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Technical article

Eucalyptus wood and pulp quality requirements oriented to the manufacture of tissue and printing & writing papers

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SUMMARY

Eucalyptus are important raw materials for paper manufacturing. They are specially suitable to make printing & writing and tissue papers. Printing and writing papers demand these fibers to improve paper formation, opacity, smoothness, bulk, porosity, printability and dimensional stability. Tissue papers show great upgrading in quality when eucalyptus fibers are added to the furnish. Most important features given to these papers are tactility, absorption, softness, fluffiness and bulk.

This paper discusses how and in which way one may take the best use of these magic fibers. A step-by-step upgrading procedure for trees, wood, pulp and paper is presented. Considering the new trends in eucalyptus intensive forestry, such as hybridization, cloning, micropropagation, etc., the author suggests rooms for improvements in each stage of the plantation and pulping and papermaking technologies. The objective is to increase productivity at the same time than pulping, papermaking and final product properties. Some important quality properties are selected and suggested to be included in breeding programs, in a strategic procedure for long-term improvements.

In this extent, market pulp manufacturers will be able to diversify production, having grades both to tissue and/or printing and writing papers. On the other hand, papermakers can better understand the relationships between eucalyptus pulp and final paper properties to define specifications

INTRODUCTION

Pulp and paper industry is very much dependent on scale of production. In addition, their products are used to show a commodity behavior regarding price/offer/demand. Because of this, the industry is oriented to production and quantities. Only some specialty grades, such as dissolving grade pulps or niche-oriented papers, are treated in straight relations with the customers. Today, the most important issues to drive the business are: cost, scale of production, Norscan stocks, prices and operating efficiency. In general, the knowledge of final customers' requirements is poorer than to those products usually found in supermarket shelves. This can be noticed when we watch pulp and paper advertisements in the TV or in magazines. They are more concerned to show a good image in terms of corporation and environment, than to present the products performance. This philosophy is typical of process industries, where the process is the core of the business. Process industries oblige the managers to run at maximum capacity to reduce costs and to have wider sales margins. In general, process industries are mature industries, with lower return on investment rates and high requirements on capital (both investment and operational).

These are some of the reasons to justify why the breeding of trees has been oriented, till now, to growth rates and wood production, in detrimental to the final customers requirements. In Brazil, it's usual to find eucalyptus plantation forests growing at an equivalent rate of 12 to 16 air dry metric tons of bleached kraft pulp/year. These marvelous growth rates are obtained thanks to volumetric growth, wood basic density, lignin content, ability to be pulped, and screened pulp yield. Few programs of tree/forest upgrading work in further steps, such us bleaching and final product properties. Based on many findings, it is believed that wood density is directly associated to many of these final product properties. However, thanks to today's technology of hybridization and cloning, wood density is a not so predictive property.

Until some years ago, there was the belief that characteristics, such as wood density, fiber flexibility, Runkel index, cell wall fraction, and others, had enormous correlation to the final paper product. Evaluating these properties could give an indication about the pulping and papermaking performance of a tree, a species or a clone. These indices had wide acceptance. They still are very good to single species, mainly to softwoods, with low biological diversity and preferable growing at the same geographical area.

In 1990, Foelkel, Mora & Menochelli (1) showed the definitive proofs that different eucalyptus species have different behavior regarding these conventional wood and fiber indices. For example, the wood of *Eucalyptus tereticornis* with basic density equal to 0.5 g/cm^3 has a pulping and papermaking performance very much different in relation to the same density wood of *E. saligna* or *E. globulus*. However, to a single species, even considering different ages, and to similar sites, these wood quality indices are valid indicators. They are very easily measured and provide good information to the forester and to the mill engineer. However, one shall know the tricks they may play.

