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PULP AND PAPER PROPERTIES AS INFLUENCED BY WOOD DENSITY
-Same species and age of *Eucalyptus* -

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ABSTRACT

A substantial amount of research has allowed the introduction of efficient techniques for genetic improvement of trees from Eucalyptus species. The basic density of wood has been identified as one of the main hereditary characteristics, to be employed as an important selection parameter for propagation of new forests. An important part of this program is the evaluation of the effect of various chemical and anatomical properties, which may be associated with wood basic density, upon industrial aspects of the production of pulp and paper.

The influence of wood basic density on chemical and anatomical characteristics, on production parameters, and on paper properties was evaluated for twenty-five hybrid trees of Eucalyptus grandis. The trees were selected at random from the same plantation site, with basic density values varying from 418 to 666 kg/m^3, at seven years of age.

Anatomically, it was observed that fibers presented smaller diameters and thicker walls as wood basic density increased. On the chemical side, denser trees showed a tendency to have more lignin and less pentosans, as compared to individuals of the same species and age, with lower density values. Fiber length and extractives content were not correlated to wood basic density, which suggests that these properties may be genetically controlled.

Pulping evaluations, performed under simulated mill conditions, indicated that pulp yield increased when basic density varied from 418 kg/m^3 to approximately 470 kg/m^3, but decreased from this point up to 666 kg/m^3, accompanied by a steady increase in rejects content. Nevertheless, an estimate for digester yield showed that production capacity can be improved through utilization of denser woods. Hence, from a production viewpoint, other aspects, such as the observed increase in chemical consumption during pulping, as well as the higher viscosity and solids content of black liquor, may become more relevant when pulping denser woods. The latter may translate into a limiting factor in production, if the recovery system is not dimensioned to handle extra loads.

Unbleached pulps of the same kappa number showed diminishing trends in viscosity and pentosan content, when wood density was increased in the range studied. The properties of paper were shown to be strongly correlated with variations in basic density. Sheet consolidation and fiber bonding decreased almost linearly with wood density, as indicated by lower apparent density and tensile strength values, which are mere consequences of lower fiber flexibility in denser woods. The porosity of handsheets, which is also closely related to sheet structure, demonstrated an almost exponential increase with wood density.

Trends in tear resistance were shown to be dependent on the amount of beating. At low to medium beating levels the tear strength was lower for denser woods, and after extensive mechanical treatment no correlation was found. All apparent variations have led to the conclusion that selection of Eucalyptus grandis trees with wood densities beyond a certain level may result in undesirable combination of paper properties, for most end-uses.

INTRODUCTION

Paper is a commodity used in a wide range of products, which, depending on their end use, have to comply with a variety of specific requirements. The papermaker can influence the characteristics of paper in a number of ways, from the choice of the fibrous raw materials to the different treatments during stock preparation, in the papermaking operation, and in the finishing and converting process. Of these the choice of raw material seems to he the most important and economical way to achieve the desired characteristics.

One of the important challenges facing the pulp and paper industry until the end of the century is the adequate selection of wood for its supply. The present status and projections into the future indicate that the eucalyptus will constitute an important part of this supply to the world.

A significant amount of research has enabled the establishment of high-quality eucalypt forests at Aracruz - Brazil. This programme was based on the development of efficient techniques for genetic selection of trees from Eucalyptus species, resulting in significant gains in forest productivity, and in wood quality. Increase in tree volume disease resistance, and site adaptability are among the improvements successfully achieved.

The basic density of wood has been identified as one of the main hereditary characteristics to be employed as an important selection parameter for the plantation of new forests through vegetative propagation. Undoubtedly, this property is measured with relative simplicity and has a significant economical impact on forestry activities. However, the relationships between the various chemical and anatomical wood properties and basic density also constitute fundamental information to be considered in the evaluation of industrial aspects related to the production of pulp and paper. A comprehensive analysis, involving economical and technical aspects from both the forest and the mill operations will certainly lead to significant improvements in the quality of the product at the lowest possible cost.

The present investigation is an attempt to contribute additional information to the same topic. The influence of wood basic density on chemical characteristics, production parameters, and paper properties was evaluated for twenty-five trees of natural hybrids of Eucalyptus grandis.

The trees were selected at random from the same plantation site, with basic density values ranging from 418 to 666 kg/m^3, at seven years of age, and processed under conditions simulating industrial experience. The uniqueness of the raw material used and the subsequent treatments utilized constitute a singular approach to the study of the relationships between wood and pulp properties.

LITERATURE REVIEW

Although wood basic density is measured by a simple method, it provides only an indication of the chemical and morphological variations which may occur in the highly complex structure of wood. Particularly in the genus Eucalyptus, the variability is large between various species (1-4) and within species due to differences between individuals, age, provenance, plantation site, and a number of factors acting during growth. Anyhow, basic density can generally be considered as an important parameter affecting pulping properties and paper manufacture (1).

Much work has been devoted to the study of the effects of wood density on pulp and paper properties of eucalypts, (2-6, 9) and other species (8,10) although, in most cases, for the former, different species have been utilized (2,3,6,9). Studies comprising the same species with varying density are rare in the literature, and, for E.grandis, the work of Taylor (5), du Plooy (4) and Barrichelo (7) can be mentioned. However, the first two authors refer to density ranges detected in trees of different ages and from various growth sites. In these cases the variations in density are also a function of age and environmental factors at different growth sites, which include additional changes affecting the interpretation of paper properties, and impairing the development of conclusions of general application. Barrichelo, on the other hand, studied the variation in wood denisty with height of different trees, having the same age, with more emphasis on within-tree variability than on differences between individuals.

Nevertheless, the general conclusions of different authors with respect to quality do not conflict with each other. For instance, Batchelor et al (2,3) showed that pulp yield, brightness, and strength decreased significantly with an increase in wood basic density, while alkali charge and refining demand increased in the same direction. Similar results were reported by du Plooy (4) for 20 trees of E. grandis grown in four different sites in South Africa, ages in the range 18 to 24 years, and by Barrichelo (7) for disc samples collected at different positions along the stems of 20 trees of E. grandis, all 6 years old.

Therefore, although the conclusions mentioned above seem to reflect general and direct influences of chemical and anatomical characteristics of wood upon pulping and paper properties, the fundamental question of how the properties from trees of the same species, with the same age and grown at the same site will vary with different basic densities has not been properly addressed. The same can be said about different aspects of pulp production, which are also of great economic value. Hence, the study, along these lines, of an unique raw material, available with a wide range of densities, at the same age, should provide a new insight into the fundamental relationships between the forest quality and the needs of the pulp and paper industry.

EXPERIMENTAL

Sampling

Special care was dedicated to sampling of trees, wood chipping, and processing, in an attempt to simulate mill conditions as closely as possible. From a total of 570 trees, twenty-five trees were selected, with basic density at breast height within the range of 418 to 666 kg/m^3. The material was collected in the region of Sao Mateus - ES, Brazil at the age of seven years (normal growth cycle).

Each tree was chipped individually, in an industrial chipper, under similar conditions (angle and sharpness of knives). The entire commercial height was utilized. After screening, also performed on a mill site, chips were collected so as to represent the whole length of the tree. A second screening was carried out in the laboratory screens, and bark was separated manually and discarded. This methodology was considered to provide samples very representative of the whole material. Handmade chips, prepared from discs, cannot be regarded as representative, since they do not include all the variation found in each individual, and do not reflect chipping stresses, which in turn may be influenced by wood density.

