Chile
3. Melhoramentos Papéis, Ltda, Caieiras, SP, Brasil

Abstract

The pulp and paper industry utilizes mechanical or chemical pulping or a combination of both methods to produce pulps of desired characteristics. Although high pulp yields and superior optical properties make mechanical and thermomechanical pulps attractive to the paper industry, high-energy consumption, and low paper strength are major shortcomings of these pulping processes. During the last decades, new technologies have been developed to overcome these problems. Among them, fungal treatment of wood chips prior to chemical or mechanical pulping (biopulping) has shown promising results. In mechanical pulping, wood biodegradation allows for pulp strengthening and energy savings. The present review would up-date information on biomechanical pulping focusing on the recent achievements obtained in a biopulping pilot plant. *Eucalyptus grandis* wood chips have been biotreated with *Ceriporiopsis subvermispora* on lab-scale and on a biopulping pilot plant. When biotreated wood samples were refined at mill scale, energy savings varying from 18% to 27% were obtained. Unfortunately, biomechanical pulps are darker than control pulps. However, alkaline washing and alkaline-H_2O_2 bleaching easily improves brightness of the pulps. In general, bleached biopulps were more stable to thermal-reversion, while the stability to photo-reversion was similar to that of control pulps.

Introduction

Biopulping is the fungal pretreatment of wood chips, designed as a solid-state fermentation process, for production of mechanical or chemical pulp. The concept of biopulping is based on the ability of some white-rot fungi to colonize and degrade selectively lignin in wood thereby leaving cellulose relatively intact. There are certain process conditions and design requirements necessary to gain a biopulping effect (1). Biopulping can be carried out in bioreactors of different types, including open chip piles, depending on the requirements of the particular microorganism would have for optimal results. Temperature has to be controlled at the level of the temperature optimum for the particular fungal strain used in biopulping. Aeration with humidified air is necessary in biopulping to provide oxygen for the fungal metabolism but also to maintain adequate humidity levels within the chip pile. High moisture content (at about the fiber saturation point) should be kept in wood chips during biopulping to ensure an optimal colonization and penetration of fungal hyphae. The degree of asepsis should be controlled or monitored to ensure a preferential lignin degradation by the particular fungal strain used depending on its resistance against contamination and ability to compete with the microbial biota available in the wood chips. The time of fungal treatment needs also to be optimized, as the selectivity of lignin degradation tends to decline with increase of incubation periods (2).

Biomechanical pulping is directed towards production of mechanical pulps for papermaking with decreased energy requirements for fiberizing and refining and improved strength properties. This process can save energy and increase paper strength properties as compared to the traditional mechanical pulping accomplished without use of fungi. In a typical disk refining of biotreated wood chips, energy required to attain a desired fibrillation level is reduced as illustrated in Figure 1. Fibers prepared under this biomechanical pulping usually presents better strength properties as illustrated in Table 1.

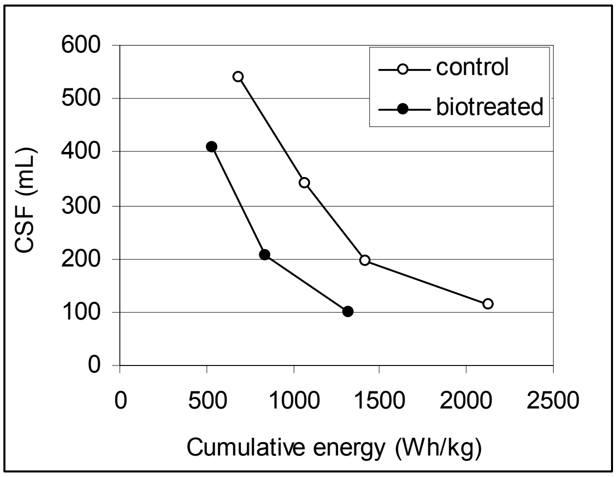

Figure 1 – Energy required to fibrillate untreated and biotreated wood chips by mechanical processing in disk refiners. Data obtained from *Pinus taeda* wood chips biotreated for 15 days with *Ceriporiopsis subvermispora*.

