PULPING EUCALYPTS – A REVIEW

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SUMMARY

The development and the current state of the technology of pulping Eucalyptus wood are reviewed through an examination of the published literature and a reflection of personal experience.

From the beginning of kraft pulping eucalypts in Brazil in 1957, the world production of eucalypt pulp has grown to millions of tons annually and continues to increase. The main reasons for this phenomenal growth are that eucalypts can be grown in 6-15 years and produce an excellent fiber for papermaking. Yet, among the over 500 species of eucalypts, only few are commercially utilized. They have been genetically improved for increased yield and better paper making properties.

The few truly pertinent literature references discussing critical technical parameters of Kraft pulping eucalyptus wood are summarized in this review of the present state-of-technology The reported ranges of pulping parameters relate generally well to pulping practices in Brazilian pulp mills.

For traditional kraft and modified pulping of eucalyptus, the response to varying temperatures, chemical charges, additives, and extended delignification techniques are evaluated. Critical pulping response parameters include kappa number, pulp yield, lignin removal efficiency, pulp properties, and spent liquor characteristics.

The results of the review indicate that many actual practices are backed up by past research and development work. They also indicate the need for additional work to explain some reported discrepancies. There is a need for more in-depth study to better understand and expand the use of eucalypts for producing pulps with superior properties for specific end-uses.

KEYWORDS

Pulping, Eucalyptus, Kraft Cooks, Soda Cooks, Soda AQ, Yield, Wood Density, Tree Breeding, Morphology, Black Liquor, Extractives,

INTRODUCTION

A search of the pertinent literature reveals a surprisingly small number of published references. More information resides in company-internal files. None of the available references offers a in-depth and comprehensive understanding of the mechanisms of pulping eucalypts.

Therefore, this review was expanded beyond merely examining pulping parameters. It provides some historical background about the moving of Eucalyptus tree cultivation from its native Australia and Southeast Asia throughout the world. This is followed by a survey of the history of Eucalyptus plantations and pulp mill development overall, and in Brazil in particular.

The important role of Eucalyptus pulp in the world market and for Brazil is briefly reviewed, followed by an attempt to shed some light on the process of sampling and selecting the best-suited species and provenances for breeding superior trees in plantations. A description of morphological properties of hardwoods and how to sample for pulping trials provides the transition to the discussion of important parameters governing Kraft and Soda pulping and the resultant pulp properties. Conclusions round off this review of Eucalyptus pulping and pulp.

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HISTORY - From Obscurity into the Limelight

The literature review covered about 70 references, but barely more than half turned out to be pertinent. This brief historical overview is intended to provide a perspective of the truly remarkable emergence of Eucalyptus as one of the major hardwood species used for pulping. Some of the major milestones on the road to Eucalyptus' prominence are listed as follows.

Table 1 **History of Eucalypt Tree Planting**

1616	Australia	Dutch "discover" Australia and Eucalyptus trees
1801	France	Eucalyptus seeds and seedlings are brought to France
1823	Chile	Planting begins
1829	Portugal	Eucalyptus is planted
1840's	India	Cultivation starts
1840's	S.Africa	Planting begins
1852	N.America	Cultivation starts in Arizona
1854	Europe	Eucalyptus trees are cultivated for their essence
1855	Uruguay	Planting begins
1857	Argentina	Planting begins
1868	Brazil	Eucalyptus is introduced in Brazil
1904	Brazil	Edmundo Navarro de Andrade starts Technical Cultivation
1934	Australia	Blakely describes 500 Eucalyptus species and 138 varieties

Eucalypts were introduced into Brazil relatively late. Initially, the main purpose behind Andrade's pioneering efforts was to use the wood as fuel for the railroads and for charcoal production. However, Andrade is said to have foreseen its use for pulpwood as well.

Pulping of eucalypts is reported to have started in Portugal[31], when Caima Celulose began production of bisulfite pulp at its mill in Albergaria. It took several decades before kraft pulping was researched and implemented by Suzano at its mill near São Paulo.

From these early beginnings, it took only about 10 years for eucalypt pulp to gain acceptance in world markets as an excellent pulp for printing and writing papers and tissue.

Table 2 **History of Pulping Eucalypts[31]**

1906	Portugal	Caima begins Eucalyptus bisulfite pulping research
1923	Portugal	Caima starts Eucalyptus sulfite pulp production at Albergaria
1952	Brazil	Suzano begins Eucalyptuskraft pulping research
1957	Brazil	Suzano starts a 50 tpd kraft pulp mill in Sao Paulo
1957	Portugal	Cia.Portuguesa de Celulose: Eucalyptus kraft pulp at Cacia
1958	Portugal	Cacia studies Eucalyptus dissolving pulp production
1963	Spain	Ence starts Eucalyptus kraft pulping

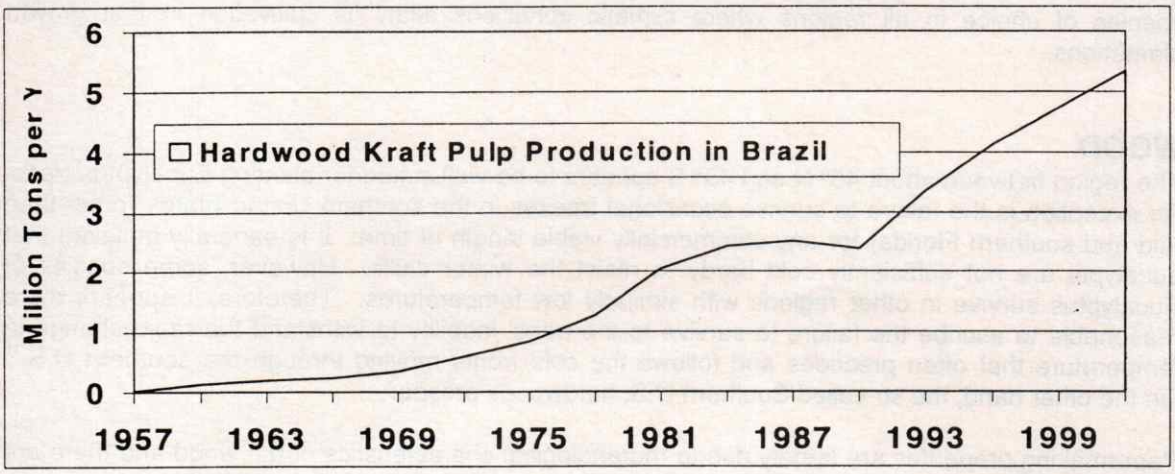
In Brazil, following the early pioneering effort by Suzano, pulp mill development progressed at an impressive pace, as shown in the following table and in **Figure 1**.

Table 3 **History of Eucalypt Pulping in Brazil[31]**

1957	Suzano	50 tpd bleached kraft pulp mill
1960	Champion	Starts a bleached kraft pulp mill
1969	Suzano	Pulp mill reaches 300 tpd capacity
1972	Riocell	Starts 870 tpd kraft pulp mill
1973	Suzano	Starts a 500 tpd bleached kraft pulp mill
1977	Cenibra	Starts 750 tpd kraft pulp mill
1978	Aracruz	Starts 1150 tpd kraft pulp mill
1979	Jari	Starts 580 tpd Kraft pulp mill

Apart from some Acacia wood pulped by Riocell, the vast majority of the hardwood pulp production shown in Figure 1 consists of Eucalyptus pulp from plantation trees. No use of Mixed Tropical Hardwoods is known, and certainly no native forest wood from the Amazon river region is pulped.