When hybridization and cloning became commonly used techniques, we are no longer talking about single species. Several combinations within and between species are being provided. Thus, it is possible to have hybrids such as *E. globulus* *x saligna, E. grandis x urophylla*, with different predominance of one or another species. The situation becomes more complicated when the forester search triple crossing or further: f.e., *E. saligna x globulus x urophylla*. Surely, the wood characteristics on these trees, they will be unique. The genome is unique and has the contribution from the parents who have provided the genes. The expression of this genome is also unique. Then, we have to know, much more in the intimacy, the tree that is to be cloned million of times. Growth rates and wood density are essential to be measured. However, do we know how to measure and how to interpret the results? Vegetative propagation and genetic breeding are powerful tools provided to us. For years, along the sexual propagation era, heritability of characteristics such as fiber length, wood density, lignin content, pulp yield, etc, have been very much studied. Today, with the prevalence of cloning, the chance to transfer wood/fiber/pulp characteristics is further higher. Although papers about heritability on eucalyptus cloned forests are not many, it is clear from the commercial operation that the probability is high to transfer the characteristics from one “plus tree” to a “plus cloned forest”. A very good paper on this subject was written by Demuner & Bertolucci, 1993 (2).

Other important points cannot be forgotten are tree/forest age and the site quality. Many breeding programs may drive to wrong directions if the forester does not pay attention to them. They are important causes of variation and must be controlled and understood to guarantee sound comparisons.

TAILOR-MADE PULPING

There are no doubts about the podium position eucalyptus fibers have now-a-days. In the early days, the eucalyptus pulps were considered as “inexpensive fibers”, low cost and weak fiber pulps. However, very fast the superior pulp properties were discovered. The success became real mainly in the tissue and printing & writing segments. Today, eucalyptus pulps are common players in most of ours ordinary lives. People, all over the world, have chance to meet papers containing eucalyptus fibers even not knowing this. As mentioned before, the fibers of eucalyptus are very well accepted and loved by the manufacturers of tissue papers and printing & writing papers. For each of theses segments, we have different specifications, and the expected behaviors from the fibers are distinct.
Shortly:

Printing and writing papers

The required properties in the paper sheet are: smoothness, opacity, formation, bulk, porosity, printability, strength, dimensional stability. They may be obtained with short and small diameter fibers. These fibers are preferable to be easily beaten, however they shall be resistant to collapsing. They have to build a well-structured network, with good fiber bonding, but keeping porosity and bulk. Vessel elements are difficult to handle, thus they are required to be small and few.

Tissue papers

The required properties in the tissue papers are: softness, smoothness, absorption, fluffiness, bulk, strength and tactility. Fibers have to be stiff, rigid, numerous and resistant to collapse. In opposition, fiber bonding is not important. Also, the amount of parenchyma cells has to be small. The sheet network is to be open, loosen and porous, favoring drainage in the wet end.

FOREST BREEDING

Many times, we believe that if we upgrade the trees, we will be improving the forest. This correlation is strong, but not complete. Although the steps for breeding includes, as a first step, to find the “plus trees” for sexual or vegetative multiplication, it is important to know the forest behavior, resulting from this selection. I know the case where a clone was planted because the superior quality of the selected tree. The forest proved to be very sensitive to winds, and the result was many trees broken (almost a devastation) after a regular strong wind.

The purpose of this paper is to discuss the ways we may improve eucalyptus forest wood, pulp and paper qualities. Our concerns about this subject were first published in 1982, when we presented the “star trees” concept: Foelkel, Gonzaga, Busnardo, Rech, Borsatto, Schmidt, Dias & Menochelli (3). In reality, my purpose is not to show my thoughts as a kind of recipe. What I want to do is to bring my accumulated experience along the years regarding this important subject. A program to improve the wood quality for pulp and papermaking has to include tree, forest, wood, process, product, and customer. Until now, the great success of all programs has been concentrated in the initial phase. Most companies had good successes raising forest productivity, wood density, wood homogeneity, wood delignification and pulp yield. Going further in direction of the final products means to include other steps in the evaluation. In many cases, we will be working in a gray area, because for many of these new parameters, heritabilities are not proven yet. Another issue, very often discarded, is the level of uncertainty and precision in the evaluations. Many foresters are selecting many trees, measuring many parameters without an adequate level of precision, and taking decision about the future. For example, you select a “plus tree” and you, unfortunately or by innocence, measure just once its volume, wood average basic density, wood lignin content, and pulp yield and kappa number of the resulting pulp. Then, you take decisions about cloning it in large scale or not. Worse than this, you go to a clonal test, you select just one tree as representative of the clone and you evaluate the clone based on this tree. In general, many foresters still believe that, as far as the genome and the site are the same, all trees should grow and perform equally. This is a great mistake because “environment” does not mean only site. It starts in the differences among seedlings, the ways they were planted, the levels of competition for food, light, etc. Thus, one tree for a clone evaluation is not the right decision. Let me tell a simple experiment we made evaluating very carefully the same tree, using exactly the same procedure all times, with the same operator. The results were the following,

