DEVELOPING THE EUCALYPTUS WOOD QUALITY FOR DISSOLVING PULP USING TREE BREEDING

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Abstract

The potential of the Eucalyptus for production of dissolving pulps has been developed very rapidly in the last years, specially for production of special grades like ethers, textile filaments, and lyocell.

The short and thick fibers of Eucalyptus provide high specific surface of the fibre material, leading to high affinity to polar solvents. Another feature of Solucell, the dissolving pulp of Klabin Bacell, is its resistance to chemical degradation, compared to other high purity grade pulps. The designed products present superior reactivity, due to their morphological and chemical attributes. With Solucell it is possible to obtain a high yield in the viscose production and very good tenacity values.

This paper focuses on the experience of a Team that combines the expertise of the forestry, pulp production, research and sales personnel, to implement a program to speed up the development of Eucalyptus wood for dissolving pulp using tree breeding combined with advanced forest management techniques.

The production of low cost and high quality raw material for the industry has been one of the main objectives of current Eucalyptus breeding program in Klabin Bacell.

The principal challenge for tree breeders is the combination of forestry productivity with desirable wood properties for different end uses. In such a context, hybridization is being largely used due to its capacity of combining desirable traits of several species. Moreover, the feasibility of multiplying superior hybrid combinations by vegetative propagation has made hybridization more attractive.

The specific needs of high-tech applications and consumer demand for special products compel the whole supply chain to count on more specialized raw material.

Introduction

Eucalyptus kraft pulps became during the last three decades an important raw materials for tissue, printing and writing papers and for some special applications. This broke the long fiber paradigm in the paper industry.

In the present days the Brazilian production is more than 5.2 million tons of bleached pulp per year. That corresponds to almost 65% of the total world Eucalyptus pulp.
One essential point to conquer this market leadership is the development of the *Eucalyptus* culture and tree improvement.

The last decades were especially intense in regard to the development of cellulose-based materials. Along with new high-tech applications, such as engineered fibers to reinforce aerospace material, also end users demand new and improved products. Thus new textiles are developed to guarantee best performance of sportswear;wrinkle-free fabrics to save busy travelers’ lives; luxurious and smooth fabrics for underwear.

The dissolving pulp market faces new challenges with the growing number of cellulose applications. And the specific needs of high-tech applications plus consumers demand for special products forces the whole supply chain towards to more specialized raw materials.[1]

Unlike the paper production, where physical interactions play the most significant role in the process, the production of cellulose derivatives requires cellulose in a purified condition. The reaction of process chemicals with any remaining hemicellulose or lignin fragments in the pulp generates undesirable by-products. Therefore the raw materials for cellulose derivatisation are either naturally pure cellulose like cotton; or bleached wood pulp with low hemicellulose content, referred to as *dissolving pulp*.

With continuous technology improvement to achieve high quality products from different sources of cellulose, such as lyocell fibers, one can expect even a trend to a reduced use of cotton, which cultivation requires intensive work and large territories. This movement can already be seen in China and other Asian countries where some traditional staple fibres producers are replacing cotton linter pulps by wood pulp.

In the era of global markets, the development of forestry plantations for industrial purposes must aim for, besides other objectives, increasing industrial competitiveness in the distinct market segments they interact with. In such scenario, forestry based companies must consider the mode in which the forestry raw material can affect their competitive capacity. The modern concept of competitiveness includes producing products to meet the customer's requirements at low costs, in a sustainable manner and with minimum impact on the environment.

**Solucell: adding value for the market**

Klabin Bacell had its start up in January 1996 using the resources of the planted forest in the area, in this case *E. grandis, E. urophylla*, a hybrid of both (the so called urograndis), and other species like *E. citriodora, E. pellita* and *E. maculata*. [2]

The mill is located in the state of Bahia, in the Northeast of Brazil (Fig. 1), 50 km from the state capital Salvador. It is owned by Klabin, the largest Brazilian pulp, paper and packaging group. Production capacity is 115.000 tpy of dissolving pulp, of which 99% are exported (Fig. 2).

The mill was based on state-of-the-art technology for environmentally sound production of dissolving pulp. Some processes were specially designed for Klabin Bacell, as the Visbatch cooking, which combines vapor phase pre-hydrolysis with kraft batch cooking and the first TCF (Total Chlorine Free) world sequence for pre-hydrolysis kraft pulp. The mill has a great flexibility process. [2],[3]
Fig. 1: Klabin Bacell’s location

Fig. 2: Sales distribution by region - 2002
The short and thick fibers of *Eucalyptus* provide high specific surface of the fibre material, leading to high affinity to polar solvents. Another peculiarity of Solucell, the dissolving pulp of Klabin Bacell, is its resistance to chemical degradation, compared to other high purity grade pulps. The designed products present superior reactivity, due to their morphological and chemical attributes.