Figure 1 **Development of Kraft Pulping Eucalypts in Brazil[33]**

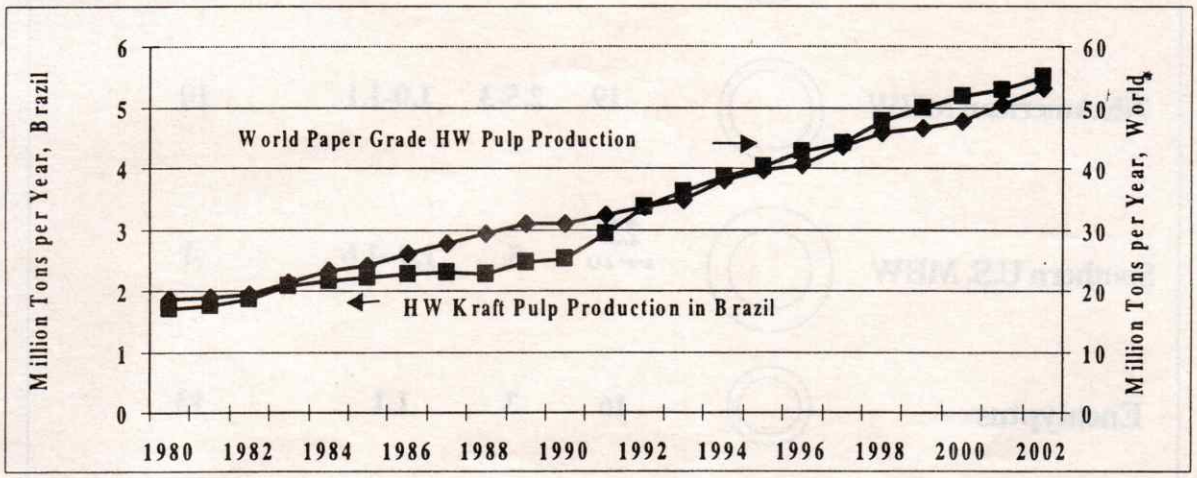


Scandinavian pulp producers were also active early on, becoming involved in planting and pulping eucalypts in Portugal and Brazil. The Swedish company Billerud (now part of Stora) explored making dissolving pulp at the Celbi mill in Portugal. The Norwegian company Borregaard built the original mill in Guaíba, Brazil, to produce unbleached pulp for market and for bleaching at a plant located in Norway. That early involvement has continued through the years, as shown by many contributions to the literature, particularly in pulp bleaching.

MARKET

Northern birch and mixed North American hardwood pulps dominated the European and American markets for short-fiber pulps until the 1970's[9] . Then, eucalypt pulps from Iberia and Brazil succeeded more and more in substituting birch pulps in Europe and some hardwood pulp in America and Asia. The very impressive growth of Brazilian eucalypt pulp production shown in Figure 1 was slowed only because of overcapacity between 1987 and 1990. The Brazilian growth is largely mirrored by the worldwide growth in the consumption of bleached hardwood kraft pulp, shown in **Figure 2**. The share of eucalypt market pulp can be estimated to about 40% of total worldwide hardwood market pulp production. It has grown to this level from about 18% in 1978, 30% in 1982, and about 35% in 1990. In addition to Brazil, eucalyptus pulp is produced predominantly in Portugal, Spain, and South Africa. Chile, China, Japan, Indonesia, Thailand and India also produce eucalypt pulp, but only as a minor share of total wood pulp production.

Figure 2 **Bleached Hardwood Kraft Pulp - Worldwide and in Brazil[33]**



Brazil's share of the world's bleached hardwood kraft pulp production is about 10%. However, it makes almost half of the world's eucalypt pulp production, much of it for export.

Overall, eucalypt pulp production has almost tripled over the past 20 years, because of its fast tree growth and excellent papermaking characteristics. Eucalyptus trees have become the wood species of choice in all regions where climatic conditions allow its cultivation in fast growth plantations.

WOOD

The region between about 45º N and 45º S appears to be well suited for planting Eucalyptus trees. An exception is the failure to survive occasional freezes in the southern United States (other than mid and southern Florida) for any commercially viable length of time. It is generally believed that eucalypts are not sufficiently cold hardy to resist the winter chills. However, some species of Eucalyptus survive in other regions with similarly low temperatures. Therefore, it appears more reasonable to ascribe the failure to survive to the trees' inability to withstand the rapid change in temperature that often precedes and follows the cold fronts moving through the southern U.S.[18] On the other hand, the so-called Southern U.S. hardwoods prosper.

Papermaking properties are largely due to morphological characteristics of the wood and there are enormous differences between the hardwood species, as reviewed briefly in the following.

Morphological Aspects

One of the best known references for the methodology of classifying hardwood pulp properties for papermaking is still the late 70's work of Dillner and Jonsson[10] . They stress that the values and trends obtained in laboratory evaluations of pulp properties need to be relatable to fundamental properties, such as morphology. Then, the interpretation of the test results will be meaningful.

"A look at fiber morphology provides a natural starting point for a presentation of pulp properties". Visualizing the morphological data for the major papermaking hardwood fibers shown in Figure 3, the fibers can be characterized as follows.

Figure 3 **Morphological Characteristics of Hardwoods** [10]

Species	Width µm	Wall µm	Length mm	Fibers /g Pulp Million
Scandinavian Birch	22	3	1.1	8
NE American MHW	19	2.5-3	1.0-1.1	10
Southern U.S. MHW	22	5	1.4 -1.6	4
Eucalyptus	16	3	1.1	13

Birch
Relatively thin-walled fibers of average length have an intermediate number of fibers per weight unit.
Birch fibers collapse easily and form flat ribbons, facilitating fiber-to-fiber contact. Birch pulps are easily refined. They give good wet and dry web strength development, but render poor bulk and opacity.

Northeastern American Mixed Hardwoods
Their smaller and more thin-walled fibers usually result from pulping the varying mixes of numerous species, such as maple, beech, aspen, birch. Pulps have relatively low strength, but good bulk and opacity.

Southern U.S. Mixed Hardwoods
Longer and thick-walled, they have a high coarseness and relatively few fibers per weight unit. Gums and oaks prevail in a varying mix of numerous species. Pulps are harder to refine. Tear resistance and bulk are high, but other strength properties and opacity tend to be low. The coarse fibers give high bulk, but the small number of coarse fibers also gives a rough sheet surface.

Eucalyptus
Fibers are relatively short and thin, but rather thick-walled. Therefore, their coarseness is low, with the highest number of fibers per weight unit . Eucalyptus pulps combine most of the important qualities in a remarkably favorable manner. They have good wet and dry web strengths, very high bulk and good opacity. The fibers are hard to collapse, but they are very thin and numerous, giving high bulk without sacrificing paper surface smoothness.

One of the "characteristics of hardwood pulps is the frequency and size of vessels". Paper made from eucalypts for offset printing initially had dusting problems that were ascribed to loose vessels. The problem was soon solved and has commonly become a non-issue. "It is important to keep in mind that a 40-50% vessel content is based on volume. The percentage based on weight is at least a magnitude smaller. Thus, it is not the vessel properties that count, but rather the interaction between vessels and fiber elements. Improving vessel-to-fiber bonding (*refining, sizing*) will enhance strength and printability."

