ADVANCES IN EUCALYPTUS FIBER PROPERTIES & PAPER PRODUCTS

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ABSTRACT

Eucalyptus pulps are rich on fibers, but fibers are not the sole anatomical elements in their contents. Fibers, fiber debris, fines and vessel elements are combined in a rich blend. The papermaking behavior of the pulp depends very much on the anatomical and chemical properties of this mixture, but also in the different pulping and papermaking processes applied to these elements. Fibers consist in the most abundant pulp component. Although their dimensions in lengths and widths are rather similar for different eucalyptus pulps, the cell wall thickness plays important difference. Based on the variation of the fiber dimensions, there are important characteristics being affected in the paper-machine operation and runnability. Fiber population and coarseness may, up to certain extent, reflect this potential behavior. However, there are other issues to be considered. Fines and fiber deformations are some of them. Fines are important for bonding. A pulp with no fines has poor bonding ability and low strengths. However, excess of fines brings problems in drainage in the wet end section, in dewatering in the press section, and higher density in the paper sheet. Fiber deformations are not natural on fibers, the pulp and paper manufacturing processes impart them. Fiber deformations may reduce individual fiber strengths, but they are important to promote bulk and absorbency properties in paper sheet. Chemical characteristics of the pulps are also proved to be important. The hemicellulose content plays important role. In addition to hemicelluloses, fines, fiber population, fiber coarseness and bonding, there are some other important pulp characteristics, such as water retention value, fiber collapsibility, and wet web strength. Moreover, the ability of the fiber to hold water is becoming a critical issue. Fiber charges and hysteresis-associated properties are now being part of a pulp evaluation, due to their potential influence in the paper-machine performance (drainage and dewatering) and final product quality. Eucalyptus pulps are recommended for papermaking due to specific properties they impart to paper: bulk, opacity, formation, softness, porosity, smoothness, absorbency, dimensional stability. Faster machines are being developed to run with these pulps, however the aim is not to lose these paper properties.

Keywords: eucalyptus, fibers, pulp properties, paper properties, paper-machine runnability, quality specifications, paper web consolidation

INTRODUCTION

Independently in which paper mill we are, the paper sector has as fundamental issues the high productivity, the high operational efficiency (no losses, no problems, no breaks, no stops, no nightmares), the low production costs and the uniform quality in the process and products. It is important to mention that all papermakers have these basic physiological needs, no matter the paper is being made, or the paper-machine is being used. For achieving these targets, the raw material must be as uniform as possible, with characteristics in a narrow range of variation in order not to cause strong impacts in the papermaking process and paper qualities. To tame this variability, the paper mill engineers are used to control a number of pulp quality parameters. However, many times, the selected portfolio of pulp quality specifications does not give a previous idea or a predicted behavior and performance in the pulp utilization, neither in the operation nor in final paper product quality.

When the paper maker ask for uniform pulp, he is not making a request only for brightness, viscosity and cleanliness. He includes here a number of pulp quality parameters that are very important to his conversion process. His objective is to have a papermaking operation with the minimum variability, without undesirable surprises. The final paper quality must be uniform and within the specification limits, and the losses along the process should be as minimum as possible. When standardization in the pulp intake is demanded by the mill manager, he is first trying to guarantee a raw material that may perform well in the paper-machine operation (machine runnability). The second important objective is to guarantee in the manufactured paper the quality specifications his customer is demanding. Since fibrous raw material performance behavior is difficult to be measured in the quality control laboratory, the mill manager requests the help from the laboratory chief to perform what I call the "management of peripherical pulp quality specifications". He needs a number of selected data to help him to justify the problems he may eventually have when the machine runnability is poor, or the paper quality specifications are not being achieved. When an uniform pulp intake is guaranteed; refining, chemical additions, sheet drainability, energy and steam consumption, web consolidation, and paper strength/physical properties do not sharply change and the process runs smoothly. The process and product qualities are more easily reached. In an attempt to control some of these pulp quality parameters, the laboratory evaluates pulp brightness, pulp cleanliness, pulp viscosity, and runs some beating runs. The first and important goal is not to vary the general pulp properties. Brightness, brightness reversion, cleanliness, ash and mineral contents, and beating performance are the key issues in this "peripherical quality specifications. The complementary pulp quality parameter is the moisture content. The papermaker

does not want to pay more to the pulp he is buying than what he considers to be fair and right.