One way to see its potentiality is to use the so-called “Pulper-Trial” to estimate the yield after the first viscose processing steps in order to compare Solucell with other viscose grade pulps.[4]

After steeping according standard conditions the alkali cellulose (AC) was pressed to about 34% cellulose content. The press liquor was analyzed for hemicellulose and the AC washed with 18% caustic solution, acidified with acetic acid and then washed with water. After drying the yield was determined as “R-pulper”.

It has to be taken into consideration that the production conditions vary considerably in different viscose mills especially with regard to alkali concentration, catalyst charge, retention time and temperature. Therefore the obtained results can only be taken as indicative information.

Figure 3 display the obtained yields of regenerated AC (R-Pulper) for all pulps at steeping temperatures of 30°C and 50°C. It becomes obvious that the eucalyptus pre-hydrolysis kraft pulp Solucell produced by Klabin Bacell exhibits a considerable yield advantage (given as R-Pulper) against the sulfite pulps produced with eucalyptus and beech. At the lower temperature of 30°C the yield advantage of Solucell is higher (1.6 %) than at higher temperatures of 50°C (1.2 %).

![Fig. 3: R-Pulper “Alpha” of pulps after steeping at two temperatures](image-url)
Also it has to be taken into concern that part of the beta-cellulose in the pressing liquor ends up in the final product via circulation to steeping and staying with the AC as attached liquor after next pressing. In addition pressing lye may be used as dissolving lye for dissolution of the xanthate. The percentage of beta-cellulose in the pressing liquor is about 80% of total hemi for the kraft pulp Solucell at both temperatures, whereas the sulfite pulps form only 30 to 60% beta-cellulose. This difference is based on the different molar mass distribution of the kraft and sulfite pulps. For the more narrowly distributed kraft Solucell pulp a higher percentage of long molecules is dissolved in the caustic liquor.

Therefore the absolute yield advantage will be even higher for Solucell. Less gamma-cellulose is formed, which is soluble in the spinning bath and is lost to the wastewater.

Allied with a competitive cost structure the market perceived these features of Solucell very quickly and the pulp has been used alone or in mixture by several costumers and not only for staple fibers production.

The paradigm of Eucalyptus for cellulose derivatives is being broken.

**Eucalyptus wood**

*Eucalyptus* is a plant that has more than 600 species occurring naturally in Australia, Papua New Guinea and Indonesia but on the other hand only a small percentage is used for pulp production even for paper market.

In order to know better its main raw material Klabin Bacell initiated already before the plant start up to study different *Eucalyptus* species with respect to physical and chemical characteristics and their behavior in the pre-hydrolysis kraft process. Table 1 gives an overview of the chemical composition of some *Eucalyptus*. [5]

<table>
<thead>
<tr>
<th>Table 1 – Wood analysis of different <em>Eucalyptus</em> species</th>
<th>E.urograndis</th>
<th>E. grandis</th>
<th>E. citriodora</th>
<th>E. maculata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucan, %</td>
<td>43,3</td>
<td>42,8</td>
<td>43,7</td>
<td>40,6</td>
</tr>
<tr>
<td>Xylan, %</td>
<td>12,3</td>
<td>11,9</td>
<td>14,3</td>
<td>16,4</td>
</tr>
<tr>
<td>Mannan, %</td>
<td>0,9</td>
<td>0,9</td>
<td>1,0</td>
<td>1,1</td>
</tr>
<tr>
<td>Total lignin, %</td>
<td>28,6</td>
<td>28,7</td>
<td>24,7</td>
<td>26,1</td>
</tr>
<tr>
<td>DCM extractives, %</td>
<td>0,32</td>
<td>0,34</td>
<td>0,79</td>
<td>0,61</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0,26</td>
<td>0,21</td>
<td>0,50</td>
<td>0,58</td>
</tr>
<tr>
<td>Iron, ppm</td>
<td>5,6</td>
<td>7,4</td>
<td>4,7</td>
<td>5,7</td>
</tr>
<tr>
<td>Silica, ppm</td>
<td>6,3</td>
<td>7,0</td>
<td>5,4</td>
<td>7,7</td>
</tr>
<tr>
<td>Calcium, ppm</td>
<td>434</td>
<td>317</td>
<td>758</td>
<td>1845</td>
</tr>
<tr>
<td>Wood density, g/cm³</td>
<td>0,50 - 0,55</td>
<td>0,45 – 0,48</td>
<td>0,60 – 0,65</td>
<td>0,56 – 0,60</td>
</tr>
</tbody>
</table>
E. urograndis and E. grandis have a very similar composition for carbohydrates whereas E. citriodora has a 2% higher xylan content and E. maculata a 4% higher. E. maculata has a 2-3% lower glucan indicating lower cellulose content.