Eucalyptus Species
Only a few of the many eucalypt species plus some hybrids have emerged as preferred species for producing pulp. Their different characteristics are partly conditioned by the local soil and climate that favor their cultivation over others, but they are mainly the result of selection and optimization processes. The most frequently used species and hybrids are listed as follows.

Table 4 Eucalyptus Species Predominantly used for Pulp

Brazil	Iberia	South Africa	Indonesia	Australia
Grandis	Globulus	Grandis	Urophylla	Regnans
Saligna		Camaldulensis	Camaldulensis	Globulus
Urophylla		Tereticornis	Grandis	Nitens
Uro-Grandis			Deglupta	Deglupta
Globulus				Viminalis
Nitens				Cloeziana

The occasionally encountered confusion about nomenclature may at least be partially removed by the clarification provided in **Table 5**.

Table 5 Eucalyptus Nomenclature and Synonyms[32]

Main Name	Synonyms	(M.G.Queiroz, 1970)	
Globulus Labill	Cordata	Delegatensis R.T.Baker	Delegatensis
Camaldulensis Dehn	Rostrata Schl.	Longirostria F.v.M.	
Botryoides Sm.	Platypodos Cav.		
Alba Reinw.	Leucadendron Reinw.	Platyphyla F.v.M.	Pastoralis Spencer Moore
Viminalis	Rubida Deane and Maiden		
Alba (Brazil)	Urophylla		

Selection of Wood for Pulping

Eucalyptus is a very large genus of plants that includes almost 600 species[4]occurring naturally in wet and dry, tropical and temperate climates, and at different geographical altitudes[19]. Very few of these many species are used for industrial purposes. Among these few species, most have been improved to obtain enhanced wood, pulp, and paper properties under optimum economic conditions

The genetic variability that exists in forest trees has been used to improve selected characteristics of plantation trees through genetic selection. The difference in magnitude is a result of the selection process towards improved growth characteristics and wood properties. The process starts at the species level, progresses through the selection of provenances within a species, and continues to the selection of individual trees (genotypes or families) within-provenances. Clonal reproduction is then used operationally to make identical copies of the selected individuals. Commercial cloning is accomplished through the use of rooted cuttings, where only the very best selections that have been thoroughly tested through research are used in operational plantations. Reduced variability has been achieved a result of the selection process towards improved wood properties[9].

Plantation Forestry

Plantations provide wood for about 30% of global pulp production. This share has been growing steadily and quite rapidly over the last three decades and is expected to grow. In some regions, wood from plantations accounts for almost all the pulp wood used, notably in Iberia, Africa, Oceania, and South America. Wood from plantations is also frequently used for energy generation in pulp mills or for charcoal production, even for steel mills. Managed regeneration of natural forests provides the largest source of wood fiber for the forest products industry. Most of these forests are located in Scandinavia, western Europe, and North America[20] .

Wood from mature trees, such as in natural forests of eucalypts in Australia and Southeast Asia, have generally a large variability[19], as summarized by Zobel[43]. Plantation forestry offers great advantages, because trees from fast-growth plantations with genetically improved stock have more uniform wood density and fewer of the extractives that can cause pulping problems.

For very old trees, such as traditionally used in Australia, varying trends have often been observed. However, there is no longer much interest in pulping studies of old trees and their patterns of variation, because today's trees are harvested from plantations and at a juvenile age.

The probably best-known example of eucalypt plantations has been the Aracruz program[39]. It is based on intensive research to reduce variability and improve wood qualities. An intensive selection program was undertaken initially, with significant, but calculated risks, to obtain desired growth, form, and wood qualities. Superior trees were originally selected from Brazilian plantations of *E. grandis* that had been established with unimproved seed. The selected trees were then evaluated in progeny tests and the very best selected for planting. These select trees are reproduced using vegetative propagation to capture the additive and the non-additive genetic qualities of the parent trees. The objective was to obtain more wood of a more uniform quality, which is "tailor-made" to suit product requirements. Following the example of Aracruz, as well as other progressive companies, intensive tree improvement programs and establishment of large-scale commercial plantations of genetically improved eucalypt trees have become quite common.

Vegetative propagation through rooted cuttings enables replication of individuals with identical genotypes[5]. It is thus possible to characterize patterns of variation precisely and determine the relative importance of genetic and environmental effects on wood quality traits.

Vegetative propagation is used for certain species of eucalypts including *E. grandis* and *E. urophylla.*, but not all species will produce sprouts which can be managed operationally. *Eucalyptus regnans* and *E. nitens* do not sprout readily or at all. *E. globulus* sprouts readily, but roots with difficulty. Therefore, each organization has to work out techniques and methodology details of vegetative propagation to suit its location's specific conditions.

Several companies worldwide plant each about 20-30 million rooted cuttings from supertrees each year. "Clonal forestry has been done for a quarter century and is now well recognized, but perhaps not as widely used as should be.

Clonal forestry or vegetative propagation is *only* a method for mass-producing desired trees and to get increased benefits by using outstanding and known genotypes. It is *not* a breeding method for developing better genotypes"[44].

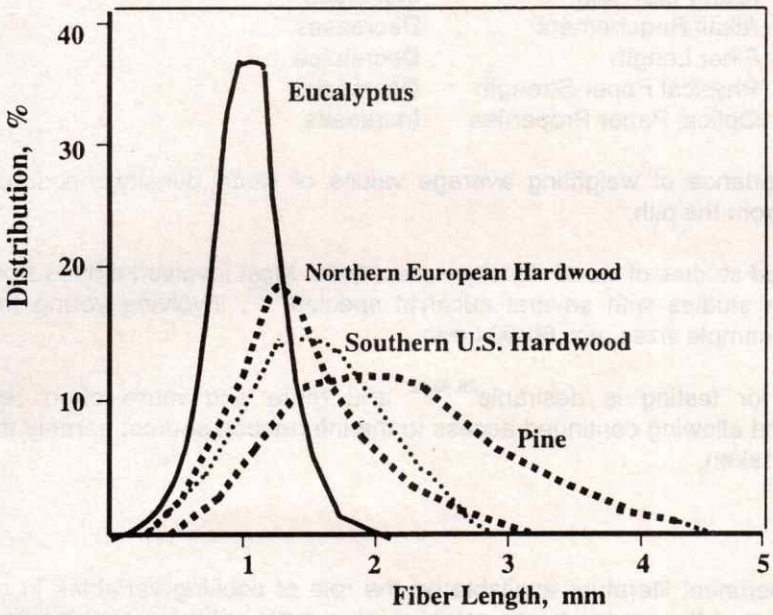
Again, it is not clonal forestry as such that provides the improvement, but the vegetative propagation of improved trees through clonal forestry. Aracruz gave an example of results obtainable on the occasion of accepting the Wallenberg Prize award in 1984[39]. The key result is an improvement in wood uniformity. Aracruz early results are summarized in **Table 6.**