- solid volume of commercial wood: from $0.489m^3$ to $0.521\ m^3$ (average $0.506m^3$),
- pulp yield based on dry weight: from 52.3% to 53.2 % (average 52.7%),

- kappa number of resulting pulp: from 15.4 to 16.7 (average 16.2).

Another simple experiment: let's show the results for the evaluation of 15 randomly sampled trees of the same clonal forest, growing in the same site:

- volume of commercial solid wood/tree: from 0.278 m^3 to 0.610 m^3 (average: 0.447 m^3),
- basic density of the tree: from 0.363g/cm^3 to 0.467g/cm^3 (average: 0.406 g/cm^3),
- tree wood weight: 0.112 t to 0.260 t (average 0.184 t).

SELECTION OF TREES

I disagree on small sample and sampling procedures. The number of trees to be sampled depends on the found variability. Pre-tests to evaluate the selection parameters variability are required. Only after knowing how safe is your sample you should continue to next steps. Coefficient of variation (ratio between standard deviation and average) is a good indicator of variation. My suggestion is to keep it maximum 5%, preferably below this. Part of this variation is due to the methodology and part due to the treatment. It is wise also to know this.

The most important parameters to be analyzed on a tree selection are: under bark volume, basic wood density, shape factor, percentage of bark, oven-dry weight of wood, heartwood and sapwood contents.

Certainly, there are many other parameters typically silvicultural, I am not mentioning here, such as branches, tree health, rooting ability, sprouting of the stump, etc.

WOOD SAMPLING

Collected disks of exactly the same thickness (suggested 2.5cm) to avoid the prevalence of one over the other. Sample disks in several tree heights: bottom (around 0.4 m from ground to avoid the root influence), 20% of the commercial height, 40%, 60% , 80% and at the top (6-8cm of disk diameter). Collect several disks (3 to 6) in each height, to avoid the possibility of becoming short on wood along the cycle of analyses.

When sampling, avoid the contact of the disks with the soil, to keep wood free from metal and sand contamination. Metal ions are poisons in today's closing cycle mill technologies. They are also harmful to the new bleaching processes using hydrogen peroxide and ozone.

Dry disks in a clean environment, avoiding dust contamination. After drying, brush gently with a plastic brush. The purpose is to remove any contamination from soil, dust or sawdust resulting from sawing machine and from the air.

Keep the disks well identified, in plastic bags, stored in a cold room.

At the time of testing, use enough and representative amount of wood for each test. For example, in case you have micro-digesters for cooking, able to hold only 100 grams of wood. Take a slice with same angle (vertex on the pith) of each disk, corresponding to a given height, so that you have all heights represented in the sample, in the same proportion it happens naturally. After that, hand chip your wood slices and perform the cook using the entire sample. In case you have a sample of several trees, modify the angle of the slice. In the digester, you shall have all trees and all heights included. For hand chipping, use titanium knives to avoid iron contamination. When preparing wood for metal ion analysis, do not make sawdust. Burn small blocks of wood to ash then dissolve the ash in the required acidic solution. Use minimum of 10 g of wood. Avoid using biomass digestion procedures with small amount of sawdust (about 0.2 to 0.5g). They are definitively not accurate.