Distinct differences can be observed between lignin content of the species. Again E. urograndis and E. grandis do not differ significantly, but E. citriodora and E. maculata show a lignin content that is 3 to 4% points lower.

E. citriodora and E. maculata have DCM extractives (wood resins compounds) 0.8% and 0.6% higher compared to E. urograndis and E. grandis, respectively.

Due to its higher specific gravity E. citriodora wood charge in the digester could be increased by 20 to 25% compared to E. urograndis and E. grandis.

The cooking yield is strongly influenced by the pre-hydrolysis conditions (less or more drastic) and by the wood species. The yield of E. citriodora cooks was 4-5% higher, at the same pre-hydrolysis condition.

On the other hand its higher resin content (DCM extractives) limits the utilization to produce pulp for some specialties like ether and acetate.

The Eucalyptus species normally do not have, at the same time, all the properties required for all the products and utilizations. Many of them occur in a differentiated form among different species. For example, some species have a group of characteristics desirable for a certain product, but present poor characteristics related to the industrial processability, or low forest growth. In another situation, species with a good forest improvement and good industrial performance results in poor product quality. It can be noticed that desirable characteristics are in general dispersed in distinct species.

We can launch some questions:

- Why not to explore the Eucalyptus wood potential to develop products and enhance properties to produce less expensive high quality dissolving pulp?
- How to do this?

**Making it come true: the right strategy**

The production of low cost and high quality raw material for industry has been one of the main current programs in Klabin Bacell. It was decided to adopt a model already running for more than 15 years in Klabin Celulose Riocell, a sister company of Klabin Bacell, that produces market pulp for paper grades.

The success point is to combine and integrate the expertise of the forestry, pulp production, research and sales personnel forming a “Team” with focus in the Client.

The principles established to speed up the development of Eucalyptus wood for dissolving pulps are based on the following driving forces:

- Economics of the forestry,
- Manufacturing costs,
- Environmental issues,
- Pulp quality and its behavior in the cellulosic derivatives producers.
For each of the above driving forces parameters and targets are defined which are used to evaluate the work development. Some of these valorized wood characteristics are presented as following:

- Growth rate
- Wood density
- Pulping yield
- Hemicelluloses content
- Lignin content
- Resin content (extractives)
- Morphological characteristics

Klabin Bacell’s wood improvement program is established to attend three of the main interfaces: forest, pulp production and product. All the actions are oriented to create superior individuals that effectively allow obtaining gains in the forest, in the industrial process and in product performance:

- the *Eucalyptus hybrid for dissolving pulp* in 7 to 10 years
- the *Eucalyptus hybrid for specific niches* in 15 to 20 years
  - hybrid for acetate pulp grade
  - hybrid for rayon pulp grade

**Making it come true: the right technology for superior wood quality**

One principal particularity of the *Eucalyptus* genus is its reproductive compatibility among species, allowing them to be intercrossed. Another important characteristic is that the hybrids are fertile and can intercross again with other species permitting to integrate genetic sets from different genetic materials. This enables to combine species characteristics that are complementary to optimize the trinomial: forest – pulping process – product.[6]

Some important characteristics such as wood, pulp and cellulose derivatives properties are inherited in an additive way, presenting intermediate results in relation to the parents. Lignin content, pulp-yield, hemicellulose content, ash and viscosity are some examples (Table 2). This knowledge is of importance in the selection of species and individuals for hybrid combinations to increase the efficiency in satisfying specific industrial requirements.

In this way, the interspecifics hybrids production represents a significant alternative when the target is to produce raw material especially designed to a certain product keeping also a good forest and industrial performance.

Hybridization enables the combination of genes present in species not adapted to the location of planting. Hybridization also has the advantages of allowing the combination of different traits from distinct species and the chance of breeding superior growing trees as a result of heterosis or hybrid vigor.
Specifically the search is to combine species with a high forest increment like *E. grandis*, *E. urophylla*, *E. pellita* and several hybrids with individuals of high wood quality. The aim is also to integrate to the genome of high yield forestry materials with genes from species of high resistance to the hydric deficit. In this case species like *E. camaldulensis* and *E. tereticornis* are very important.

The forest productivity is one characteristic that has been positively modified by the clone utilization. The average productivity of the new developed materials is 50 m$^3$/ha/year for regions with a pluviometer rate higher than 1,200 mm per year and 30 m$^3$/ha/year for more dry areas.

The hybrids and cloning selection program (Table 3) is oriented to increase the wood density and the yield in dissolving pulps and to reduce the pulp contents of hemicelluloses (pentosans), extractives and lignin. It was established a good correlation between pentosans and $S_5$ that means the fraction soluble in 5% alkali solution. The laboratory analysis from various hybrids already produced in this breeding program show the efficiency of this technique to generate superior individuals.