Table 6 **Results of Clonal Forestry[39]**

	Unit	Initial Seedling Forest	Improved Rooting Forest	Improvement %
Wood Yield	m3/ha/yr	33	70	112
Pulp Productivity	T /ha/yr	7,85	18,45	135
Basic Wood Density	Kg/ m3	460	575 (wood only)	25
Pulp Yield	%	48	51	6
Pulp Content	Kg/ m3	238	293	23
Wood Consumption	m3 /t pulp	4,2	3.41 (wood only)	19

The table also gives an idea about the relatively smaller improvements obtainable with using seeds, even though those results can be quite impressive also. For example, wood density of individual trees of E. grandis grown from seed varied from 300 to 900 kg/m^3. The clonal material varied only from 500 to 600 kg/m^3 in 1984[30]. Since these early successes, control of properties, such as wood density, has improved even more. Specific wood properties can be improved through genetics research. The primary objective of any tree improvement program should be to achieve increased wood uniformity[41]. Then, specific wood properties can be improved through suitable means, such as genetic manipulation. An illustrating example is the impressively uniform fiber length distribution of Eucalyptus, shown in **Figure 4.**

Figure 4 **Comparison of Fiber Length Uniformity[39]**



Tree Breeding

Commercial rotations for most eucalypt plantations are between 6 and 15 years. The interval between-tree generations is important for tree improvement. The faster the generations can be cycled, the greater the potential for genetic improvement. The objective of breeding is not as easily determined as it might seem. The traditional goal is to improve volume production per hectare, diseases resistance, and a long list of traits, such as form, bark thickness, density, pulp yield, and pulp strength. All traits must be given a relative economic importance and critical levels must be defined.

Selective tree breeding requires long-term investments and produces results which can be realized economically in the medium and long term.
Therefore, it seems imperative that paper industry people in marketing, product development, production, and forestry should be working closely together to achieve the strategic results necessary for the long-term profitability of their company.

Cotterill[9] makes a persuasive case for this cooperation, which should result in a greater utilization of specific eucalypts to achieve specific pulp properties.

Wood, pulp, and paper traits are expensive to assess. Therefore, breeding requires careful planning, optimized experimental design, and competent sampling.

In spite of the apparent improvement potential and economic incentives of product development, little progress has been made towards developing tailor-made eucalypt trees for specific value-added products or market segments. It will probably require efforts beyond the traditional commodity orientation of the pulp and paper industry, such as suggested by Cotterill[9]. He envisages expanding the by now traditional uses of E. globulus and grandis pulps through the introduction of pulps made from E. nitens or E. viminalis pulps for attaining specific paper properties.

Sampling
Choosing a sample location in a tree for testing wood properties is a complex process and depends on the trait and the species involved. Balodis et al. [3] performed a detailed analysis of sampling parameters. Whiteman[41] gave a general model of the variation of wood properties within trees of E. globulus.

Table 7 General Variation of Wood Properties within Trees of E. globulus

From Bottom to Top of a Tree	
Wood Density	**In**creases
Lignin	**De**creases
Kraft Pulp Yield	**In**creases
Alkali Requirement	**De**creases
Fiber Length	**De**creases
Physical Paper Strength	**De**creases
Optical Paper Properties	**In**creases

Brouard[3] stresses the importance of weighting average values of wood density measurements according to their distance from the pith.

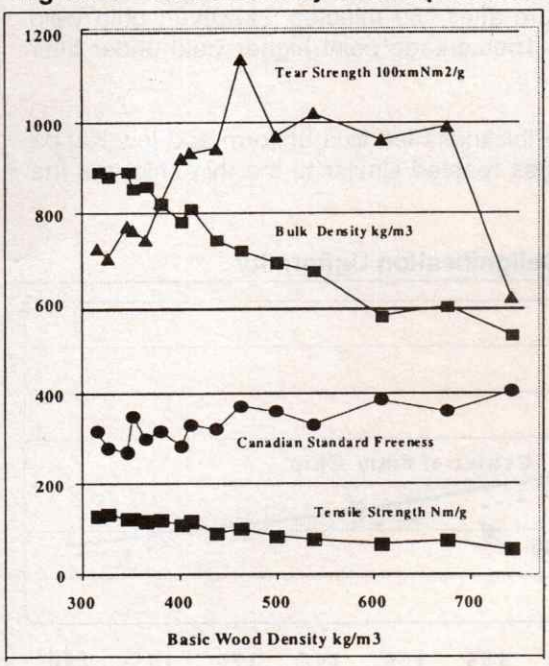
There are very few published studies of wood density in eucalypts. Most involved clones from only few trees. Some Brazilian studies with several eucalypt species[12,13], involving young trees of seedling origin, used larger sample sizes, viz. 60-90 trees.

Non-destructive sampling for testing is desirable[26,40,42] and more and more often realized, shortening breeding time and allowing continued access to the information source, namely the tree from which the sample was taken.

PULPING

There is surprisingly little pertinent literature available on the role of cooking variables in pulping eucalypts. Presumably, most of the research into establishing a mill's optimum cooking variables has all been kept as proprietary information in company files. Only a little over half the (primary) references listed in this paper concern themselves with pulping, and only a few of those are actually studying pulping parameters.
The main variables in eucalypts are basic wood density and extractives content.. However, in most plantation wood, extractive contents are very low, particularly when harvested at 5-7 years of age. For dissolving pulp manufacture, an otherwise very favorably performing *E.citriodora* (about 17 years old), was judged to present potential problems because of its relatively high extractives content[13].

Figure 5 Wood Density vs.. Pulp Characteristics



The test results shown in **Figure 5** come from several eucalypt species and trees that were selected with the objective of obtaining a full spectrum of wood densities.

In well designed experiments, Arbuthnot[2] obtained high degrees of correlation between wood density and the parameters shown, confirming that density is an important determinant of pulp and papermaking properties.

He concluded that 460 kg/m^3 was the optimum density, because maximum tear was obtained at favorable levels of the other parameters.

This wood density is about the same as Aracruz' value obtained from the initial seedling-based eucalypts (Table 6). The improved rooting forest produced trees with substantially higher densities and pulp yields.

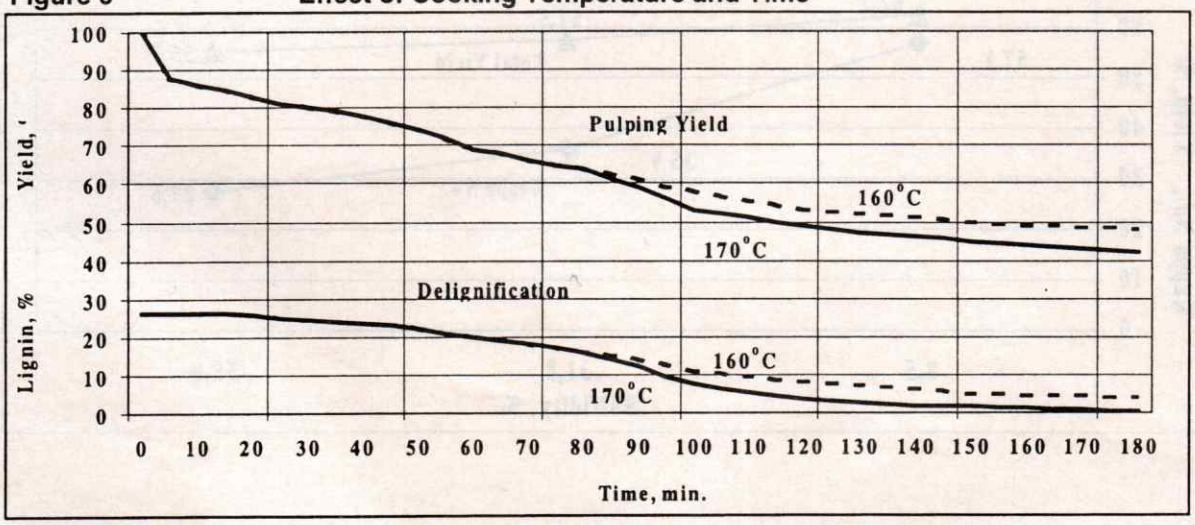
Effect of Pulping Variables - Conventional cooking

Over the years, a number of models of kraft pulping have been developed, usually with one shortcoming or another. Mirams et al.[27] reviewed these models in 1994 and presented a more comprehensive model of pulping eucalypt wood. They chose conditions for mature trees as raw material, rather than plantation wood, but gave a more comprehensive overview of the effect of the key pulping variables than any other literature source referenced here.