Table 1 - Strength properties of 100mL-CSF mechanical pulps prepared from *P. taeda*

Pulp property	Control	Biotreated
Tensile index (N.m/g)	15.6	24.6
Tear index (mN.m^2/g)	2.8	5.1
Burst index (kN/g)	0.6	1.2

Bio-TMP and bio-CTMP have been evaluated for pulp production from loblolly pine and lodgepole pine softwoods (1). In these cases, energy savings during refining were similar to the ones observed in the RMP process. However, the pulps' strength properties depended on the fungal strain used in the biotreatment and the pulping process. In general, pulp strength properties were diminished in bio-TMP and increased in bio-CTMP. A recent study evaluating bio-TMP of *Eucalyptus grandis* hardwood presented encouraging results concerning both energy savings and pulp-strength improvements (3). Compiled data clearly demonstrated that the wood and the fungal species as well as pre- and post-refining conditions affect the overall process, and optimization for each case is necessary.

Another key aspect is that biopulps are darker than control pulps (1,4). In a pioneer study on the biopulp bleachability and brightness stability, Sykes (4) reported that although bio-RMP aspen pulps have a lower initial brightness, high brightness levels could be attained during bleaching using only slightly higher hydrogen peroxide dosages. Control RMP pulps required 2% H_2O_2 to increase brightness from 62% to 80%, while 3% H_2O_2 was necessary to improve bio-RMP pulps from 50% to 76%. Brightness stability for the aspen biopulps was only slightly lower than for the control pulps.

TMP and CTMP processing of *E grandis* biotreated on a 50-ton pilot plant

E. grandis wood chips were biotreated with *C. subvermispora* for 60 days in a 45-ton chip pile mounted on a biopulping pilot plant (5). Wood weight loss owing to the biotreatment was estimated as 9% based on basic wood density values of untreated and biotreated samples (413 kg/m^3 and 376 kg/m^3, respectively). Biotreated wood samples and undecayed controls were refined at mill scale by using a two-stage thermomechanical pulping process. Net energy consumption in the first and second disk refiners, as well as the total energy consumed in both stages is showed in Figure 2. The mill refiners operate at experimental conditions for around 14h receiving control wood chips under TMP refining conditions (1st slab in Figure 2 – Control TMP), biotreated wood chips under TMP (2nd slab in Figure 2 – Bio-TMP), biotreated wood chips under CTMP (3rd slab in Figure 2 – Bio-CTMP), and finally control wood chips under CTMP (4th slab in Figure 2 – Bio-TMP).

The average energy consumption for producing TMP pulps with 450-470 CSF was 913 kWh/ton and 745 kWh/ton for control and biotreated wood chips, respectively (18% of energy saving in the pulping process). In the case of CTMP pulps with similar CSF, energy consumption was 1038 kWh/ton and 756 kWh/ton for control and biotreated wood chips, respectively (27% of energy saving in the pulping process). Energy savings during mechanical pulping of wood pretreated with *C. subvermispora* is a well-known benefit of biopulping (1). Data reported here for the biotreatment on a pilot plant and the refining at mill scale confirms laboratory-obtained data for biopulping of *E. grandis* wood (3). Unfortunately, the bio-thermomechanical pulp (bio-TMP) was darker than control-TMP with a reduction of 16 brightness points in bio-TMP (44% ISO and 60% ISO for bio- and control-TMP, respectively). Sykes (4), using aspen wood biotreated by *Phanerochaete chrysosporium* followed by refiner mechanical pulping, had also demonstrated that biopulps were darker than control pulps. However, the sources of the darkening observed in biopulps remain unclear.

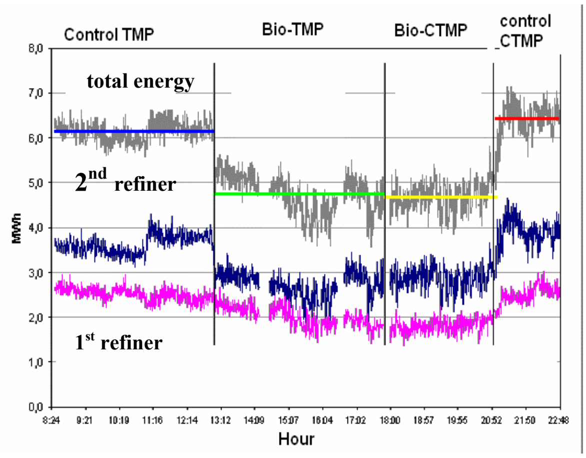

Figure 2 – Energy consumption on disk refiners (MWh) during TMP and CTMP processing of biotreaated *E. grandis* wood chips.