The second type of management that the mill manager wishes is the variability control. The "management of pulp variability" tries to guarantee a narrow variability in the pulp and its consequences. The variability is measured indirectly, by watching the paper-machine behavior and performance. When machine works smoothly, without breaks, at pre-settled speeds, and the quality specifications in the product are met, the process is said to be controlled, and variability has been tamed. When problems start to happen, the usually first accused is the pulp quality.

Management of peripherical quality and management of pulp variability are really basic physiological requirements in any paper mill. The mill manager needs to have these exigencies fulfilled to go further in the next type of management: the "management for product differentiation", or "tailor making orientation in the manufacture of products". This type of management requires substantial changes and offers important challenges to the mill personnel. The changes may happen in pulp quality (for example: long fibers and short fibers blends), pulping process conditions (for example: ECF or ECF-Light bleaching sequences reflecting on AOX or OX pulp contents), or even others recently added qualities (certified or non-certified wood in the pulp). Differentiation of products is more easily achieved in mills with more than one paper-machine. This means that the mill may run each machine with a differentiated product, without experiencing the usual troubles with transitions from one product to another using a single paper-machine. Anyhow, the tailor making concept only will be winner when the pulp maker has guaranteed the two first mentioned types of management: peripherical pulp quality specifications and variability plus machine performance. It is very simple to say, but very difficult to understand and to implement. For this reason, many conflicts and misunderstandings are frequent between the commercial, production and product innovation areas in a paper mill. Each of these areas has its own needs and dreams about product uniformity, product uniqueness, and product differentiation. In most of the cases, each area has difficulties to understand the other side's position. As a result, few paper mills have products that may be said completely differentiated in their products portfolio. Most of the paper manufacturers aim to have a single product, as uniform as possible, with the minimum cost and maximum in productivity and in operational efficiency. Having in mind that the behaviors, needs, commitments and purposes are different, what is really important to promote a culture for tailor making in paper manufacturing? What is important to be managed? How to do this? What properties in the pulpwood may be successfully controlled to offer differentiation in paper products? What are the most important pulp parameters that the mill manager should care about? And the commercial director? What about the R&D manager?

It is relatively difficult to say what is the single most important pulp characteristic for a given paper mill. The reason is that there is not a universal pulp property to be managed. Depending on the paper mill bottleneck, the pulp quality is defined to guarantee the maximum performance to this mill. The most common bottlenecks are: refining capacity, drainage and retention in the wire section, paper-machine speed, steam availability, wet web consolidation and strengths, final product uniformity. As a conclusion, it may be said that the type of mill bottlenecks will define the most desirable pulp quality, up to a certain extent. This is the case for existing mills. For new greenfiend mills, the quality may be previously built and designed, before the construction of the paper-machine and auxiliary equipment's. However, soon the mill starts up, and the bottlenecks will appear to define the new pulp quality standards. This is the reality, no doubt about. This is also the cause for domestic conflicts within the company.

EUCALYPTUS PULP AND FIBER QUALITY REQUIREMENTS FOR THE PRODUCTION OF PAPER

Paper mills have targets for productivity, costs and efficiency. Eucalyptus pulp is a raw material for the manufacture of several grades of papers. For each paper grade and for each paper mill design, different may become the pulp quality requirements. This means that there is not an universal pulp, a pulp that may perform well everywhere.