They had to make several assumptions: "since no data was available for the diffusion of hydroxide in hardwoods, the diffusion coefficient measured for hydroxide in loblolly pine pulp was used. Since no data was available for the diffusion coefficient of the hydrogen sulfide ion in wood, it was assumed that the diffusion coefficient is equal to that of hydroxide".

Mirams et al. examined the effects of cooking temperature, sulfidity, and chip thickness on delignification rates and pulp yield. They used their model to describe the effects of process conditions on the extent of delignification, the selectivity of the process, and the uniformity of the pulp produced. The results are summarized in **Figure 6** and **Figure 7**.

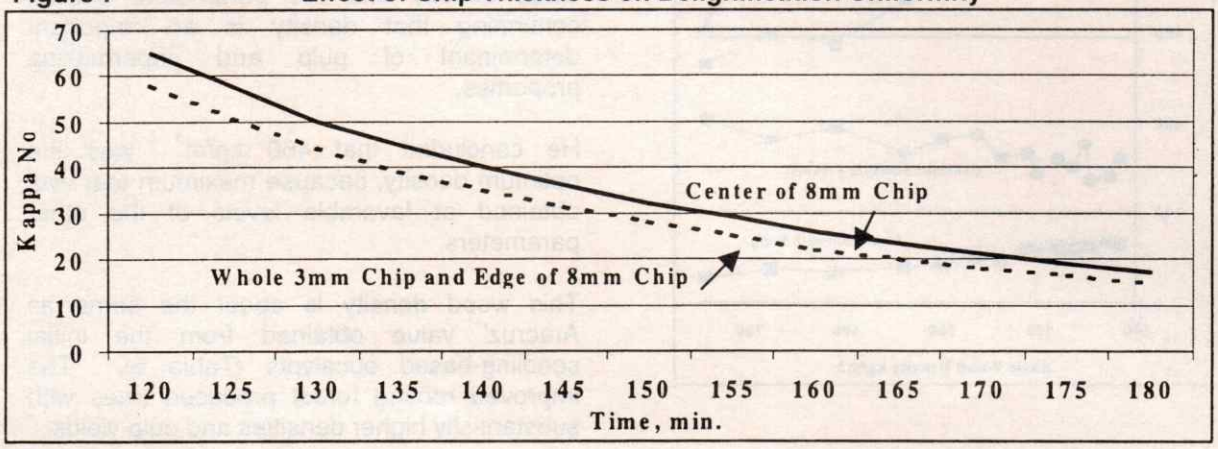
Figure 6 Effect of Cooking Temperature and Time



Increasing cooking temperature from 160ºC to 170ºC reduces the lignin content in the pulp to about one fourth of the level obtained at the lower temperature after 180 minutes. However, pulp yield drops also, by about 12 %. Irvine et al.[21] found about 1percentage point higher yield under their conditions.

As shown in **Figure 7**, cooking a chip of a 3 mm chip thickness led to a uniform and low Kappa No., as opposed to cooking a 8 mm thick chip. Its edges reacted similar to the thin chip, but the center was pulped less, even after 180 minutes.

Figure 7 **Effect of Chip Thickness on Delignification Uniformity**

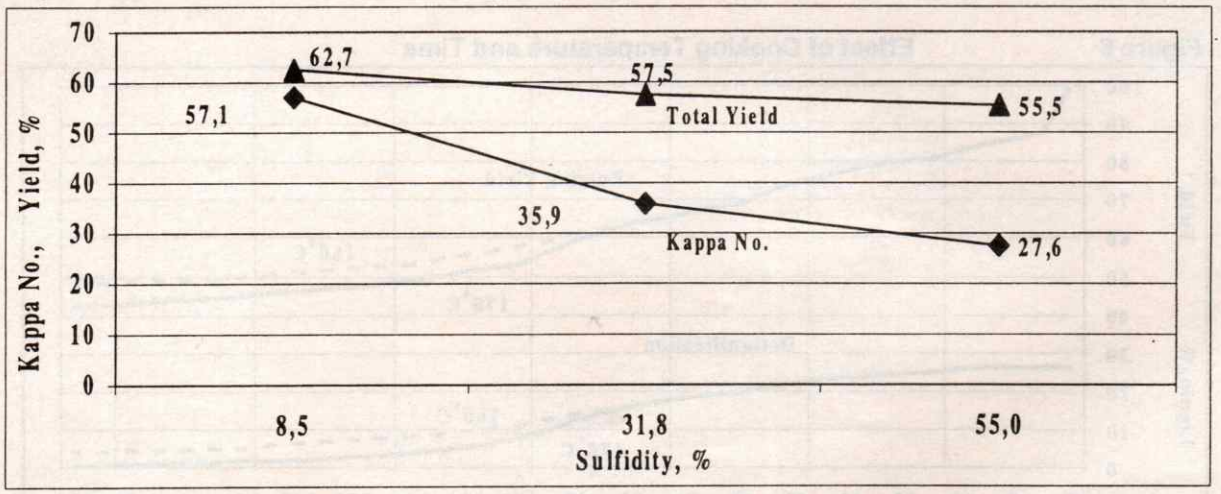


The porous structure of eucalypt makes impregnation of wood chips with cooking liquor very rapid, but heat transfer is even more rapid than the delignification reactions, as evident from the narrowing of the difference in Kappa No. towards the 180 minute time. Kappa number variation increased from 4% to about 20% with the increase from 3 mm chip thickness to 8 mm.

The effect of increasing cooking liquor sulfidity from 26% to 33% (NaOH basis) brought an increase of about 1% in carbohydrate yield and thus overall yield.