Chemical Analyses and Pulping

Chips obtained as described above were used for these determinations. Chemical analyses of the wood were performed according to TAPPI Standards, and included determination of ethanoltoluene extractives, lignin, and pentosans.

Cooks were carried out in M/K digesters, with stainless steel vessels. Fixed conditions were : cooking temperature, 170°C; time at temperature, 90 min; heating up period, 90 min; liquor to wood ratio, 4:1; sulfidity, 30%. The charge was always 1 kg of bone-dry wood. To obtain kappa number 20 as an objective, the charge of effective alkali was varied for each tree. This was also considered an important design parameter, as a simulation of the actual operation of a continuous digester, since cooking time is linked to production rate, and adjustments of pulp kappa number are usually made by changing the alkali charge.

After determining the ideal alkali charge, three replicates were obtained for each tree. Disintegration and washing were performed under constant conditions of water quality and temperature. The pulps obtained from the three replicates were mixed together, forming a composed sample for each tree, which was then analysed with regard to screened yield, kappa number, rejects content, pulp viscosity and pentosans content. Black liquors were collected for analyses of viscosity and solids content.

Paper Properties

The unbleached composed sample for each tree was bleached to a target brightness of 90 ± 1 °ISO, and then pressed and dried to 90% dryness, under conditions simulating the pulp drying machines of market pulp mills. The bleached and dried pulps were then utilized for characterization of paper properties. Three distinct beating replicates were carried out at each number of revolutions in the PFI mill and then mixed. Beating levels were 500, 1500, 3000 and 5000 revolutions, and the unbeaten pulp was also evaluated. Paper testing was performed according to SCAN Standards.

RESULTS AND DISCUSSION

Chemical Analysis of Wood

A wide variation in chemical properties of wood was observed as can be seen in Figure 1. Extractives contents varied from 1.0 to 1.8%; total lignin contents increased from 27.5% to 33.9%; and, pentosan contents were shown to decrease from 15.2% to 11.9% when wood density increased from 418 to 666 kg/m^3. No correlation was found between extractives content and wood basic density, which was a very interesting finding, since for increased density, with different species, a general increase in extractives content has been usually reported (9).

These observed trends in chemical composition, which were significant at the 95% confidence level (Table 1), bear immediate consequences on subsequent treatments of wood, as will be discussed later. It is important to recognize that both the hemicellulose and lignin contents in wood seem to be strong functions of basic density, and therefore the optimization of these chemical properties in the trees will apparently be linked with the selection by density. On the other hand, the extractives content appears to be controllable, since they are highly inheritable (11) by selection of lowest levels, independent of wood density.

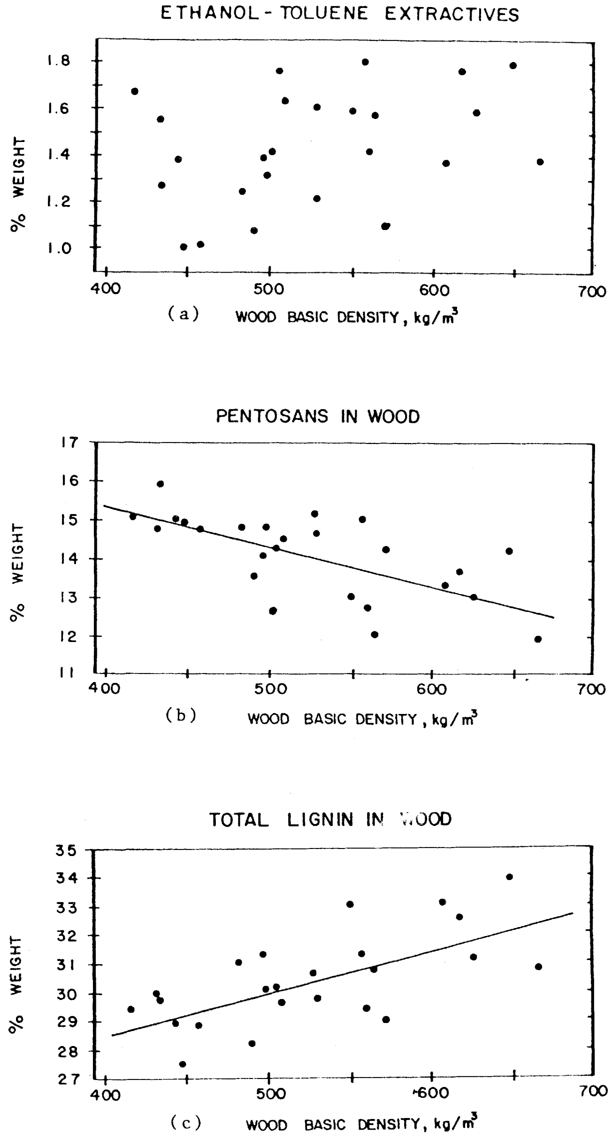


Fig 1—Variation in wood chemical properties with basic density

Morphological analyses were also performed, and they will be reported in a future study. At this point it can be mentioned that the most important observations with increase in wood basic density include:

- a steady reduction in fiber diameter, accompanied by an increase in fiber wall thickness;

- no significant variation in vessel dimensions or proportion
- the same can be said about ray parenchymateous cells;

- weighted average fiber length seems to be completely independent of wood basic density, and again this may be used as a selection parameter.

		r^2	F
% Et.-Tol. Ext	no correlation found		
% Pentosans	$= 19.1 - 9.6 \times 10^{-3} \times BD$	0.409	15.97
% Lignin	$= 22.8 + 1.43 \times 10^{-2} \times BD$	0.425	17.06

Table 1 - Linear correlations between chemical properties and wood basic density (significant at the 95% level)

Wood Density and Production Rate

The chips obtained separately from the twenty-five trees were analysed with respect to their kraft pulping behaviour. Although the kappa number of the pulps obtained was kept within the target of 20 ± 1, a wide scatter was observed in some properties. This aspect is somewhat expected, since wood is a natural material, and hence it is subjected to complex combinations of genetic and environmental factors.

Nevertheless, the correlations obtained for the curves in Figure 2 (and most of other properties) were significant at the 95% level (Table 2). For the pulping yield a second order polynomial equation provided the best fit for the relationship of pulping yield with basic density, with a maximum near 470 kg/m^3. It is worth mentioning again that the chips were cooked until the target kappa number was reached, with constant temperature and cooking time, with charge of effective alkali being varied.

This same trend, of decreasing pulping yield with increasing wood density, is reported by some authors (4,7), although not frequently. Other results in the literature, obtained mainly from studies with conifers, state just the opposite, i.e., that pulping yield increases with wood basic density (8). Although the conditions employed in such experiments may be the subject of much discussion, it can be said that compared to production rate, as estimated by the theoretical digester yield (calculated as pulping yield x basic density), the variation of pulping yield becomes of secondary importance. Since all digesters are fed by volume of wood, higher density chips will provide, within limits, a larger mass of wood per unit volume of digester, and hence higher production, as illustrated in Figure 2 ($r^2 = 0.94$; $F = 170.6$), except in extreme cases, when very high densities cause a much greater difficulty to liquor penetration into wood, and thus a drastic increase in rejects content may occur. This was not the case with laboratory results, most probably due to the ideal impregnation conditions. With these, a steady but slow increase in rejects was observed at higher densities (Figure 2).

This projection of production, obtained from laboratory data, indicates that other processing properties may be more relevant to analyse when trying to assess the influence of wood density on production rate. Variables such as consumption of chemicals both in pulping and in bleaching, and black liquor characteristics should always be considered, as they may constitute limiting factors to production capacity due to possible over-charges upon existing recovery systems.