Bio-TMP and control-TMP were submitted to peroxide bleaching in order to evaluate their respective bleachabilities. The control reaction, in which DTPA-treated biopulp was soaked in alkali (pH 11) and then washed in water, showed an increase in initial bio-TMP brightness from 44% to 55 % ISO. Conversely, the same treatment had a negligible bleaching effect on the control-TMP (Figure 3). This result indicates that a fraction of the chromophores present in bio-pulps are easily removable by a simple alkaline treatment.

At identical peroxide loads, Bio-TMP gained more bleaching points than the control-pulps. However, the final brightness of the biopulps was always slightly lower than the brightness of the control pulps, regardless of the peroxide charge applied. For one-stage bleaching, with 5% Hydrogen peroxide, brightness values were 70% and 72% for bio-TMP and control pulps, respectively. Higher peroxide dosages had negligible effect on the final brightness of both pulps (Figure 3).

Photo- and thermal-reversion tests were performed on bleached TMP and bio-TMP. Bio-TMP was more stable during the first hours of photo yellowing when compared to control-TMP (Figure 4A). For example, bleached bio-TMP with 63% initial brightness lost 18 brightness points after 1 hour of photo-reversion, while control-TMP with the same initial brightness lost 24 points during the same period. However, prolonged photo-reversion resulted in similar brightness values for both pulps.

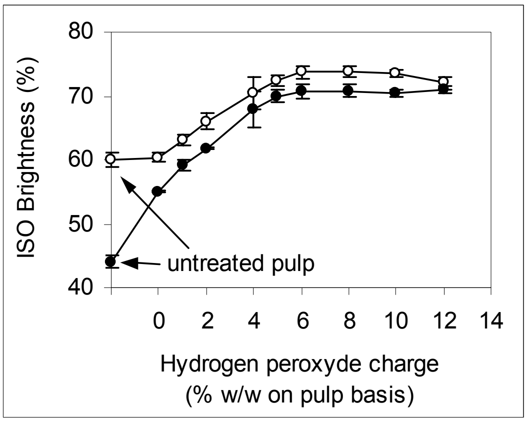

Figure 3 - Bleaching responses of thermomechanical pulps prepared from untreated (open circles) and *C. subvermispora*-biotreated *E. grandis* wood chips (black-filled circles).

Studies on thermal-reversion of brightness in both control and bio-TMP pulps showed that bio-TMP lost less brightness points than control-TMP throughout the thermal reversion experiments (Figure 4B).

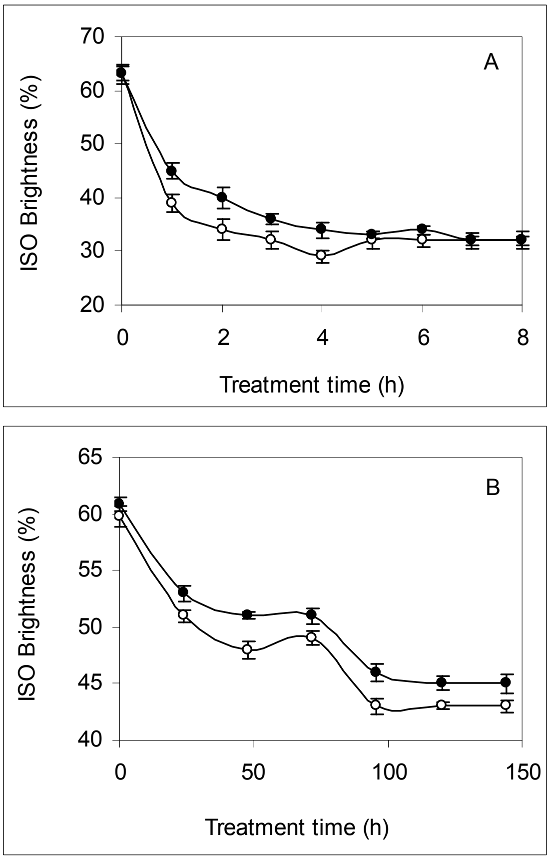

Figure 4 - Photo- (A) and thermal-reversion (B) of brightness in peroxide-bleached thermomechanical pulps prepared from untreated (open circles) and *C. subvermispora*-biotreated *E. grandis* wood chips (black filled circles).