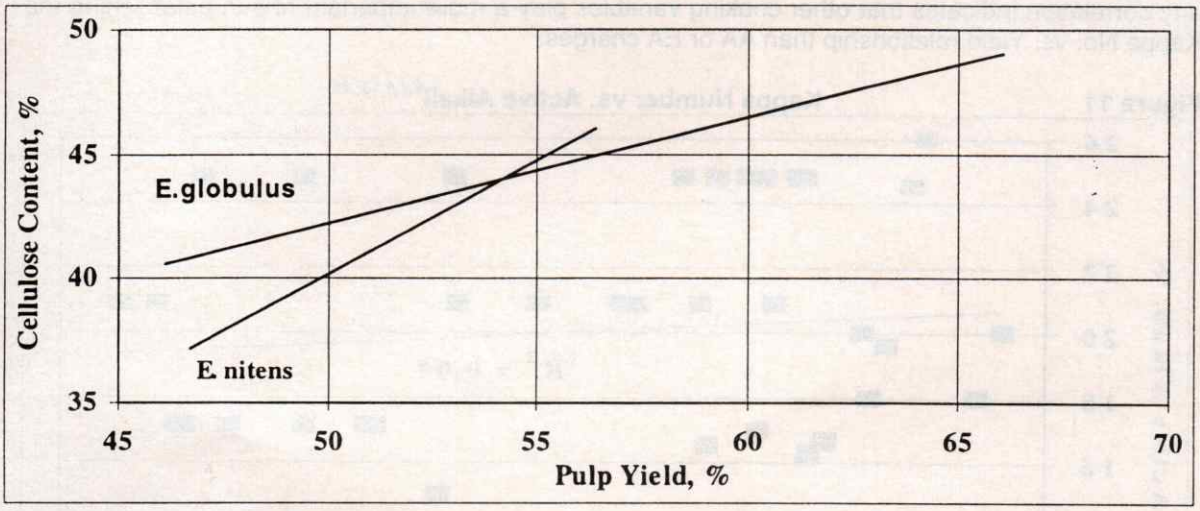
The usual way of characterizing the improved delignification achievable from increased sulfidity is through a decreasing Kappa No., as was shown by Bugajer et al.[6] in their optimization of cooking variables. As shown in **Figure 8**, increasing sulfidity from a very low 8.5% by about 23 percentage points to the more normal 31.8%, decreased Kappa No. from 57 to 36 (for a given, normal level of about 21% AA and a H-Factor of about 675). Raising sulfidity another 23 points to 55% continued to improve delignification, but at a lower rate. Total pulp yields dropped from about 62.7% to 57.5% and 55.5%, accordingly.

Figure 8 **Effect of Sulfidity on Delignification**



Comparing the differentials of yield/Kappa No, of 0.245 and 0.241, respectively, suggests that the Kappa No. decrease from 57 to 36 was more selective than the decrease from 36 to 28. Particularly for bleachable grades, there seems to be an opportunity for optimization through including an analysis of the carbohydrate or cellulose yield. When optimizing the use of different eucalypt species, it becomes virtually imperative to add this step of analysis, as becomes evident from **Figure 9**[40]. The ratio of yield loss / cellulose content differentials is about 2 for E. globulus and only about 1 for E. nitens, but to a lower cellulose content, at the same yield.

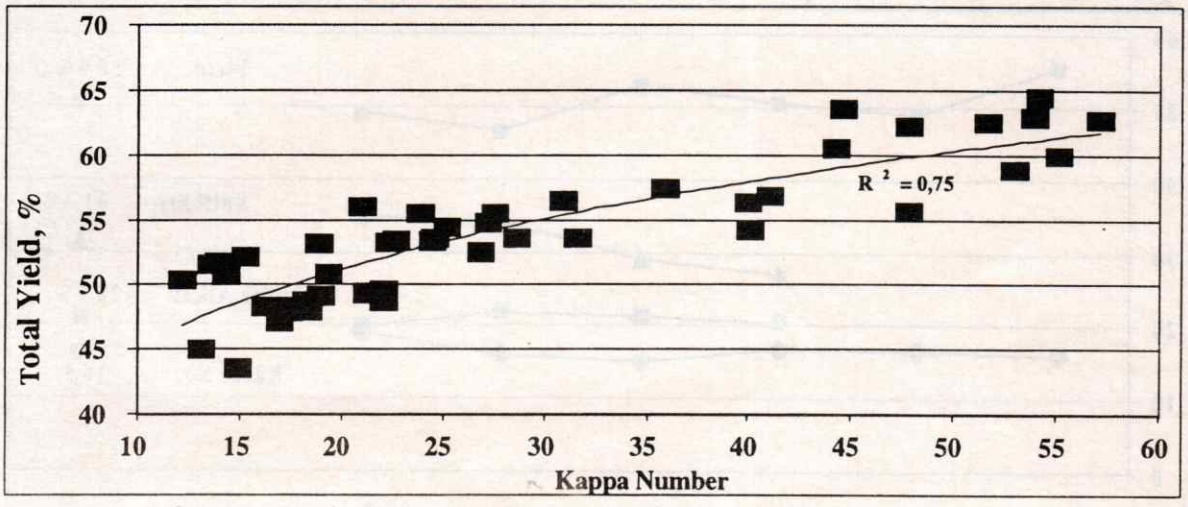
Figure 9 **Pulp Yield vs. Cellulose Content**



Below the intersecting point at about 54% yield and 44% cellulose content, E. nitens would have a higher yield for a given cellulose content,. To the right of the intersect, the relationship was in favor of E. globulus.

Pulp yield / Kappa No. relationships reported in the literature[6,7,8,15,22,25,37,38] for several different eucalypt species have a somewhat surprisingly high correlation of R^2 =0.75 between delignification level (as represented by the pulp's Kappa No.) and pulp yield, as shown in **Figure 10**.

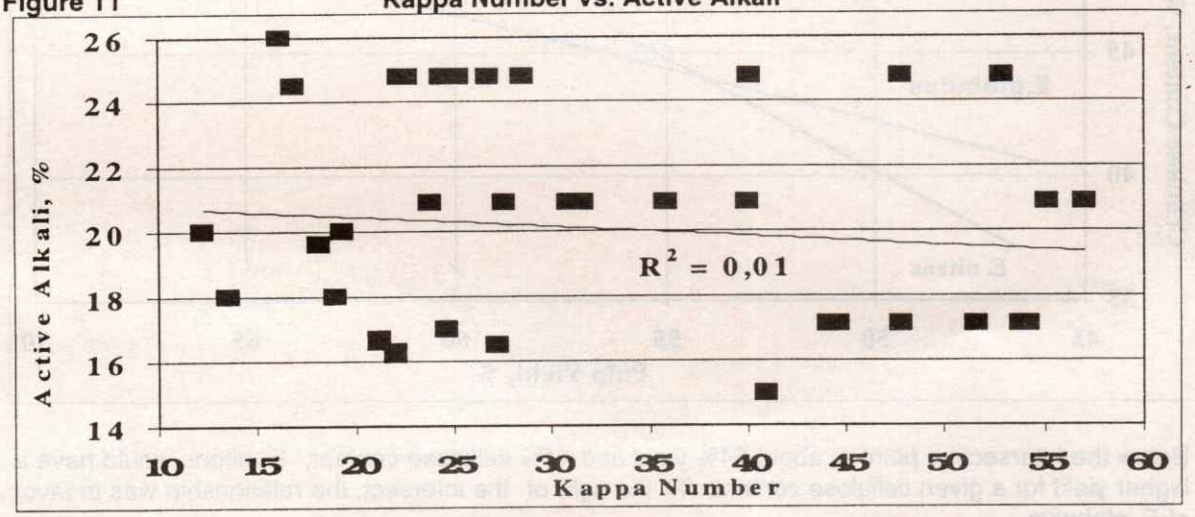
Figure 10 **Kappa Number vs. Total Yield**



For plantation eucalypts, kraft pulp yields are often strongly correlated to cellulose content[40]. The development of rapid methods of cellulose determination takes advantage of this correlation[42]. However, valid rankings require thorough background information, particularly if different species are involved. As was shown in **Figure 9,** there was a pulp yield largely because of a higher hemicellulose content.