Productivity means fast speed in the paper machine, fast drainage in the wet end, high consistency after wet presses, excellent consolidation in the paper web, and minimum number of paper sheet breaks along the machine. Quality implies in maximum percentage of paper in the specification range and minimum generation of broke. Machine operation efficiency is the dream of any paper manufacturer. He wants his machine working smoothly, at the maximum speed as possible, no breaks, no maintenance problems, and achieving the required quality in the manufactured products. The consequence of all this is that the specific unit cost is also here optimized. No doubt that a good pulp is the one able to provide good paper-machine runnability and appropriate quality in the end product, no matter this paper product is a commodity (toilet tissue, cut size paper, etc) or a specialty grade (industrial filters, cigarette paper, etc).

Some of the pulp properties are very much related to these performances. For this reason, the papermaker should keep an eye on them. Some of these properties are result of the wood quality, other depends on the conversion of wood to pulp (chipping, cooking, bleaching, pumping, blending, etc), and many are a combination of these two factors influencing the pulp quality. For example, some properties that are related to pulping and bleaching are: viscosity and degradation of cellulose chains, fiber deformations and individual fiber strengths, surface charges in fibers,

etc. One important pulp property that is related to wood quality and pulp conversion is the hemicellulose content in the pulp. This content depends on how high is the content in the wood and in the ability of the pulping process to preserve them in the fibers. There are other properties that are 100% dependent on the wood supply, the pulping and papermaking processes cannot modify them: fiber length, fiber wall thickness, vessel dimensions, etc.

There are many pulp properties that are dependent both on wood quality and on pulping/bleaching processes. There are also many cases where the exigencies are placed on the wood quality, when the wood is not the only factor to determine the pulp quality for paper. It is the case of properties as: WRV – water retention value, WWS – wet web strength, fiber bonding and individual fiber strength. There are many other properties related not only to the wood quality. For example, the fine content of the pulp. Fines in the wood are mainly parenchyma cells, but in the pulp they are also fiber fragments that are generated in operations such as wood chipping, pulp pumping, pulp dynamic mixing, pulp pressing for dewatering, etc.

As a rule, there are some physiological properties that any pulp has to fulfill to be loved by papermakers. They are related to the following:

Physiological need number 01: *Drainage and retention in the wet end section in the paper-machine*

This behavior is very much affected by the fiber population (number of fibers per gram of pulp), by the initial or refined pulp freeness (drainability of the pulp measured as Canadian Standard Freeness or Schopper Riegler degree), by the Water Retention Value (hydration and swelling ability of the pulp furnish), by fiber flexibility and ability to form and to consolidate the web and by the fines content in the pulp furnish. The wire/fabrics design and cleanliness, many times forgotten as quality parameters, are also very important to the fulfillment of this physiological need.

Physiological need number 02: *Paper sheet strength along the paper-machine, mainly at the wet end and press section*

This sheet behavior is very much dependent on the individual fiber strength, fiber length, fiber bonding, furnish contaminants (shives, sand, solid debris, etc), and on the consolidation potential of the paper web. Individual fiber strength is related to fiber wall thickness, fibril angle, fiber deformations and micro-fractures, and *Eucalyptus* species.

Physiological need number 03: *Achievements of final paper specifications as requested by customers (or by the quality control laboratory!)*

According to the paper we are manufacturing, the demands on specifications (fibers and pulps) are different. Sometimes, these differences varies for the same grade of paper, but being manufactured in different paper-machines. Each individual process may have some particularities that leads to different pulp needs and operational conditions.

As far as the physiological needs are achieved, the papermaker feels enthusiasm to work for differentiation of products. Differentiation implies in different products to be supplied to different markets or customers. One of the most important ways to reach differentiated products is through the control of the eucalyptus pulp and fiber quality. The genetic improvements on the wood quality may, not only help to reach the physiological needs in the pulp and paper manufacturing, but also to provide very different pulp fibers to be supplied to the manufacture of different products. This is what is known as to tailor making the wood to the end product.