Plots of brightness reversion as a function of initial brightness, permitted a broad view of the brightness stability of the studied pulps (Figure 5). Based on these plots, it is clear that the brightness stability of bleached control and bio-TMP to photo-reversion were similar, while bio-TMP was more stable to thermal-reversion than control-TMP.

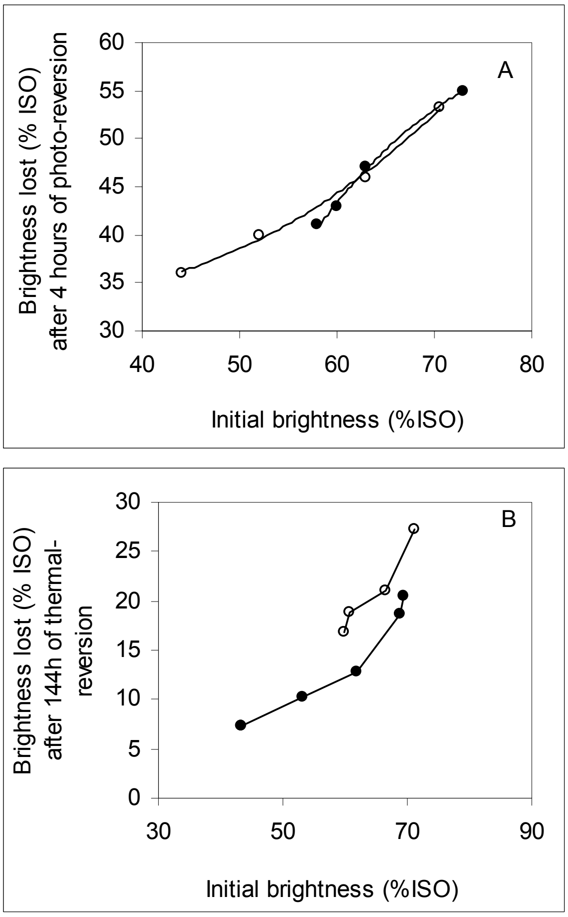

Figure 5 - Photo- (A) and thermal-reversion (B) of brightness as a function of initial brightness levels in peroxide-bleached thermomechanical pulps prepared from untreated (open circles) and *C. subvermispora*-biotreated *E. grandis* wood chips (black filled circles).

Bio-CTMP pulps from *E. grandis*

Industrially produced bio-CTMP pulps were not evaluated in details to date, but lab-prepared pulps from *E. grandis* biotreated in a 100-L bioreactor for 15 days were studied (6). In this case, wood biotreatment was characteristic of a selective biodelignification (7.6 ± 0.2% and 0.3 ± 0.2% of lignin and glucan losses, respectively) with concomitant extractive removal (17.7 ± 0.2%). Biotreated samples and non-inoculated controls were pre-cooked in alkaline sulfite and post-refined in a Jokro mill. This CTMP pulping of untreated and 15-day biotreated *E. grandis* wood chips was performed in two steps: a mild cooking in alkaline sulfite liquor followed by fiberization and refining of the cooked wood chips in a Jokro mill. Total pulp yield, amount of rejected pulp, and freeness pulp levels are presented in Table 2. Total pulp yield varied from 87% to 76% as a function of the beating time. The biopulps presented lower total pulp yield than the control pulps. On the other hand, the biopulps fibrillated more rapid and contained lower amounts of rejects. Rapid fibrillation of the biopulps could represent increases in the process throughput or energy savings during the refining step, since a reduced beating time is necessary to achieve a desired freeness level. For example, to achieve 400 mL of freeness, the control pulp required 125 min of beating, while the biopulp required only 95 min (beating time reduced by 24%). Akhtar et al. (1), using loblolly pine biotreated by *C. subvermispora*, had also demonstrated that the refining steps enhanced during production of alkaline hydrogen peroxide- and alkaline sodium sulfite-CTMP pulps, resulting in energy savings and pulp-strength improvements during the processes.

Table 2 - Pulping yield, amount of rejects and degree of fibrillation of CTMP pulps prepared from untreated and biotreated *Eucalyptus grandis* wood chips.