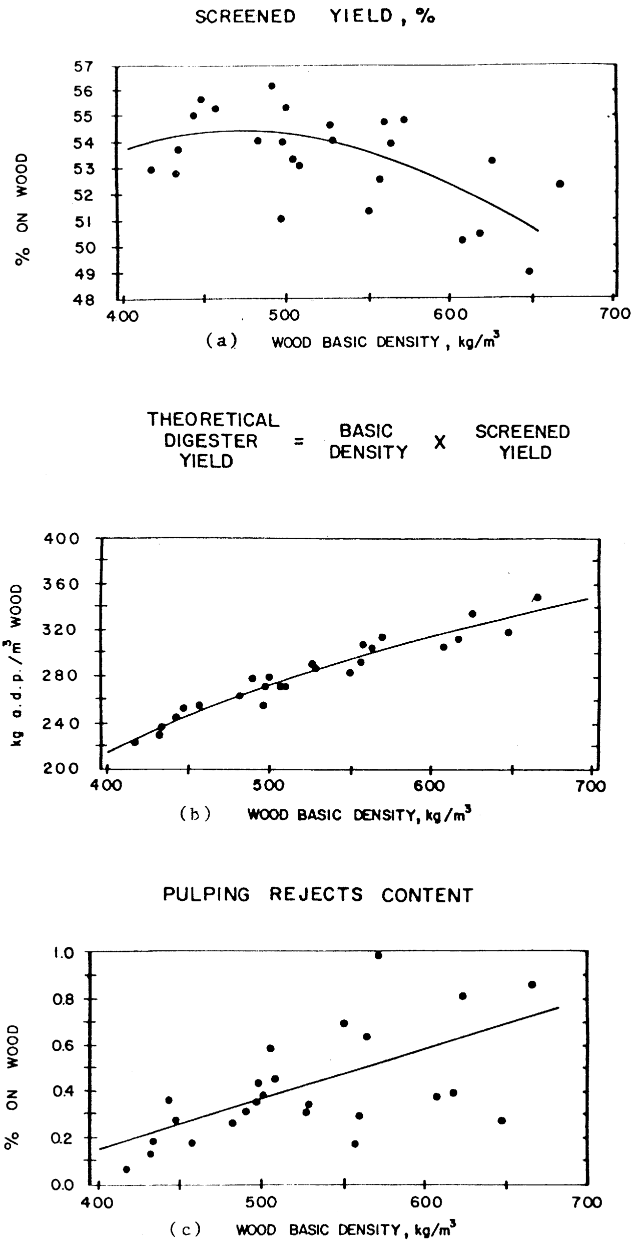


Fig 2—Pulping parameters as influenced by wood basic density

With regard to the consumption of effective alkali during pulping the data have indicated a significant correlation with wood density (and in the opposite direction, relatively to the one obtained for pulping yield), as shown in Figure 3a. It should be observed that the minimum value in the adjusted curve and the maximum value in Figure 2a, occur approximately at the same density value, that is 470 kg/m^3.

		r^2	F
Screened Yield	$= 34.0+8.69\text{x}10^{-2}\text{xBD*}-9.39\text{x}10^{-5}\text{x}(\text{BD})^2$	0.354	6.05
Rejects Content	$= -0.64+1.97\text{x}10^{-3}\text{xBD}$	0.347	12.27
Pulp Viscosity	$= -304+7.41\text{xBD}-7.88\text{x}10^{-3}\text{x}(\text{BD})^2$	0.694	25.03
Liquor Viscosity	$= 147+0.413\text{xBD}$	0.387	14.53
Kg solids in Liquor a.d.t.p.	$= 2750.5-7.33\text{xBD}+7.67\text{x}10^{-3}\text{x}(\text{BD})^2$	0.540	11.78
Effective alkali	$= 37.01-9.05\text{x}10^{-2}\text{xBD}+8.76\text{x}10^{-5}\ \text{BD}^2$	0.313	4.61

*BD = Basic density

Table 2 Correlations between laboratory kraft pulping properties and wood basic density (significant at the 95% level).

When weak black liquor properties, resulting from the cooks, were analyzed, a trend of increasing solids contents accompanying the increase on basic density was also revealed (Figure 3b). Black liquor viscosity also demonstrated a rise, although not as steep, as can be seen in Figure 3c.

Consequently, when considering both the production capacity of the pulping and recovery systems, these results suggest that a balance must exist between digester output, alkali consumption during pulping, and the effects of black liquor properties upon evaporation plant, solids to the recovery boiler, etc. in order to determine an ideal density range of wood, which will provide an optimum production capacity at the least possible cost for the whole system.

Physical Chemical Properties of Unbleached Pulps

The observed decrease in pulping yield, for trees with basic density in the range above 470 kg/m^3, may at first, be explained by the higher effective alkali demand to reach the target kappa number 20. As discussed previously, chemical analyses indicated higher lignin contents and lower pentosan contents for denser woods, and the effective alkali charge was shown to correlate almost linearly with the lignin plus extractives content in wood. Consequently, the need to dissolve more lignin from higher density woods, in order to obtain the same kappa number, could partly explain the decrease in yield. A more pronounced degradation of carbohydrates may also be expected, in addition to this process. Figure 4a shows that the curve for variation in pulp viscosity throughout the density range is similar to the trend observed for pulping yield (a maximum in the 470 kg/m^3 value is again detected).

However, there are other observations worthy of notice when analysing pulp properties, which indicate that results for pulp viscosity cannot be attributed solely to alkaline degradation. As shown in Figure 4b, it is evident that although a negative correlation exists between

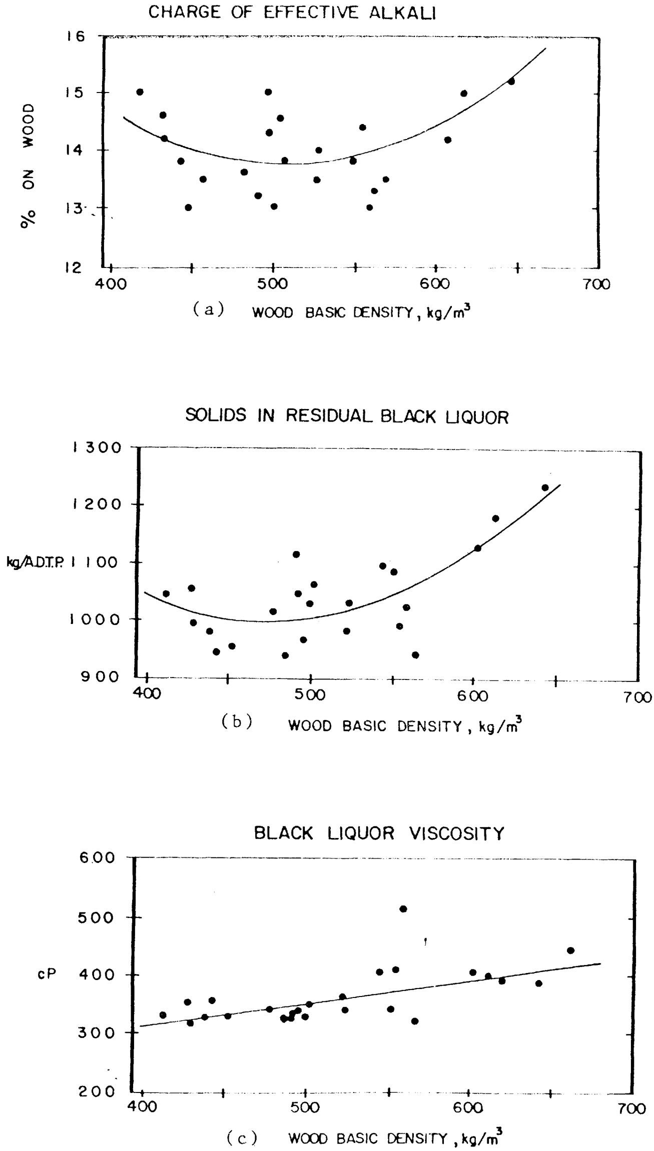


Fig 3—Consumption of alkali during pulping and black liquor properties as functions of wood density