### Table 2 – Using complementarity and variability – Lignin content (%)

<table>
<thead>
<tr>
<th>Specie</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. grandis</em></td>
<td>25.5</td>
<td>23.5 – 27.0</td>
</tr>
<tr>
<td><em>E. globulus</em></td>
<td>22.0</td>
<td>18.0 – 24.0</td>
</tr>
<tr>
<td><em>E. globulus</em> (18%) x <em>E. grandis</em> (23.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hibryds</td>
<td>21.0</td>
<td>19.0 – 24.0</td>
</tr>
</tbody>
</table>

### Table 3 – Results of assessments on wood properties in selected hybrids

<table>
<thead>
<tr>
<th></th>
<th>Current average</th>
<th>New current plantation</th>
<th>Future forests (year 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Annual Increment m$^3$/ha/year</td>
<td>30</td>
<td>40-45</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Density g/cm$^3$</td>
<td>0.52</td>
<td>0.53</td>
<td>0.57</td>
</tr>
<tr>
<td>$S_5$ %</td>
<td>12</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

**Making it come true: the commercial scale implementation**

Hybridization produces individuals with the potential to generate improvements in the forest and industrial activities and cloning is the way to transform these gains in benefits for the business. Cloning is the tool for the establishment of productive *Eucalyptus* clonal forestry and to guarantee its positive effects on industrial process and product quality.

This method of propagation allows maximum gains in the shortest timing, because it enables the capture of the total genetic variance, whether in volumetric productivity or in wood properties. The second great advantage is the possibility of producing a uniform raw material. From an industrial point of view this has significant benefits both for industrial process and product quality.
The traditional cloning method of *Eucalyptus*, the rooting stem-cuttings, has many technical and operational limitations. Because of such limitations, the company invested in alternative methods more adequate for commercial cloning of *Eucalyptus* species: the micro-cutting and the mini-cutting.

These techniques have many advantages leading to operational, technical, economical, environmental and quality benefits. Jointly with the development of a new concept to induce the root formation by *Eucalyptus* vegetative propagules it was created a super intensive system to multiplicate the propagules in large scale based in mini clonal hedges managed with the hydroponics cultivation. This system permits to produce 25,000 propagules/m²/year, while the most productive traditional system is about 2,000 propagules/m²/year. Additionally the average gain in the rooting index was around 20%.

To increase the flexibility investments were made to form a wide genetic basis and there are more than 1,000 families of priority species (*E. grandis*, *E. urophylla*, *E. camaldulensis*, *E. tereticornis* and *E. pellita*) from the area of natural occurrence. This genetic basis is enough to support a long-term program, allowing continuous genetic gains. In the present days there are more than 2,000 clones in field tests that will provide the basis for the establishment of the future forests. The program is centred on implementation of clonal forests derived from interspecifics hybrids:

Photos 1 and 2 - Making hybrids by controlled pollination using *in door* breeding orchards
Photos 3 and 4 - Cloning Eucalyptus hybrids by mini cutting

Photo 5 - *Eucalyptus* forest for Klabin Bacell
**Final remarks**

- Solucell, the dissolving pulp of Klabin Bacell is produced with very uniform *Eucalyptus* wood ensuring a very narrow Molecular Weight Distribution allowing a more homogeneous reaction and products obtained from the pulp at the customer’s processing.
- The market recognized very quickly the features of Solucell and several cellulose derivatives producers have used this *Eucalyptus* pulp alone or in mixture.
- The wood development program at Klabin Bacell combines and integrates the expertise of the forestry, pulp production, research and sales personnel forming a “Team” with focus in the Client.
- Some important characteristics such as wood, pulp and cellulose derivatives properties are inherited in an additive way, presenting intermediate results in relation to the parents. Lignin content, pulp-yield, hemicellulose content, ash and viscosity are some examples. This knowledge is of importance in the selection of species and individuals for hybrid combinations to increase the efficiency in satisfying specific industrial requirements. Hybridization is being largely used due to its capacity of combining desirable traits of several species.
- *Eucalyptus* breeding programs combined with advanced forest management techniques and good climate allows fast maturation of the trees (7 years).
- Klabin Bacell is developing an extensive *Eucalyptus* breeding program where the objectives are the production of superior individuals that effectively allow to obtain gains in the wood quality for the dissolving pulp market as for example high alpha and low hemicelluloses content, higher viscose filterability and higher working capacity.
- The target is to develop *Eucalyptus* hybrids for dissolving pulp in 7 to 10 years and hybrids for special applications like rayon – acetate in 15 to 20 years.

**References**

6. T. F. Assis, “Production and use of *Eucalyptus* hybrids for industrial purpose”. In Hybrid Breeding and Genetics of Forest Trees. Proceedings of QFRI/CRC-SRF Symposium, 2000 April 9-14, Noosa, Queensland, Australia.