Beating time (min)	Untreated *E. grandis*			Biotread *E. grandis*		
	Total yield (%)	Rejects (%)	CSF (mL)	Total yield (%)	Rejects (%)	CSF (mL)
30	86.8	33.6	708	84.9	30.4	702
60	84.3	10.0	638	83.2	7.4	622
90	83.4	2.8	504	79.5	1.2	424
120	80.8	0	432	77.6	0	323
135	78.3	0	323	76.0	0	253

Strength properties of pulps prepared from 15-day biotreated samples are shown in Figure 6. Biopulp tensile indexes increased significantly (+24.3% and + 6.2% at 630 mL and 430 mL of freeness, respectively), while tear strength improved only for pulps with freeness values below 500 mL (+25% at 320 mL of freeness). Burst indexes were similar for both pulps. Tensile *versus* tear graphs (Figure 6D) clearly indicated that the biopulps presented better strength properties than the control pulps, since higher tensile indexes were obtained for the entire range of tear indexes.

Scott et al. (3) evaluating a two-stage TMP process for biotreated *E. grandis* observed that energy saving for producing pulps with 400 mL of freeness was 17%, and bio-TMP pulps presented doubled tensile and tear indexes when compared to control pulps. This improved strength of biopulps allows the preparation of pulp blends for tissue paper production using 80% bio-TMP and only 20% bleached kraft pulp instead the typical 50%-50% used with conventional TMP pulps. In the case of CMP pulps of *E. grandis*, increases in the strength properties were not as significant as observed for TMP. For comparison purposes, bio-CTMP pulps with 400 mL of freeness presented tensile and tear indexes improved by 6% and 13%, respectively (Figure 6).

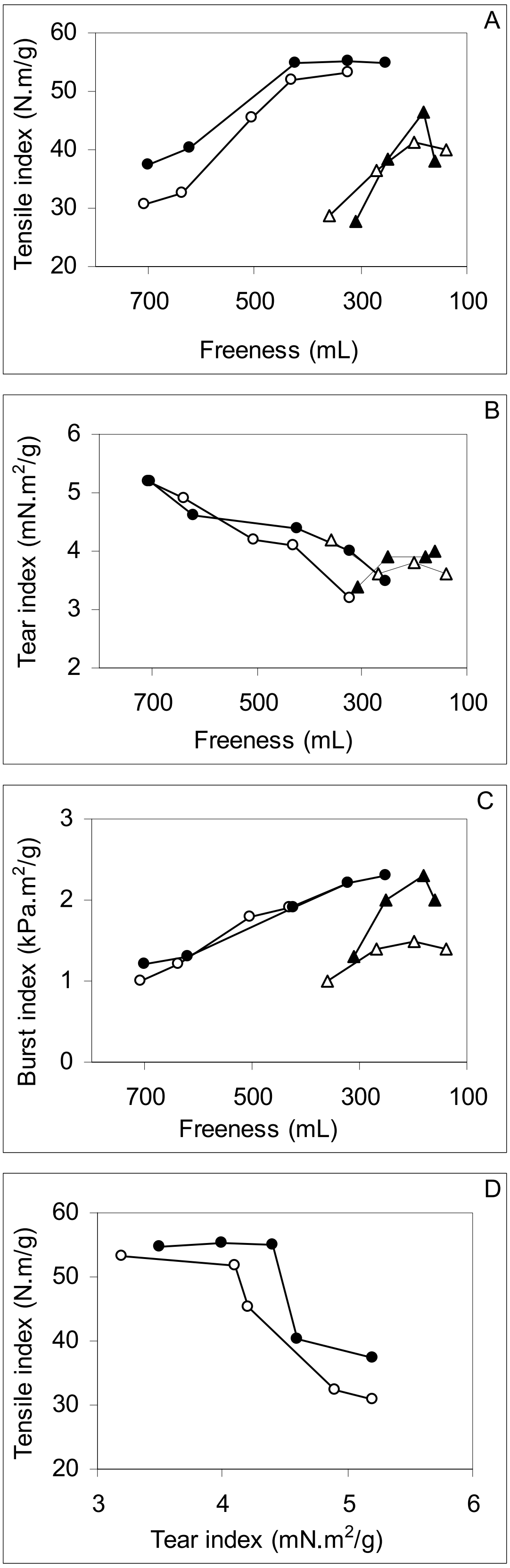

Figure 6 - Strength properties of CTMP pulps prepared from untreated (open symbols) and biotreated (black filled symbols) *Eucalyptus grandis* wood chips. Circles are related to unbleached pulps. Triangles are related to hydrogen peroxide-bleached pulps.