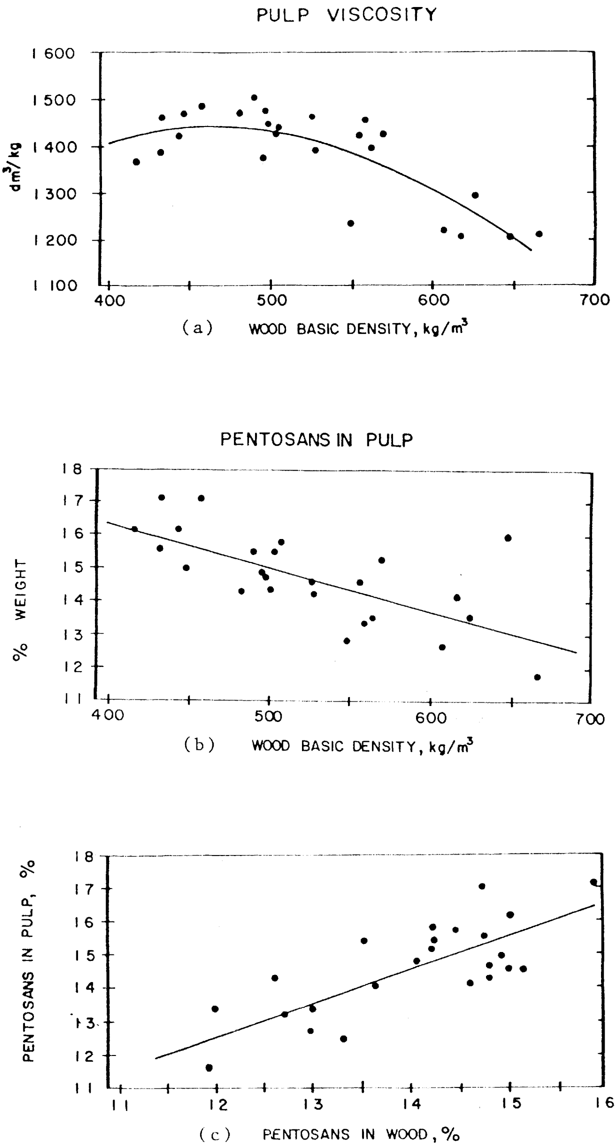


Fig 4—Properties of unbleached pulps at constant K = 20

pentosan content of pulps and wood basic density, the former correlates well (r^2 = 0.50; F = 30.9) with the initial pentosan content in wood, while no correlation whatsoever was found between final content of hemicelluloses and effective alkali charge or pulping yield.

These considerations have led to the conclusion that, at least in relation to pentosans, no preferential degradation occured with higher alkali charges, since the final content of hemicellulose in pulps was a function primarily of the initial content in the respective woods, which is a very important fact with regard to quality control in the pulp mill. Consequently, a degradation of these carbohydrates as a function of the applied alkali does not seem to have happened, and thus it becomes more difficult to understand the greater degradation of cellulose, since the access to it is even more difficult than in the case of pentosans, due to the high degree of crystallinity of the former.

One possible explanation of the observed effects in yield and pulp viscosity is the supposition, still left to be confirmed, that the cellulose chains may be found with a lower degree of polymerization (higher proportion of amorphous regions) in its natural state in denser woods, and hence they are more easily attacked by alkali, resulting in easier dissolution, and consequently in lower yield and viscosity. The association of this effect upon cellulose, with higher lignin content in denser woods, could then explain the reduction in pulping yield, and the parallel increase both in black liquor solids content and viscosity.

It is, therefore, quite clear from the results presented here that the pulping operation would benefit from higher density woods from the same species, mostly from the production point-of-view, provided the impregnation of chips is good enough to allow for minimum cooking rejects, and that the recovery system is adequately dimensioned to handle additional loads. However, quality considerations indicate that pulp properties may change in an undesirable direction, independently of how the operation is performed, since these characteristics seem to be inherent functions of wood properties, as affected by basic density. The discussion of paper properties, presented below, will provide better means to the general assessment of the pulp quality issue.

Paper Properties

Bleached and dried pulps, all in the range of 90 ± 1 °ISO brightness were analysed to evaluate their papermaking properties. Data obtained from the analysis of degree Schopper-Riegler, apparent sheet density, tensile index, tear index, air resistance and light scattering coefficient are illustrated in Figures 5 to 12, at three different beating levels. These properties were correlated to wood basic density and high determination coefficients were obtained in all cases.

The °SR of unbeaten and beaten pulps was shown to generally decrease for pulps from higher density woods. Since slowness or freeness of pulps are complex functions of fiber properties, and not well understood, it is not easy to provide, at first, a good explanation for the observed phenomena. Arnevick and Helle (12) have suggested that this measurement may be inversely related to the conformability of pulp fibers, which the morphological aspects described before tend to confirm. In any case, a better picture of the drainability properties of the pulps is usually obtained when conditions which simulate better the operation of the papermachine are utilized in the laboratory.

The first results from the ongoing investigation are indicative that pulps from higher density woods should drain faster and be wet-pressed better on papermachines, when compared at the same beating energy. Comparisons at the same amount of mechanical treatment, rather than same °SR or CSF tend to be more conclusive, as also indicated by the data in Figure 5.

Present knowledge about the structure of paper, and how fiber conformability influences paper properties (1-3) indicates that, from the morphological observations, an increase in wood basic density should result in a decrease in apparent sheet density, as it was indeed observed

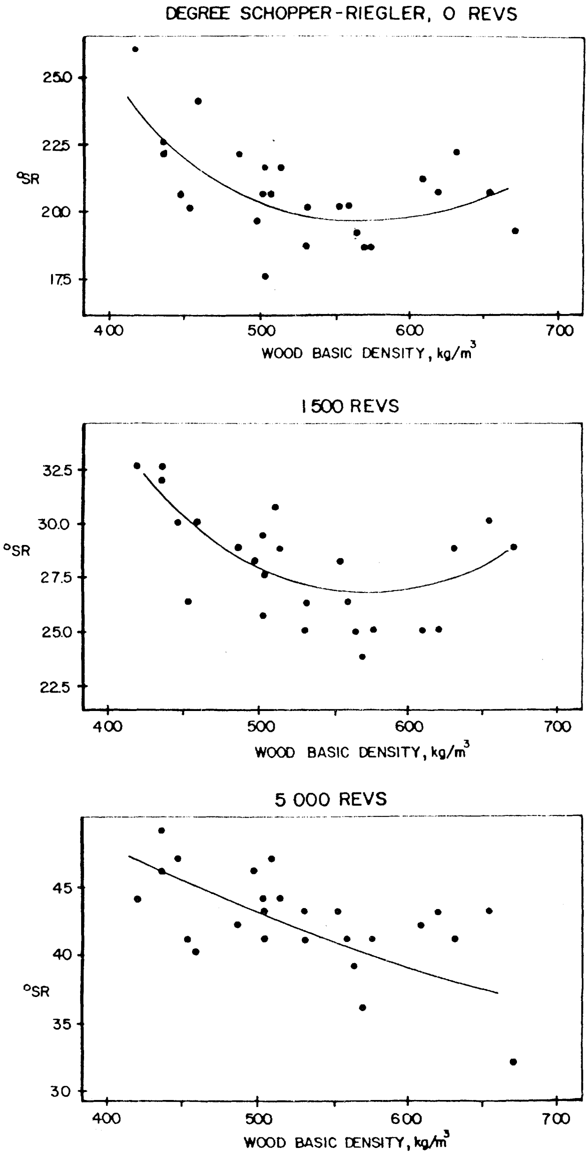


Fig 5—Degree Schopper-Riegler vs wood basic density — unbeaten pulps and beaten for 1500 and 5000 revolutions in the PFI mill