However, genetics, silviculture and wood quality are not the sole responsible for the pulp behavior. The pulp performance may have its foundations at the forest, but this is not all. We have seen that pulping and papermaking processes may contribute a lot in changing the pulp qualities and behaviors. What we definitively need is to know is what and how to take control of this.

THE MOST IMPORTANT EUCALYPTUS PULP AND FIBER PROPERTIES

Today, the pulp and paper laboratories are squeezed by thousands of different types of analyses. Some mills are spending so much time on measuring everything, that the speed to take decisions and actions is completely affected. The laboratory manager has fewer people, due to the constant downsizing obliged by the company's high administration. He feels lost, but he wants to keep his area working as much as possible to satisfy his customers (paper production manager and commercial manager). Since the number and the type of analyses grow due to the TI support, the time to reflect over the results decreases. The danger is that the quality of the data may also be affected.

The following pulp quality parameters are key drivers to distinguish the different eucalyptus fibrous raw materials and to allow pulp furnish optimizations:

- Fiber population or the number of fiber per gram of pulp (associated to fiber coarseness)

The fiber population is related to the weight of each individual fiber, and by extension to the fiber coarseness and to the percentage of fiber wall in the fiber volume. There is a number of fiber properties associated to fiber population and fiber coarseness: fiber length, fiber wall fraction (ratio between cell wall thickness and fiber ray), Runkel index, fiber flexibility index (ratio between the lumen diameter and fiber diameter), fiber collapsibility, ratio fiber wall thickness and fiber perimeter, wood basic density, and fines content.

It may be shortly said that pulps with lower fiber population show better drainage in the wet end, and the paper sheets are more porous, bulkier, more permeable and absorbent. They are very much

appreciated by papermakers because they allow faster machine speeds, as far as the furnish may impart enough strengths to the wet paper sheet.

- Individual fiber strength

This fiber characteristic is very difficult to be measured in short fibers as those from eucalyptus. There are tests correlated to this strength, as the zero span, very useful for predicting pulp quality and behavior previously to send the furnish to the pulp-machines. Fiber deformations (curl and kinks), micro-fractures in the cell wall, and other fiber defects may contribute to reduction on the individual fiber strength. The consequence of reduced individual fiber strength may be reduced WWS (wet web strength) and dry paper strength properties.

- Fiber collapsibility

Fiber collapsibility is associated to the wet paper sheet compactability. The sheet compactability makes the paper sheet denser and places the fiber walls closer to each other during paper manufacturing. As a consequence, fiber bonding is sharply improved, and the strength properties depending on bonding (tensile, burst, folding) have their results raised. On the other hand, some very welcome eucalyptus pulp properties are lost: bulk, porosity, opacity, water absorption, dimensional stability. Fiber collapsibility and wet sheet compactability are result of the fiber resistance to collapse. In most of the cases, the thick-walled fibers, with higher fiber wall fraction are stiff, rigid, and more resistant to collapse. Eucalyptus fiber collapsibility is also negatively related to fiber coarseness. Higher the fiber coarseness, lower is the ability of the eucalyptus fibers for collapsing. Those fibers with great potential for collapsing are usually more difficult to drain the water in the wet end of the paper-machine. One indirect measure of fiber collapsibility is the dry paper sheet bulk (or sheet density) at a given Schopper Riegler or freeness level. Higher the bulk in a certain level of drainability, more resistant are the fibers to be collapsed. Higher the densities of the sheet, more collapsed are the fibers, and more compacted the paper sheet. Bulk or density at a given drainability (for example 25 or 30ºSR) and fiber coarseness, are able to give a good indication of pulp behavior in relation to fiber collapsibility.