Bleachability and brightness stability of CTMP pulps

Unbleached biopulps were slightly darker than the control pulps (initial brightness values of 22.7% and 23.7%, respectively). Initial brightness values of such pulps were very low in comparison to commercially available unbleached alkaline sulfite-CTMP pulps from *E. grandis* (56% ISO for pulps from a Brazilian pulp mill). Inefficient washing of the laboratory-prepared pulps as well as autoclaving of the wood chips could contribute to the initial low brightness levels. Only the treatment with DTPA and alkaline washing without hydrogen peroxide increased initial pulp brightness to 36.7% and 35.2% for control and biopulps, respectively. The two-step pulping process also produces pulp darkening since mechanical refining is preceded by a long period of impregnation in autoclave. Under industrial conditions, impregnation and refining are very quick due to the use of efficient disk refiners. Still, laboratory-prepared control and biopulps are more suitable for comparison purposes since a complete control of process variables can be assured in their preparation.

The bleachability of the pulps was evaluated according to a standard 2^4-experimental design. The variables appraised were peroxide load, consistency, temperature and bleaching time. Analysis of variance performed on obtained data indicated that, only the peroxide load affected significantly the final brightness of both the control and biopulps. To further evaluate the effect of the peroxide load on pulp brightness, additional bleaching experiments were conducted with increasingly peroxide dosages. Although control and biopulps presented low initial brightness values, a single bleaching step with 8% hydrogen peroxide was enough to increase the brightness values by 17 points (Figure 7). At low peroxide load, the brightness increase in biopulps was lower than in the control pulps. Bleaching with 1% H_2O_2 increased 8 points of brightness in control pulps while biopulps gained only 4 points. On the other hand, the bleachability of both pulps was similar for peroxide loads higher than 2%, reaching maximal brightness values of 52% ISO with 8% H_2O_2. Higher peroxide levels had a negligible effect on final pulp brightness. One-stage-bleached pulps were washed and submitted to a second peroxide bleaching step with 8% H_2O_2, where the maximal brightness achieved was 59.7 ± 0.8 % and 60.5 ± 0.4 % for control and biopulps, respectively. Mechanical pulps of *E. grandis* wood are usually difficult to bleach to high brightness levels. For example, bleaching of industrially prepared TMP pulps (using a similar optimization procedure) showed that hydrogen peroxide loads of 8% were necessary to increase initial brightness values from 59% to 75-80%. Similar pulps prepared from aspen wood gained 15 points in brightness, reaching 75-80% with a load of only 3% of hydrogen peroxide (11). After two-stage bleaching, the strength properties of the control and biopulps were almost the same while burst indexes were slightly higher in biopulps (Figure 6).

The brightness stability of bleached CTMP and bio-CTMP pulps was determined by submitting samples of different initial brightness levels to accelerated thermal- and photo- aging tests. Figure 7 illustrates time courses of accelerated photo and thermal brightness reversion for the pulps. After exposing the pulp handsheet for one hour to light, the brightness values decreased rapidly, stabilizing after 4 hours of photo aging. In a similar way, thermal reversion of brightness for these pulps was rapid during the first day of thermal treatment (Figure 7B). Figure 8 shows the brightness reversion (brightness points lost) plotted against initial brightness levels of several of the control and biopulps exposed to photo- and thermal- aging tests. It is possible to conclude that the brightness stability for bleached control and bio-CTMP pulps to photo and thermal aging was very similar.