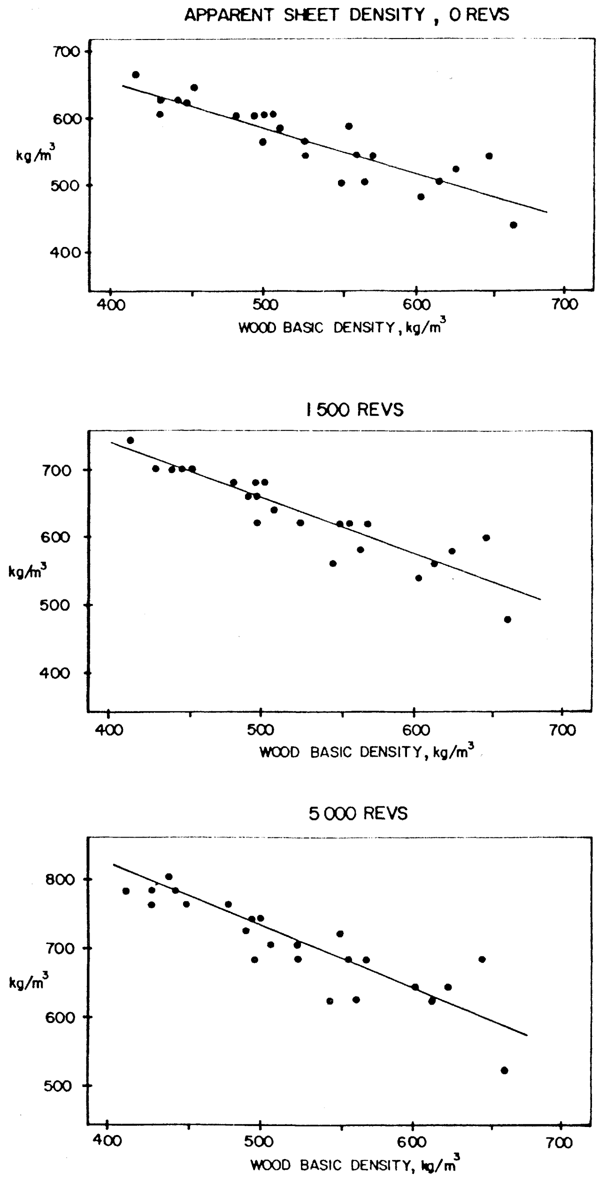


Fig 6—Apparent density of handsheets vs basic density, from unbeaten pulps and beaten for 1500 and 5000 revolutions in the PFI mill

(Figure 6). Fibers with thicker cell walls are expected to have a higher degree of rigidity, due to large moments of inertia of the fiber cross-sections (13), therefore reducing the action of consolidation forces during the formation of the paper web.

The result is a more open structure, with higher bulk, light scattering coefficient (large number of fiber-air interfaces) and porosity, as can be observed in Figures 6-8. The fact that the same trends are found for the various levels of mechanical treatment is also indicative that these properties are strongly dependent on fiber morphology. It also means that pulps from lower density wood are expected to consume less refining energy to reach a certain degree of sheet consolidation, the same holding true for paper strength as discussed later.

Other properties not evaluated during this investigation, such as surface smoothness and surface strength are expected to display the same trends as observed for handsheet bulk, due to the same reasoning.

SEM micrographs were prepared from the Z-direction profile of selected handsheets of pulps from woods with 418, 560 and 666 kg/m^3, and they are shown in Figure 9. The important differences are obvious, illustrating the high bulk and porosity of handsheets with stiffer fibers from denser woods. These fibers have thicker cell walls and also smaller diameters, providing a lower probability of fiber-to-fiber contacts, which probably are also smaller in area, and with lower hemicellulose contents, due to pulp properties discussed previously.

These characteristics will have important consequences on paper strength properties, which are known to depend mostly on the number and strength of fiber-to-fiber bonds. Due to the large number of fibers per gram, which are typical of eucalypt pulps, paper strength, in this case, is mostly controlled by fiber conformability, which is an indirect function of fiber wall thickness, and by the pentosan content, which affects not only the increase in flexibility during beating but also participates directly in the formation of fiber bonds. It

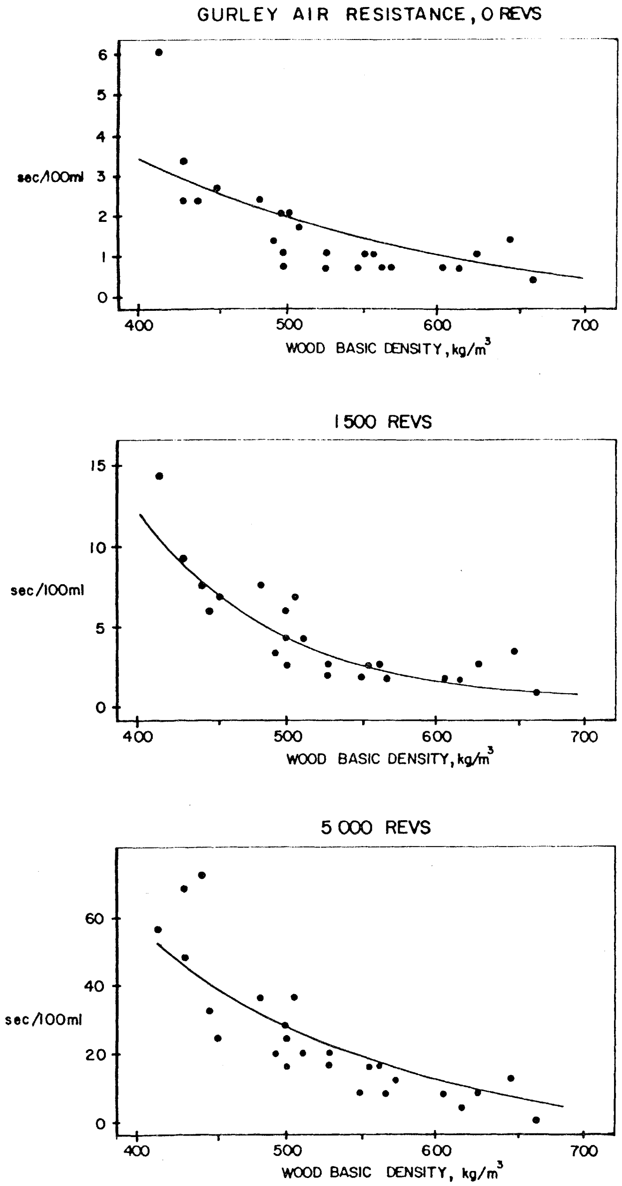


Fig 7—Gurley air resistance of handsheets vs basic density, from unbeaten pulps and beaten for 1500 and 5000 revolutions in the PFI mill