WOOD PARAMETERS FOR SELECTION

Wood quality has a great impact on final product and on the manufacturing process. The manufacturing process also has a strong effect on the final product. Thus, special care has to be taken not only by the foresters, but also by the mill engineers. Wood is not the responsible for all pains or all smiles in the pulp/paper industry. The properties to be evaluated are:

a)- Wood density

Wood density is probably the main factor related to forest and pulp mill productivity. Digesters are fed based on wood chip volume. Thus, denser wood provides more weight/volume in the time unit. Variations in wood density caused by blend of species or blend of stands with different ages have to be minimized. A good stability in wood supply to a given final product is fundamental. Wood density is perhaps the most important wood parameter to control pulp mill production. For example, let's suppose you have an average density of 0.5 g/cm^3 and a pulp yield of 52%. For eucalyptus is relatively simple to reach 0.55 g/cm^3, but due to the barriers of the kraft process, hardly you reach 55% yield. In general, most of the pulp mills are running at full capacity in the digester. This means that they are feeding all possible wood chips they can do to the digester. Let's suppose one mill (case A) is feeding the equivalent of 4,000 m^3 of the solid wood/day through its digester. The wood comes from a selected clone whose wood has an average density equal to 0,5 g/cm^3 and the pulp yield is 55%. The ratio to transform solid wood volume to wood chip volume is about 3. This means 1 m^3 of solid wood gives 3 m^3 of wood chips. This ratio is relatively stable in wood preparation machinery and it is accepted as it is. Certainly, it may represent a room for improvements, when someone wants to feed more solid wood through the digester. In case A, the mill is able to manufacture 1,100 tons of oven dry pulp/day.

Let's imagine now a case study B, where the same mill is adding another selected clone whose performance is 52% yield and wood density equal to 0,55 g/cm^3.

Given the fact that the mill has a limitation to add 4,000 m^3 of solid wood, the daily production for this cloned wood raw material is 1,144t/d. A daily production 44t higher, or around 15,000t/year. This is very impressive and very much important to pulp mills. Raising production means reduce fixed costs and wide margins. The foresters shall pay attention to this. Selecting a clone implies in technical and economical point of views.

Wood density is also very much affected by tree age. In most of the cases, due to the volumetric orientation, the eucalyptus forests are harvested in Brazil from 6 to 8 years of age. When you start considering wood weight and pulp equivalent produced/hectare, the economical age may also become attractive from 9 to 11 years. One has to evaluate the impact on forestry and pulp/paper properties, but surely this is an attractive alternative.

b)- Lignin content

Due to the differences in lignin content among species (for example, *E. globulus* wood is about 4% lower than *E. grandis* wood), hybridization is a good alternative to incorporate this characteristic in the wood. It is simpler and less expensive than genetic engineering, and more environmentally friendly. However, both techniques are appropriate, depending on the situation.

c)- Ash content

Some species as *E. dunnii* and *E. globulus* have showed higher mineral content in the woods than *E. grandis* or *E. saligna*. Some species are accumulators and others are recyclers, when you consider the mineral elements cycling. It is important to consider that mineral elements in wood are related to the tree metabolism and to the efficiency in growing wood using them. The species able to produce higher biomass weight per weight of each mineral element (potassium, calcium, magnesium, iron, sodium, etc.) are said to show higher nutritional efficiency. This is an important characteristic to be included in forest and tree breeding programs.

d)- Extractives content

Some eucalyptus species are able to produce some extractives in the wood that can give pitch problems when making or using the corresponding pulps. For this reason, the evaluation of wood extractives provides important information to those willing to improve the wood for pulp/papermaking.

PULPING THE WOOD

In this step, maximum and stable productivity and high quality are the objectives. Pulpmakers are willing to get maximum production and higher running performance. Also, minimum costs represented by lower raw materials consumption and higher yields are a must.

When we are planting forests to a greenfield mill to be built, we can even obtain savings in capital requirements, what is very much welcome by shareholders.

The care about sampling the wood and cooking representative material is fundamental. Important decisions have to be based in reliable tests. We cannot have a cooking program only to “justify” our decisions. In forestry, due to the long-term results, it may take years to discover the poor quality of the breeding program.