- Fiber bonding ability

Better the fiber bonding, better is the paper sheet cohesiveness. Cohesiveness and bonding are developed by beating (fibrillation and fiber collapsibility) and by the presence of fines and fiber debris. Bonding may be measured by the dry/wet short span (B value) technique or by other equipment for dry paper bonding tests, as the Scott bond tester or wax picking of paper surface. It is also related to the hemicellulose content of fibers, fiber population, fiber drainability (CSF or ºSR), fines content and fiber collapsibility. Bonding is very much related to pulp fines content and web consolidation by pressing and collapsing fibrous materials. Higher is the sheet density, the more bonded are the fibers and other anatomical and chemical elements present in the paper structure. Low hemicellulose content and high coarseness fibers reflect in low cohesiveness and low bonding. Instead of being “glued or linked” to each others, these types of fibers are rigid and stiff, they tend to touch and to stick one to another. Finer fibers with lower coarseness values and higher fiber population make closer-formed and better printing oriented sheets of paper.

- Fiber swelling and hydration

This property is very affected by the pulping and bleaching operations during pulp manufacture, and by the pulp hemicellulose content. Several properties are associated to the swelling of fibers: WRV - Water Retention Value, fiber charges, carboxyl groups, fines, fiber wall micro-porosity, fiber wall micro-fractures. Fiber swelling may be a problem in integrated mills, when the pulp has never been dried prior to its use in paper manufacturing. When a pulp is dried, the hysteresis phenomenon provides a substantial reduction in the WRV of the pulp. Dried pulps, with lower WRV, have a much better drainage in the wet end. However, they are somewhat more difficult to be refined, but the strengths are reached in a drainability level that is still convenient to the machine operation. For this reason, in many occasions in an integrated paper mill, the mill manager loves to add some broke to the furnish. He believes that some broke is required to improve the performance of the furnish. It is a completely inappropriate thinking, since broke recycling is a loop in your process; you are wasting all the value has being added to the manufacture of this paper. Even worse, you are reducing the paper-machine net production. The machine has part of its capacity filled by a recycled material, in a loop that consumes resources, reduces capacity and raises costs and inefficiency. In case an integrated mill may eventually have problems due to excessive furnish swelling caused by any reason, the most simple method to improve machine runnability is to buy or to add some dried market pulp in the furnish recipe.

- Fiber deformations

The deformations in the fibers are measured as curl index, fiber kinks, fiber latency, and fiber micro-fractures in the cell wall. They affect the individual fiber strengths, but they provide substantial improvements in the paper sheet porosity, bulk, smoothness and water absorption. Fiber deformations are possible to be developed by artificial means at the pulp or the paper mills (shredders, washing presses, etc). Although not completely implemented as a source of pulp and paper differentiation, the utilization of

fiber deformations for this particular subject may become more significant in the years to come.

- Fines content in the pulp

Fines are perhaps one of the most important pulp properties, and most of the times they are seen as a problem, never as a solution. This fundamental property is being neglected by pulp and papermakers, perhaps because fines are no fibers, they are debris or "weak parenchyma cells". Fines are seen as a filler in the pulp supply. They are created in great extent when the pulp is refined, what means that fines dramatically affect drainability in the wet end section. What I would like to propose to papermakers is really to pay attention to fines in the furnish. The "management of fines" in the furnish may provide to paper operators one the most simple and convenient methods to control the great majority of the end-product properties. When a paper mill has two or more machines, the management of fines may be even more effective, by distributing fines in right dosages in one or another paper machine, according to the paper grade being manufactured.

THE MOST USUAL EUCALYPTUS PAPER PRODUCTS

In case we are good enough in providing the right furnishes to the paper manufacturer, he is able to add runnability to his machine and to go sleeping without any nightmare. However, according to the grades of paper he is manufacturing, he is demanded to have differentiated properties in the final product. Eucalyptus pulps are special products to the manufacture of bulky and/or opaque papers. Today, Eucalyptus pulps are preferred raw materials in the manufacture of tissue, printing and writing, cartonboards, industrial filter, base-paper for impregnation or coating, cigarette and many other papers. Eucalyptus fibers may be the sole fiber in the pulp furnish or to be part of a blend with other short and/or long fibers.