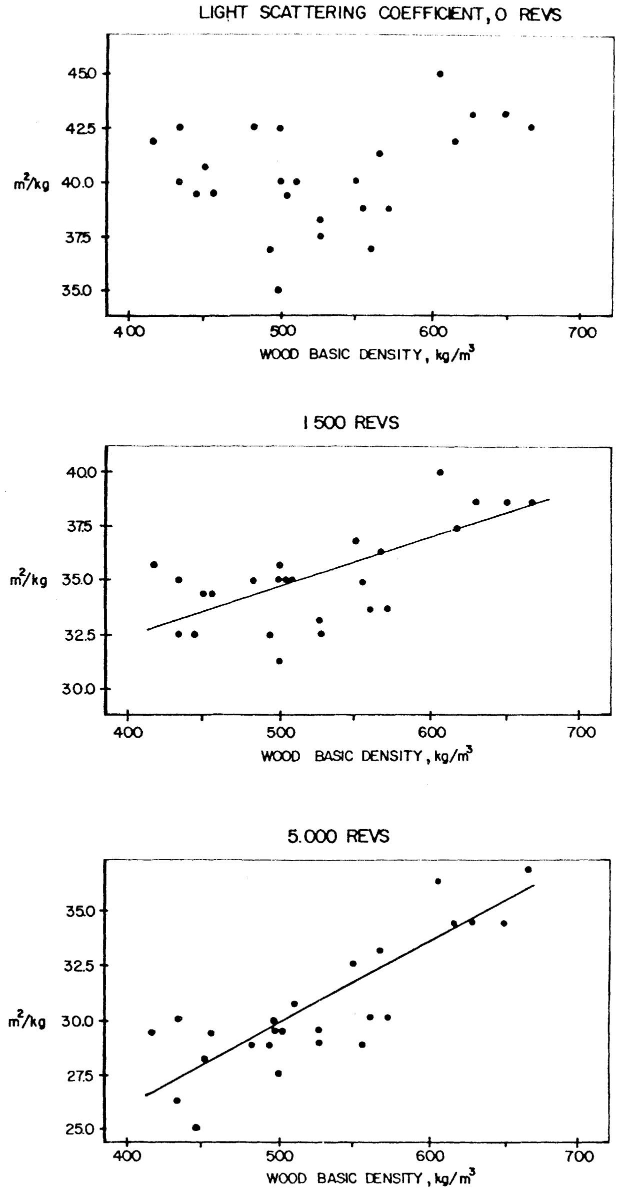
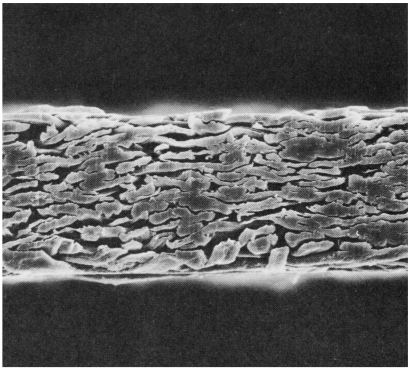
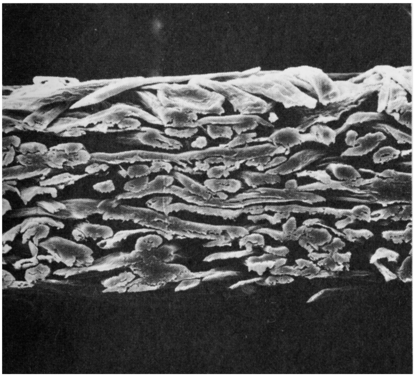


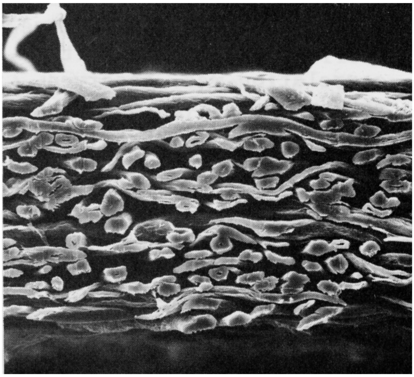
Fig 8—Light scattering, coefficient of handsheets vs basic density, from unbeaten pulps and beaten for 1500 and 5000 revolutions in the PFI mill



a. wood basic density - 418 kg/m^3



b. wood basic density - 560 kg/m^3



c. wood basic density - 666 kg/m^3

Fig 9—Scanning Electron Micrographs of cross sections of handsheets from three levels of wood basic density - unbeaten pulps, bleached and dried, 60 g/m^2 ⎵ 10μm was observed that, when the wood density of eucalypts from the same species and age is increased, both properties move in the same direction to produce a weaker paper. The result is evident in Figure 10, where a steady decrease in tensile index can be observed, and also in Figure 11 for the relationship between tear strength of paper and wood basic density.

The understanding of the data on tear strength is not as straightforward as in the case of tensile strength, since the former is a property dependent on a complex number of factors, including fiber strength, fiber length and number of fibers per gram, in addition to fiber bonding. Among these properties only fiber strength (as indicated by pulp viscosity) and the degree of fiber bonding were shown to correlate with the basic density of the wood, both changing in the direction which leads to lower energy absorption during tearing, when wood density was increased. This behaviour was evident for unbeaten pulps, as well as for those treated for 1500 revolutions in the PFI mill. After intensive beating, however, no correlation was observed, indicating that probably fiber strength was taking over from fiber bonding strength, and the tear curve was reaching a maximum for each pulp.

The tear vs tensile curves illustrated in Figure 12 help to evaluate the combination of these two important strength properties, and show that the best combination is obtained for medium to low density woods, with lower beating demands.

Therefore, pulp quality with regard to paper properties is strongly affected by the basic density of wood, mostly due to morphological factors. Since papermaking often involves optimization of raw materials and processes in order to obtain the best possible combination of properties at lowest cost, the task to draw guide lines and propose limits for desirable properties as functions of wood density is a formidable one.

Certainly the bulk, opacity and porosity of eucalypt pulps are well appreciated, and any improvement would certainly be welcome, but strength is also very important, as well as stiffness, smoothness and softness. The search for the best compromise is still going on, taking also into consideration economical and technical aspects in forestry and the pulp manufacture operation. At this point it may, however, be said that for the hybrids studied, with this growth cycle, the properties of wood with densities above 600kg/m^3 would probably cause more problems, from the manufacturing and quality points-of-view.

CONCLUSIONS

The study of wood and pulp from twenty-five trees of natural hybrids of Eucalyptus grandis, all at cutting age, 7 years, grown under the same conditions and with basic densities varying from 418 to 666 kg/m^3 has provided fundamental data with respect to morphological and chemical changes in wood, important parameters for kraft pulp production and pulp and paper quality.

Well defined trends of variation in lignin and pentosan contents were observed in wood, the first increasing linearly and the second decreasing steadily when the basic density was increased. Contrary to earlier observations by other authors, no correlation between extractives content and wood density was found. On the morphological side, the increase in basic density was accompanied by the visible presence of stiffer fibers, with smaller diameters and no significant changes in fiber length. Vessel dimensions and content were not appreciably affected either.

Production considerations in the pulp mill have indicated that although the cooking yield showed a tendency to decrease for densities above 470 kg/m^3 the production of the digester would benefit from higher density woods, being limited only by probable difficulties of impregnation for extremely dense woods, as well as overcharges in the recovery system. The stiffer fibers of denser woods with lower hemicellulose content should also allow higher speeds on pulp drying machines, due to faster drainage and wet pressing, again providing means for production rate increases.