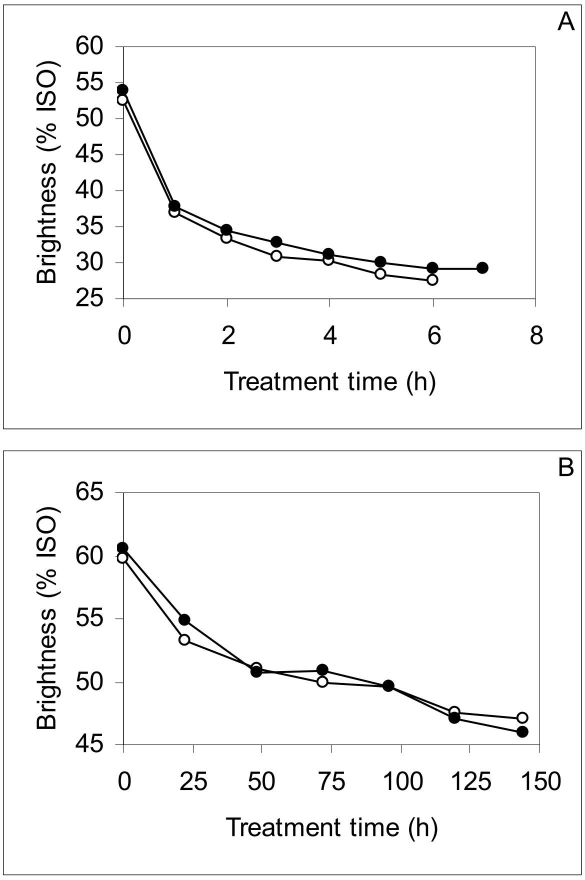

Figure 7 - Photo- (A) and thermal-reversion (B) of brightness in H_2O_2-bleached CMP pulps prepared from untreated (open circles) and biotreated (black filled circles) *Eucalyptus grandis* wood chips.

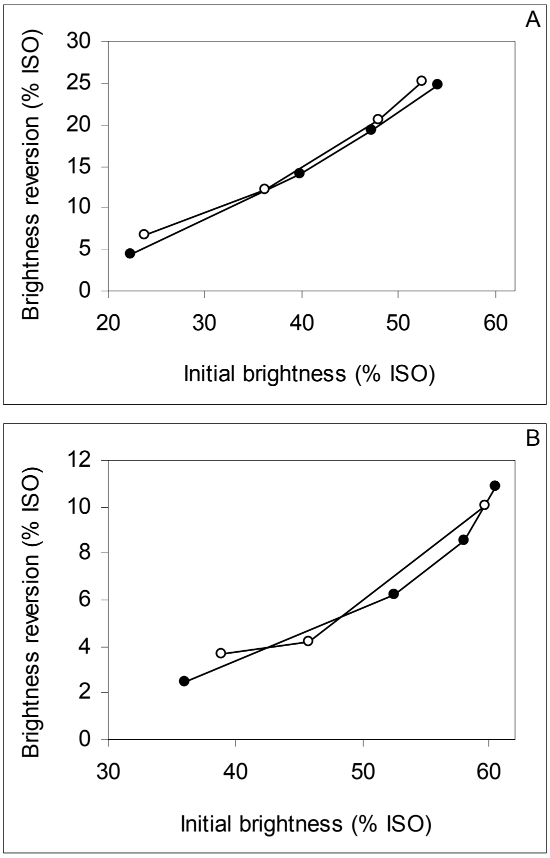

Figure 8 - Brightness reversion as a function of initial brightness levels in H_2O_2-bleached CMP pulps prepared from untreated (open circles) and biotreated (black filled circles) *Eucalyptus grandis* wood chips. Photo- (A) and thermal-reversion (B).

Acknowledgements: Financial support form FAPESP, CNPq, CAPES and Melhoramentos Papéis Ltd. is acknowledged.

References

1 Akhtar, M., Blanchette, R.A., Myers, G. and Kirk T.K. - An Overview of Biomechanical Pulping Research**,** In Young R. and Akhtar M (ed.) Environmentally Friendly Technologies for the Pulp and Paper Industry, Wiley, NY, p. 301 (1998).

2. Guerra, A, Mendonça, R, and Ferraz, A. - Molecular weight distribution of wood components extracted from *Pinus taeda* biotreated by *Ceriporiopsis subvermispora*, *Enzyme Microbial Technol.* **33**:12(2003).

3. Scott, G.M., Akhtar, M., Swaney, R.E. and Houtman, C.J. - Recent developments in biopulping technology at Madison, WI**,** In Viikari L. and Lantto R (ed.) Progress in Biotechnology 21 – Biotechnology in the pulp and paper industry: 8th ICBPPI, Elsevier, Amsterdan, p.61(2002).

4 Sykes, M. - Bleaching and brightness stability of aspen biomechanical pulps, *Tappi J.* **76(11)**:121(1993).

5. Guerra, A., Pavan, P. C. and Ferraz, A. Bleaching, brightness stability and chemical characteristics of *Eucalyptus grandis*-bio-TMP pulps prepared in a biopulping pilot plant. *Appita J.*, **59**:412(2006).

6. Guerra, A., Mendonça, R. and Ferraz, A. - Bio-chemimechanical pulps from *Eucalyptus grandis*: strength properties, bleaching, and brightness stability, *J. Wood Chem. Technol.* **25**:1(2005).