Cooking is recommended to aim constant kappa number in the pulps. Depending on the mill design, kappa number of unbleached screened and washed pulps varies from 14 to 18. A range of $\pm$ 1 is the maximum accepted variation (for example 15 $\pm$ 1). After cooking the wood, you should evaluate: active alkali charge, consumption of active alkali based on wood, gross or total yield, screened yield, reject content, brightness, viscosity, hemicellulose content. With some calculations, including figures of forest growth rates and wood density, it is possible to calculate: growth rate of the forest in equivalent tons of pulp/ha.year; tons of pulp produced at the target mill/day running at maximum chip feeder speed; tons of pulp/1000 m^3 of digester. Another important calculation is the amount of organic and total solids generated per ton of pulp. This characteristic is fundamental to the performance of the liquor recovery system. Many mills have the recovery system as the bottle-neck and demand higher pulp yield and lower total solids in the black liquor.

BLEACHING THE PULP

Very seldom the upgrading programs reach this step. It is well known the fact that some eucalyptus woods lead to easily bleached pulps, and others to the opposite. Today, with the closing water cycle concepts and new bleaching technologies (TCF and ECF), this step became very important to be evaluated. Important issues in the bleaching step are: chemical charges to a given brightness, brightness stability, extractive content, pitch deposits, pulp viscosity, mineral elements in the pulps.

PRINTING AND WRITING PAPERS REQUIREMENTS

As stated before, printing and writing papers demand very good formation, dimensional stability, opacity, printability, strength and smoothness. Eucalyptus fibers may provide all these properties. With proper quality upgrading programs, the eucalyptus wood can be oriented to these grades of paper.

Desired properties in the fibers are: higher number of fibers/gram of pulp and lower fiber coarseness. This means, shorter, abundant and light fibers, but resistant to the collapse. In order to guarantee strength, these fibers are required to have good fiber bonding ability. The hemicellulose content of the fibers, expressed by the 5% caustic soda solubility of the pulp (S_5) provides a very good indication of this feature.

A well-balanced equilibrium between bonding and opacity is very important. When the number of fibers/gram of pulp is more numerous, the light, to cross a sheet of paper, finds more obstacles and has to switch from the fiber medium to the air medium (and vice-versa) more often. This increases opacity. Eucalyptus pulps from low density woods have, in general, higher number of fibers/gram of pulp and they lead to high opacity. The fines content (or the content of parenchyma cells and fiber fragments) also helps, to a certain extent, to raise the value of paper sheet opacity. Special care must be taken during the refining to avoid collapsing the fibers or damaging fiber structure. For this reason, refining has to be gentle and should not go too further. In case higher strengths are required, pulp blends are good options.

Eucalyptus pulps containing higher fine content and higher number of fibers per gram of pulp (with corresponding lower fiber coarseness and thin-walled fibers) have, as usual, a higher resistance to drainage in the wet end wire. This means they show a slightly higher Schopper Riegler degree in the unbeaten pulp.

The pulp refining evaluation is important, It is recommended to have a single point refining, since both the 25º SR or 30º SR (depends on the mill common use) are able to give good predictions of pulp quality along the entire beating curve.

Strength evaluation is important, but we do not need to evaluate all of them. Tensile and/or tear strengths are good enough to show fiber bonding ability and fiber intrinsic strength of the pulps. The pulp beating properties to be considered as reference are: tensile/tear strengths, opacity, bulk and porosity.

The selection of the better pulp depends on the final printing and writing papers to be manufactured. For low basis weight pulp, opacity is essential. For papers to be printed at high speeds, strength also becomes key factor.

In all cases, paper formation and smoothness are improved by the shorter and more abundant fibers.

Printability is very much affected by vessel elements. Vessels of eucalypts have diameters varying from 100 to 300 μm. They are numerous: 20,000 to 150,000 vessel elements/gram of pulp. There is a negative correlation between wood density and number/diameter of vessels: lower the density more open spaces given by vessels. Vessel picking is an important defect when printing hardwood containing papers. With proper refining and good surface sizing the problem can be controlled. Many printing paper mills, using eucalyptus pulps, require vessel counting as a specification.