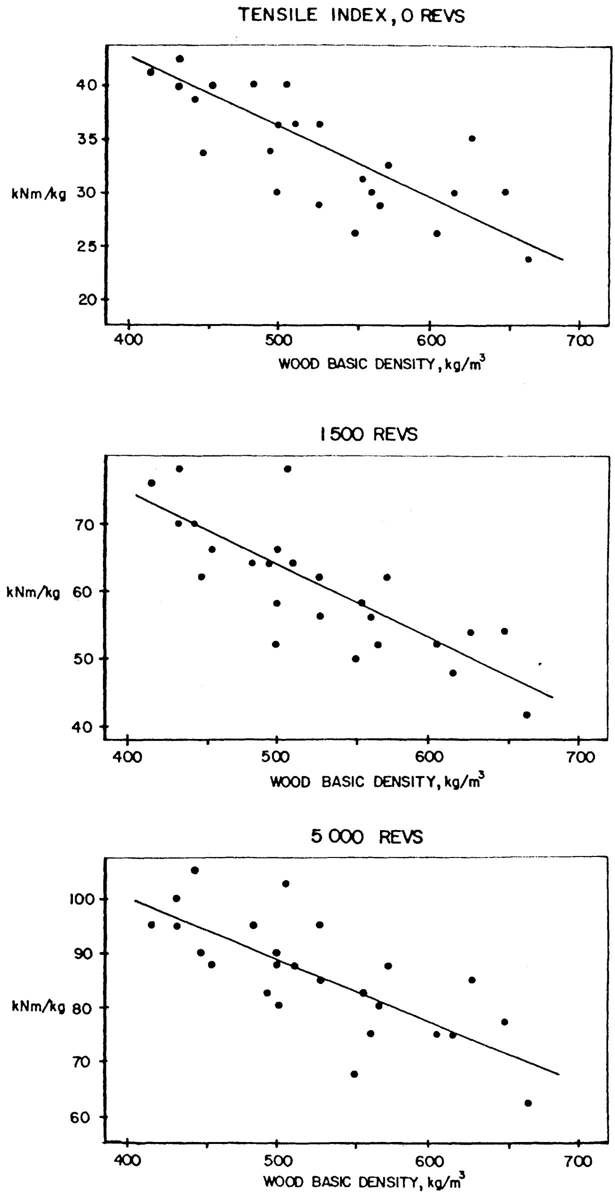


Fig 10—Tensile index of handsheets vs basic density, from unbeaten pulps and beaten for 1500 and 5000 revultions in the PFI mill

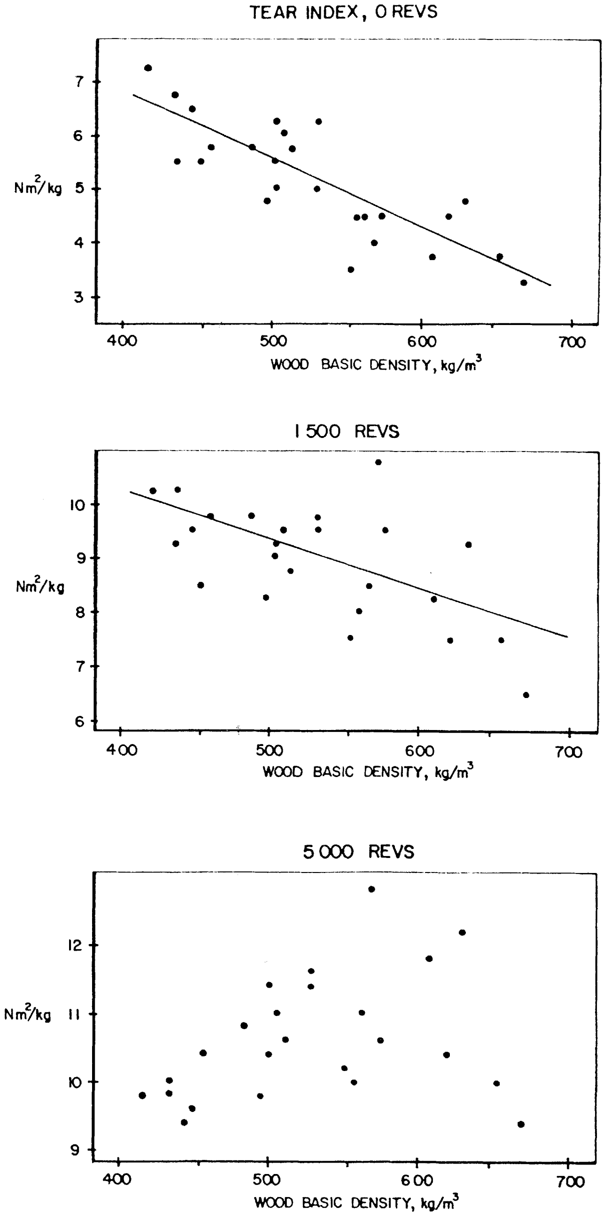


Fig 11—Tear index of handsheets vs basic density from unbeaten pulps and beaten for 1500 and 500 revolutions in the PFI mill

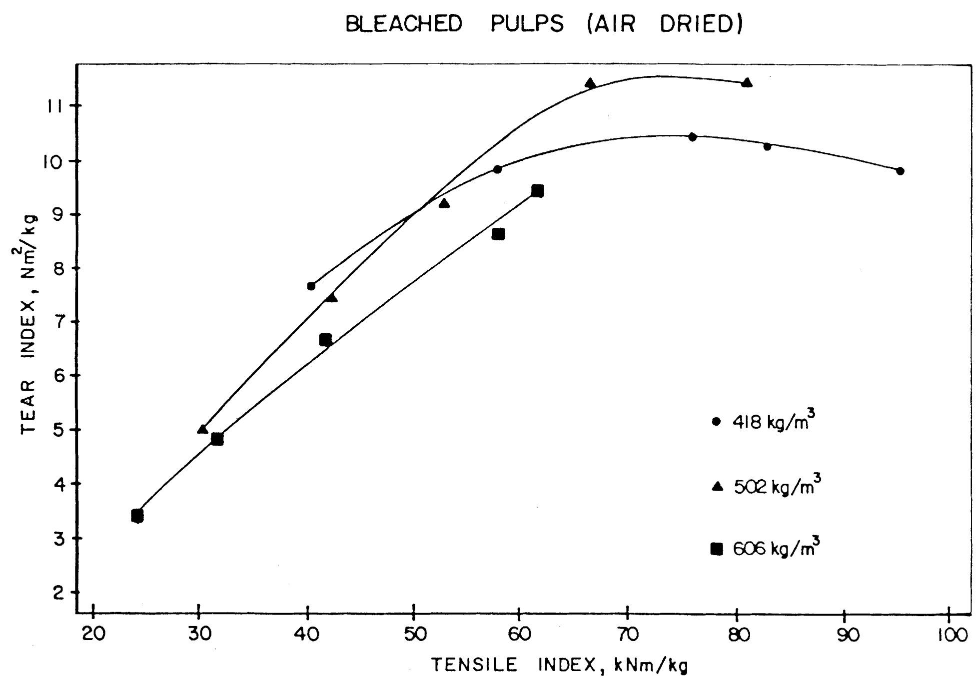


Fig 12—Tear-Tensile relationship for pulps from woods with three levels of basic density - PFI mill beating

Nevertheless, pulp quality, in general, was shown to be negatively affected when moving from low to higher density woods. Pulp viscosity and pentosan content decreased significantly, paralleled by reductions in paper strength and rise in bulk, opacity and porosity. Since papermaking often involves optimization of raw materials and processes in order to obtain the best possible combination of properties at lowest cost, the search for the best compromise should be carefully planned, taking also into consideration the different economical and technical aspects in forestry and the pulp manufacturing operation. This joint effort will provide excellent means for optimum selection and propagation of the best raw material, through the use of new and efficient techniques.