Tissue papers demand softness, absorption, bulk, tactile feeling and the exact strength to provide machine runnability and very fast drainage in the wet end. Bonding is a poison up to a certain extent. The fibers cannot collapse because this will flat the paper surface; the paper becomes stronger in tensile, but all the tactile properties are lost due to sheet compactability. Pulp fines are also undesirable for two reasons: fiber bonding and building up in the paper-machine white water system, reflecting in losses of drainability. The most indicated eucalyptus pulps for tissue and highly porous paper manufacturing are those showing: low fiber population and consequently high coarseness, low fines content, low bonding ability, low fiber collapsibility, low hemicellulose content, high bulk, porosity and water absorption in the manufactured paper sheets. Fiber deformations are also important, since these deformations improve the bulk, porosity and absorption of these papers. An important issue to remember is that fiber deformations may be artificially created in the pulp mills. The manufacture of industrial filter papers, and impregnation-based papers are demanding the same properties, but in a higher level. This means, to go to these specialty paper markets, the pulp differentiation must be even more pronounced. The simplest way to work in differentiated pulps to these very specialty markets is to work towards very high coarseness (low fiber population, what means high wood basic density), low hemicellulose content, low fine content (by removing fines from one paper line and using them in another one, where more desirable) and to intensify fiber deformations (by high consistency presses, fiber shredding, or pulp flash drying).

For printing and writing papers, the desirable paper properties are: formation, paper strength, porosity, surface smoothness, dimensional stability and opacity. At the same time, the papermaker wants to keep the machine runnability. We should never forget about the papermaking physiology. A higher fiber population is welcome for improved opacity, associated to lower fiber coarseness. Also, fiber bonding is important to improve strength. Hemicellulose and pulp fines contents do help in this task. However, there are limits to all this and the limits depend on each paper-machine system and operation. A very high fiber population may be wonderful to improve opacity and formation, but drainage in the wet end and consistency after wet presses may be deteriorated, and machine speed reduced. The papermaker is to refuse this pulp. He wants quality and runnability both aligned, remember this. Fiber deformation here may not be so important, but they may help to balance the pulp properties, since machines may create it. Higher contents of hemicelluloses are welcome because they favor refining, bonding, consolidation of the paper web, and strength properties (tensile, burst, tear, folding). An ideal pulp should have high strengths at the low levels of refining (fast beating response). This indicates the possibility to have strengths and bulk / porosity at the same time in the paper sheet. The papermaker don't like to refine a pulp very hardly: he is raising energy costs, reducing the life of refiner discs, and deteriorating machine drainage, machine speed, steam consumption and a very important paper property that is dimensional stability. Definitively, the best pulps are those showing good strengths at low levels of refining. For this reason, an interesting beating test for pulps is the measurement of strengths properties (tensile, tear, stretch) at a given bulk (for example: 1.8 cm^3/g), or at a given sheet density (for example: 0.55 g/cm^3), or at a given freeness level (25, 30 or 35ºSR, depending on the paper grade being produced). P&W papermaker is very sensitive to all these pulp and paper properties. In addition, there is another wood anatomical characteristic very important to the printing grade papers: vessel elements content and vessel dimensions (specially the vessel diameter). Large, wide and

numerous vessels are undesirable for P&W papers. They are responsible for a printing defect known as vessel picking. The papermaker needs to have special conditions to combat the vessel-picking tendency in the paper. For these reasons, a wood with smaller vessels and not so abundant is preferred. The same for the corresponding pulps.

There are many other grades of papers manufactured with eucalyptus pulps. In most of the cases, the Eucalyptus fibers are used to improve paper formation, opacity, smoothness, dimensional stability, bulk and porosity. The eucalyptus fiber population in the pulps, and their rigid and difficult to be collapsed fibers are important properties loved by the papermakers. Eucalyptus pulps are not oriented to be highly refined, unless the papermaker is willing to discard the best properties the eucalyptus pulps have: bulk, porosity, formation, dimensional stability, opacity, and water absorbency.