TISSUE PAPERS REQUIREMENTS

Recently, Ratnieks & Foelkel (4) presented an overall discussion about eucalyptus pulp specification for tissue papers.

Tissue papers require more rigid and stiff fibers, with low bonding ability. The sheet of paper is loosen and fluff, but has to be strong enough to resist the embossing/creping operations.

Fibers to give such properties are thick-walled, in general associated to denser woods. Heavier the fibers, for similar fiber lengths, smaller is the number of fibers/gram of pulp. This means that fiber coarseness is also higher. On the other hand, to reduce fiber bonding, fibers have to be resistant to collapsing and they should have lower hemicellulose content (lower S_5). As consequence, a good pulp for tissue manufacturing is slightly resistant to the refining. They do not develop beating very easy, they do not collapse or break during processing. This helps to form sheets very loosen, bulk and soft, and slightly free from fines.

In this case, tensile strength cannot be high. A high strength is associated to high bonding and more brittle sheet, what is not appropriate for tactility and softness.

Other important characteristics, also high in poorly beaten pulps, are water absorption (speed of absorption and amount of absorbed water) and sheet bulk.

Tissue papers are low basis weight papers (15-20g/m2). In general, the network of fibers is very loose and many porous can be seen watching the sheet against the light. A structure like this has poor ability to retain fines in the papermachine wet end. Fines flows through the wire and they tend to build up in the white water systems. This is undesirable. Some tissue mills have fine content of pulps as specification parameter. In general, eucalyptus pulps have from 5 to 12%, based on weight determination by the dynamic drainage jar test.

CONCLUSIONS-FINAL CONSIDERATIONS

Although the breeding program may be long-term and it is timing, cost and labor consuming, it helps to create a link from the forest to the final product. This is not very familiar in the pulp industry, which is labeled as a commodity-like industry, or a production-oriented process industry. Eucalyptus pulps are mainly driven to these two segments: tissue and printing & writing. It is not very difficult to select the most adequate wood from selected forests to each of them. My opinion is that we shall not place our decisions in very complicated programs of evaluations. Simplification and accuracy are key words. Decisions are to be correct because the penalty is very severe. It is better to discard good genomes because simplification, but accepting many other good ones, than to accept as good material what is not. The danger is that it will be discovered only years ahead

Today we want very productive forests, with high quality and low cost. The wood shall lead to good operational efficiency in the mill site. We also wonder to have the best wood to each kind of final product. Customers are always demanding for quality and price. We must concentrate our efforts in large-scale segments, such tissue and printing & writing papers. It is not very wise to engineer wood for low demand segments, since most mills have no scale for this. In case we wish to act in low demand markets (for example, filter papers), the alternatives are: start with an eucalyptus fiber close to the requirements and try to handle alternatives such as tree age, wood blends, pulp blends, cooking, bleaching, refining, additives, etc.

I do not believe that customers are willing to pay more to the engineered and improved pulps or papers. However, all the effort leads to market share position and production position. Both are responsible to the company profitability and competitiveness.

Other points very often forgotten: it does not make sense to have a good wood quality if the forest, or the pulp and paper mill, are no good. The worst situation I am continuously seeing in my life is: good forest, good wood quality, good mill operation. However, the forest is harvested and the wood is stored for months under precarious conditions and get decayed. Harvesting and wood handling are also important steps to guarantee peak performance. Another very common mistake is to take a superb wood and to chip it in very poor quality chips. This leads to wasting lots of sawdust and/or generating thick chips, difficult to be converted to pulp.

Today, the integration between forestry and mill operations enables the pulp/paper mills to use homogenous and high quality woods, according to the final markets.

The cloning technologies provide good productivity and quality, based on stable genotypes with predictable behavior, according to forest sites. Clones can also be sorted according to final product properties and markets. They also may be elected to guarantee top performance in mill operations.

This is all a question of planning and hard working. Also, it is a question of decision: shall I do it or not?!

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