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Transcription of Discussion

Pulp and Paper Properties as Influenced by Wood Density
by R.L. Vasconcellos Dias and E. Claudio-da-Silva Jr.

Dr. P.F. Nelson APM, Melbourne, Australia

I would like to congratulate Dr. Claudio-da-Silva on a most interesting paper. I have a comment and a couple of questions.

In Australia, it is customary to determine the hot-water solubles of eucalypt wood as an indicator of the extractives content, as we have found that the greater part of the extractives consists of water-soluble polyphenols such as ellagitannins. These compounds are associated with heartwood and their amount normally increases with the age and density of the wood. Their presence contributes to a lower pulp yield in older wood. Your wood is much younger than that generally used in Australia and presumably has little, if any, heartwood, but it would be interesting to know whether the hot-water extractive content changes with basic density.

You mentioned that the vessel diameter did not increase with increasing wood basic density, but I wonder whether you observed any change in vessel frequency or wall thickness or in their response to refining which might be significant for picking. You also observed the expected increase in fibre stiffness with increasing basic density. Could you tell us what effect this had on sheet stiffness?

Dr. E. Claudio-da-Silva We use ethanol-toluene extractives when trying to relate our experimental work to pitch problems that we may experience in the pulp mill. We are continuing a very big programme of work and therefore have to be very selective in the number of analyses performed and hence have not included hot water extractives.

So far we have not noticed any change in size or frequency of vessels nor any relationship between density and vessel wall thickness. Stiffness is a paper property that we have not evaluated as yet, although it will appear in our future programme. Anyway, we should expect somewhat stiffer papers from denser woods, judging from the significant effect on handsheet bulk.

Dr. H.G. Higgins CSIRO, Victoria, Australia

Studies with different species of Eucalyptus have shown that the main determinant of basic density is in fact the ratio of the wall thickness to the fibre diameter. Have you looked at this ratio in your work? I would have expected you to have seen a very close correlation between this ratio and basic density.

Claudio-da-Silva Yes, we have plotted this ratio, but we got better results when plotting the moment of inertia of the fibres against wood basic density. As a result of earlier work (13), we estimate fibre stiffness as the product of the fibre modulus by the moment of inertia of the fibre cross section.

Dr. A.M. Scallan PPRIC, Pointe Claire, Canada

I would like to add something to what Dr. Higgins had to say. This is that the morphological feature which controls the density of softwoods is the ratio of lumen width to fibre width. It also holds true for hardwoods once correction has been made for the volume occupied by the vessels. Green and I derived the theoretical relationship in two papers [Scallan A.M. and Green H.V., Wood Fibre 5 (4) 323 (1974); 7 (3) 226 (1975)] and amongst the experimental data to which it was applied, were two species of Eucalyptus.

Claudio-da-Silva I think that is more or less what we have seen, although we got better correlations when using the fibre's cross-sectional moment of inertia than when using the Runkel ratio. It should be remembered, though, that we do not have latewood fibres in our case, and in <u>your</u> reference, they may be the controlling factor as far as basic density of wood. Furthermore, we are still collecting evidence that a great deal of basic density variation may also be due to wood chemistry.

Prof. K.J. Ebeling Helsinki University, Finland

Have you carried out full scale refining experiments and have you seen whether the effects of wood density on paper properties have become larger on industrial refiners compared to what you saw under the gentle action of the PFI refiner?

Claudio-da-Silva No, we have not carried out refining trials yet, but we are planning to do so in the near future. However, we expect to find the same trends as shown with the PFI beater.

Bridge Why is it that these twenty-five trees each have a different density?

Claudio-da-Silva I do not think that I am really qualified to answer this question, but it is possible to speculate. Firstly, wood is a natural material and variations do exist even among individuals with the same wood density. In this case, the natural hybridisation certainly played a major role, probably affecting the genetics of the material.

S.F. Loveday Townsend Hook, Snodland, England

Having for many years been persuaded by pulp salesmen that their products are uniform and that any variability is introduced by the papermaker's inadequacy, can you tell me if the figures you quote are near to the maximum range of densities you would expect?

Claudio-da-Silva This is the maximum range from this natural hybrid of <u>Eucalyptus Grandis</u>. It doesn't mean we are using this range of densities, actually we aren't, but it shows that this range is there if we should need it.

Clayton How do you account for the minimum in the charge of effective alkali at around 500 kg/m^3? The lignin content seems to rise regularly with basic density and I would have thought that would have been a major factor in controlling the required charge of effective alkali.

Claudio-da-Silva We were struck by this too. There was a very good correlation, though, between effective alkali charge and lignin content plus extractives.

Dr. P. Noe CTP, Grenoble, France

You have been talking about the possible genetic improvement in the size of vessels; what implications do you think this will have on paper properties?

Claudio-da-Silva We have seen that there is the potential to select trees with smaller vessels and with a smaller proportion of vessels, and that will most definitely lead to improved printability properties. It should also lead to improvements in the vessel picking problem associated with eucalypts in printing papers.

S. Okushima Oji Paper Co., Tokyo, Japan

According to your results, pulp viscosity appears to decrease with increasing wood density. Does this come from the chemical components of the wood or from the pulping conditions?

Claudio-da-Silva I am not sure. We have tried to simulate normal cooking conditions and in doing so we found this relationship to hold. Probably, the increased effective alkali had its influence, but since other carbohydrates were not affected as much, we also suspect that denser woods may have more accessible cellulose chains, and/or a lower DP.

Nelson Given that you are able to choose to grow trees with a wide range of basic densities from a single species, which would you regard as most suitable for the manufacture of, say, printing papers, high, low or medium density?

Claudio-da-Silva This is a very difficult question to answer because there are so many considerations involved, both during pulping and paper making. As we have stressed in the paper, there should be a joint effort of all parties technically and economically involved, in order to reach the best compromise. In other words, we must have a significant input from papermakers. On a short term basis, it is certainly safer to be conservative, and stick to the range of densities with which we are working now, before we have more knowledge in this area. The percentage of hardwood fibres in fine paper furnishes is much higher today, and this tends to continue. Therefore, the implications of such a choice are considerable, and ought to be thoroughly evaluated.

Higgins I would not like to see this discussion end without some further reference to fibre conformability. It is related on the one hand to basic density through the Runkel ratio and on the other hand to fibre properties. One consequence of this is that the relationship between bonding properties in paper and basic density is not a linear or even a monotonic function. Up to a certain basic density there is very little effect and then there is a critical area in which the bonding properties decline and they reach a certain low level beyond which again there is not much effect. This can be explained very easily in terms of a simple model relating lateral conformability to the ratio of wall thickness to fibre diameter and to the extent to which the fibres collapse during papermaking. This concept is quite basic to the relationship between density and the strength properties of paper.

Claudio-da-Silva Yes, we are aware of that curve but we have not reached that level of basic density where we may approach that plateau region, but of course we should bear it in mind. Nevertheless, the fibre stiffness concept is also valid in this case.