There is another key driver to papermakers for using eucalyptus fibers: the market pulp prices of this fiber. Thanks to the low production costs, high pulping yield and lower chemical and wood consumption, these pulps are in general less expensive than softwood pulps. No doubt that production costs are also key issues for papermakers. The same to the entire eucalyptus pulp and paper production chain.

CONCLUSIONS

Eucalyptus pulps have today gained the status of the most admired fiber supply. They are growing in an unbeatable rate in the paper world business. They may be used as the single fiber in the furnish or blended with others, such hardwoods, softwoods or recycled fibers. However, there are still a good number of opportunities to even further optimizations in this pulp use. As a simple recommendation, please think about the following issues:

- management of the swelling ability of the furnish;
- management of fines (removal or addition in controlled rates);
- management of fiber deformations (created by specially designed equipment's, as a high consistency pulp shredder);
- management of pulp blends in the furnish (incorporating different pulps with different potentials);
- management of wood supply to the pulp manufacture in integrated mills.

SUGGESTED READING

Campos, E.S.; Martins, M. A .L.; Foelkel, C.E.B.; Frizzo, S.M.B. Selecao de criterios para a especificacao de pastas branqueadas de eucaliptos na fabricacao de papeis para impressao offset. **Ciencia Florestal 10** (1): 57 – 75. (2000)

Colodette, J.L. **III ICEP guidelines**, 2006. www.sif.org.br/3ICEP

Cowan, W.F.; Cowan, J.; Foelkel, C. Z-span testing of eucalyptus bleached pulps obtained by different bleaching sequences. **Proceedings 35th ABTCP Annual Congress**, Sao Paulo, Brazil, 11 p. (2002)

Foelkel, C. Eucalypt wood and pulp quality requirements oriented to the manufacture of tissue and printing & writing papers. **Proceedings of the 52nd Appita Conference**, Brisbaine, Australia (1): 149 – 154. (1998)

Foelkel, C. **Fibras e polpas**. Powerpoint presentation: 30 slides. (2004). http://www.celso-foelkel.com.br/artigos/Palestras/Fibras%20e%20polpas.pdf

Foelkel, C. **Differentiation in market pulp products: is market pulp a commodity product?** Powerpoint presentation: 74 slides. (2005). http://www.celso-foelkel.com.br/artigos/Palestras/Differentiation%20in%20pulps.pdf

Gatari, J.W. **An experimental analysis of the zero and short span tensile tests**. Chalmers University of Technology, Sweden, MSc Thesis. 36 p. (2003) http://www.md.chalmers.se/EM-Masters/theses/archive/pdf/thesis_joan.pdf

Lehtonen, J. **Influence of commercial hardwood fibers from different production regions on wood free paper properties**. Faserstoff Pulp Technology Symposium. Powerpoint presentation. 15 slides. (2005). http://www.glocell.fi/Lehtonen%20Presentation%20FS_503_Brfl.pdf

Lundqvist, S.0.; Grahn, T.; Hedenberg, 0.; Hansen, P. **Visions and tools for forest and mill integration. Part 2: Some new approaches under development at STFI for prediction of paper properties**. Eurofiber Seminar, STFI, Powerpoint presentation, 31 slides. (2003). http://www.stfi.se/upload/3439/02_d14-3_stfi-lundqvist2_Part%202x.pdf

Ratnieks, E. , Foelkel, C. Uma discussao teorico-pratica sobre polpas de eucalipto para a fabricacao de papel tissue. **Proceedings 29th ABTCP Annual Congress**, Sao Paulo, Brazil, p. 717 – 734. (1996)

Raymond, C. A. Genetics of *Eucalyptus* wood properties. **Annals of Forest Science 59**: 525 – 531. (2002)

Santos, C.R. **Qualidade da madeira e sua influencia nas caracteristicas de papeis de imprimir & escrever e tissue**. Universidade Federal de Vicosa. 45 pp. (2002)