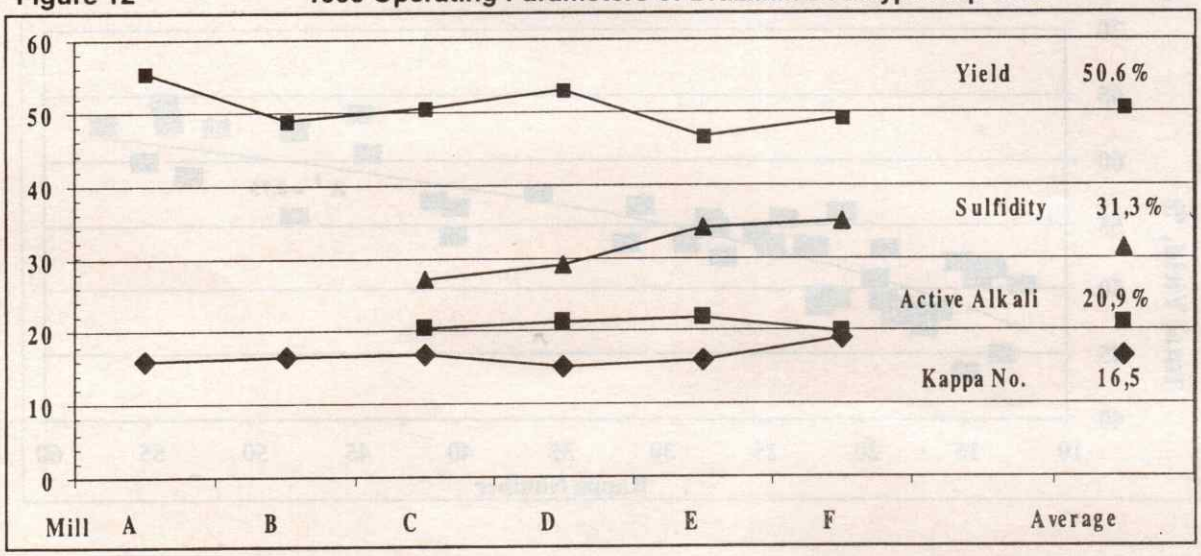
Thus, "woods of the same species can be ranked and selected on the basis of their cellulose contents, but selecting trees with superior performance from more than one species would not be valid without detailed knowledge of the cellulose vs. pulp yield relationship".
As Dillner[11] showed, high cellulose content can enhance a pulp's tear resistance, but also its beating time. This may point at the impact of varying cooking conditions on the chemical composition of the resulting pulp.
Cooking condition variables include "Active Alkali" (AA) or "Effective Alkali" (EA) charges. Data taken from the same data sources as were used for Figure 10[6,7,8,15,,25] reveal that a wide range of AA levels was applied to reach the given Kappa Numbers, as evident from **Figure 11**. The lack of any correlation indicates that other cooking variables play a more important role in establishing the Kappa No. vs. Yield relationship than AA or EA charges.

Figure 11 **Kappa Number vs. Active Alkali[6,7,8,15,,25]**



An overview of cooking parameters used by the major pulp producers in Brazil shows (**Figure 12**) that there is some variation in the level of the cooking parameters Active Alkali and sulfidity. However, a greater variation in pulp yield can be observed than would be expected from the variation of the cooking parameters only.

Figure 12 **1995 Operating Parameters of Brazilian Eucalypt Pulp Mills**



Clearly, process and equipment parameters play another important role in determining the fate of eucalypt chips as a result of kraft pulping. Extended delignification in continuous digesters has been gained widespread acceptance in the pulping industry, particularly in Brazil.

Extended delignification in batch digesters has seen in Brazil only one, recent installation for the manufacture of dissolving pulp in the Northeast.

Extended Delignification

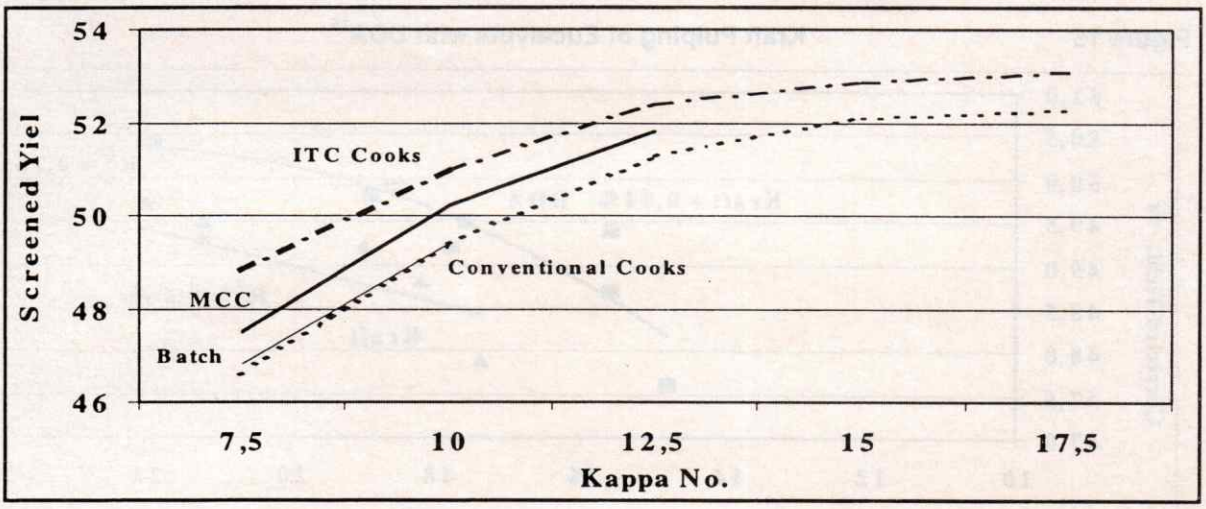
The 1994 paper by Irvine et al.[21] gives more information than the other few literature references covering extended delignification of eucalypts. The original work on extended delignification in general was carried out at the Swedish Forest Products Research Institute, the Swedish Royal Institute of Technology, and the Pulp & Paper Research Institute of Canada in the late 70's and early 80's. It led to the identification of four "key factors that allow delignification to be extended without unacceptable deterioration in pulp properties":

1. Controlled, even alkali profile throughout the cook to spare carbohydrates
2. High initial hydrogen ion concentration for bulk delignification
3. Low concentration of dissolved lignin and sodium ions to enhance delignification
4. Optimally low pulping temperature to improve selectivity

Irvine's conclusions basically confirm the results discussed earlier. Their lab experiments simulated modified continuous pulping processes with 10-year old Tasmanian plantation E.globulus. They obtained kraft pulps with Kappa No.10 and little loss in tearing strength, compared to conventional pulps at Kappa Nos. 18-20. Screened pulp yield was about 2 percentage points higher for the modified (ITC) cooks at the same Kappa No., as shown in **Figure 13**.

Modified batch pulping resulted in pulps of even lower Kappa Nos. and higher tearing strengths, but without a yield gain. This finding is in contrast to Mirams' results, who found as much as a 2% yield improvement from modified batch pulping.

Figure 13 **Extended Delignification vs. Conventional Cooks**



Therefore, some of the differences in the Brazilian mills' pulp yields may be explainable through the different extended delignification processes they use.

Kraft vs. Soda and AQ Pulping

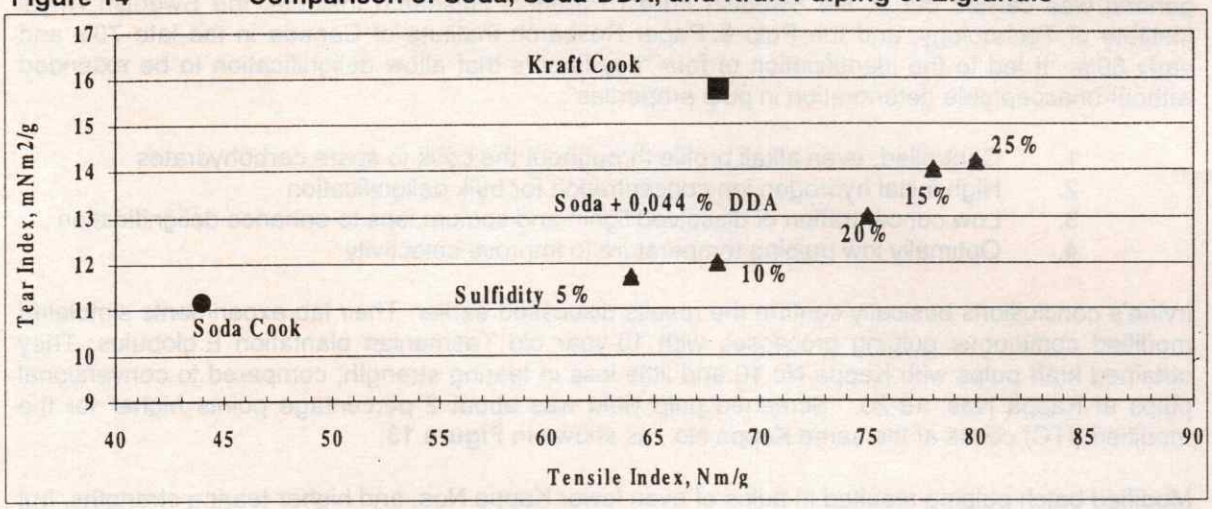
With the discovery of the benefits of anthraquinone (AQ) and related compounds, their use in soda cooks or even kraft pulping became of interest to several researchers[1, 15, 16, 24, 34, 35, 37].

Robert[34] found for E.globulus that a soda-AQ cook could produce results superior or equal to a kraft cook: faster delignification, higher yield, and identical or slightly superior strength properties. More recently, Silva and Barrichelo[35] pulped E. grandis using soda, soda-DDA, and kraft processes. They used DDA (disodium salt of 1,4 dihydro-9,10dihydroxianthracene), a compound widely used in Japan because of its solubility in cooking liquor.

Their key results are shown in **Figure 14**, where tear and tensile indexes are plotted for the cooks. The soda-DDA cooks were performed at sulfidity levels of 5,10,15,20, and 25%, using 0,04% DDA. The use of DDA allowed a reduction in active alkali and sulfidity with favorable results for pulp yield and pulp properties.

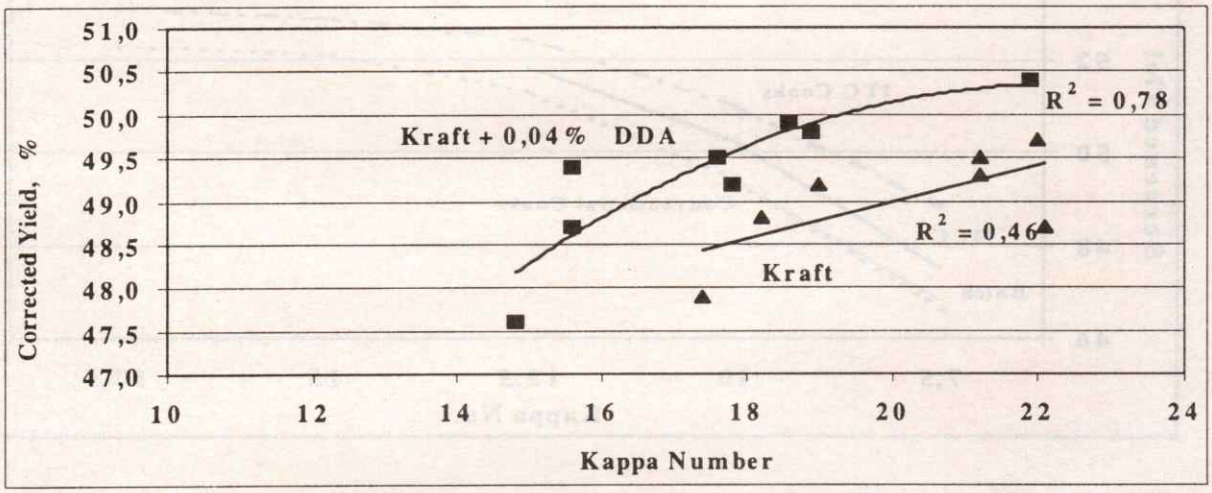
It is remarkable to see both tear and tensile strengths increase when sulfidity is raised. The addition of DDA allows great flexibility in process conditions.

Figure 14 Comparison of Soda, Soda-DDA, and Kraft Pulping of E.grandis[35]



Furuya[15] described the Japanese practice of using DDA in kraft pulping for increased production because of higher yield and shorter cooking times. However, the DDA converts to AQ during cooking and remains in the black liquor, which can lead to deposit formation in evaporator tubes.

Figure 15 Kraft Pulping of Eucalypts with DDA[15]



Black Liquor

Several references deal more or less extensively with the properties of black liquors obtained from pulping eucalypts[15, 23, 25,28,29,30,36] . There seems to be general agreement that black liquor from pulping eucalypt is more viscous at a given temperature than black liquor from pulping other woods, even though different viscosity measurement equipment was used and sometimes drastically different values were obtained[23] .

Oye et al.[29] recommended that black liquor viscosities should be compared at the same organic matter concentration. They also found that the thixotropic characteristics of the concentrated black liquor make viscosity measurements at higher concentrations difficult and perhaps not always precise.

During an alkaline cook, extractives in the eucalypt wood are dissolved and are present in the spent black liquor. Phenolic compounds, such as gallic and ellagic acids form complexes with metals that tend to cause hard deposits in evaporator tubes. Fortunately, extractives content is relatively low in the young trees from plantations.

Conclusions

This review confirms the opinions expressed by several authors, namely that further, more detailed and systematic studies of pulping eucalypts could produce valuable additional information. Specifically, the following subjects deserve future efforts:

1. Define optimal wood sampling procedures to assure obtaining statistical validity of downstream study results at reasonable economics.
2. Develop standard rapid testing procedures reliable enough to support tree breeding efforts.
3. Conduct in-depth and conclusive fundamental studies about the mechanisms, which govern the action of cooking chemicals upon wood and the fate of reaction products.
4. Examine additional Eucalyptus species for specific and superior pulp properties that will provide a superior end–use performance.

Acknowledgements

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