Wood characteristics influence pine TMP quality

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ABSTRACT *The influences of basic wood density and tracheid length on the quality of radiata pine TMP have been examined. Seven wood samples were refined on a Bauer 410, 1000-mm, double-disc refiner to produce 163 pulps for analysis. Basic wood density ranged from 345 kg/m³ to 565 kg/m³, and tracheid length ranged from 2.2 mm to 3.6 mm. Within the groups of corewood and slabwood, both wood density and tracheid length have some effect. A high tracheid length generally results in high content of long fiber, high tear strength, possibly high tensile index, and low sheet density. No simple trend was found for the overall influence of basic wood density on refining energy consumption, on sheet density, on tensile strength, or on light-scattering coefficient. It is proposed that there are compensating mechanisms that balance out the relative contributions of thin- and thick-walled fibers and their coarse fines in the development of these properties.*

KEYWORDS
Wood
Fiber classification
Chips
Juvenile wood
Mature wood
Fiber fractions
Chip classification
Cellulose fibers

The range of fiber properties that may be obtained from fast-grown plantation pines gives the pulp and paper industry considerable opportunity to vary the properties of its mechanical pulps and their corresponding paper products. These fiber properties are derived from tracheid characteristics and may be influenced by forest management practices that determine the relative proportions of juvenile and mature wood in the stem. Juvenile wood may also be obtained during harvesting as thinnings and top logs, and mature wood may be obtained as residues during sawing.

In general, industry has a good practical appreciation of the benefits of using wood with specific sets of wood quality characteristics. However, inconsistencies remain in the responses of some wood types to refiner mechanical pulping, and these inconsistencies require an explanation. Here, I present the initial results of a major study performed to extend the understanding of the critical relationships between the wood quality of radiata pine and the characteristics of its thermomechanical pulps.

Wood quality variation

Within the trunks of radiata and other pines, both basic wood density and tracheid length increase from the pith out to the bark and decrease up the trunk from the butt to the top logs, as shown in **Fig. 1** (*1*). The trunk may be conveniently divided into two components:

1. The slabwood, or mature wood, located in the outer region of the lower logs outside the 15th annual growth ring
2. The corewood, or juvenile wood, containing up to 15 growth rings and located (a) in the central region of the lower logs or in the whole of the top logs of a mature tree and (b) in the whole of a young tree (thinnings).

Slabwood will have higher basic density and longer tracheid length than corewood of the same genetic material.

Potential influence of wood quality on mechanical pulp quality

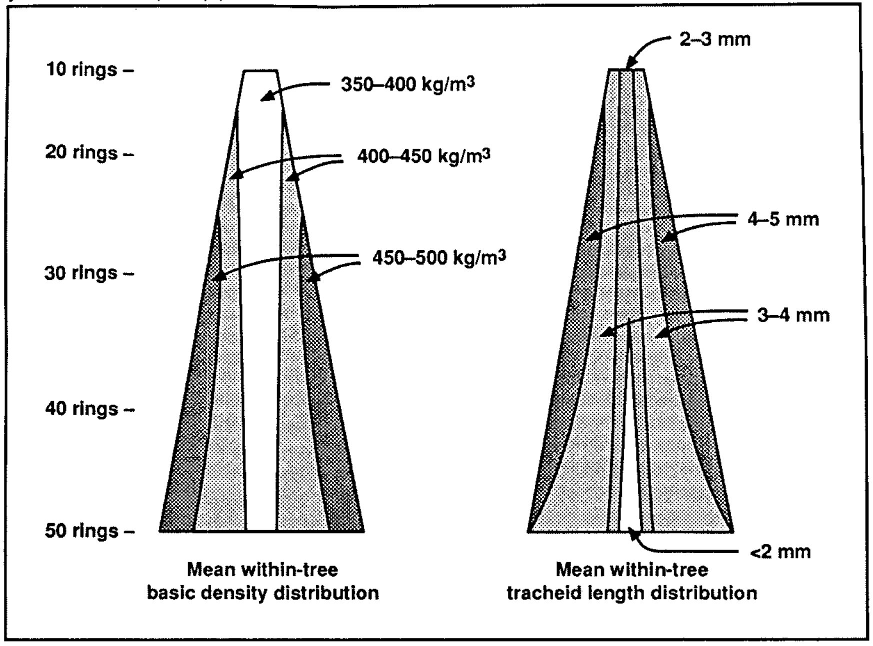
The performance of a mechanical pulp is determined by the relative qualities and quantities of its component fractions (*2*). Its basic wet web and dry sheet characteristics are defined by the interactions of the long, medium, and short fibers in the development of the fiber network. Well-developed fiber fractions consolidate to form a denser sheet with higher wet and dry tensile strength and better optical properties than the more bulky sheet formed of poorly developed fiber fractions. Sheet density will also be improved by a reduction in mean fiber length. The actual density achieved is determined by the synergistic contribution of the fines fraction. Fines assist the consolidation of the fiber network and further improve sheet density. The increased degree of fiber-to-fiber contact caused by the fines and the presence of the fines in the fiber bond zone increases sheet strength. Additionally, the fines fill the void spaces between the fibers and enhance the sheet optical and printing properties.

The nature of the fiber network developed by a specific pulp should be determined by the morphological characteristics of the wood from which it is prepared. Fiber length will influence the degree of fiber packing. Fiber diameter and fiber wall thickness may be expected to influence fiber compliability, or flexibility, both along the fiber length and through the cross-section. The performance of the fines will also contribute to the sheet behavior. Notwithstanding this reasonable expectation of a predictable relationship between wood and pulp behavior, the mechanical pulping industry has not yet developed a comprehensive model.

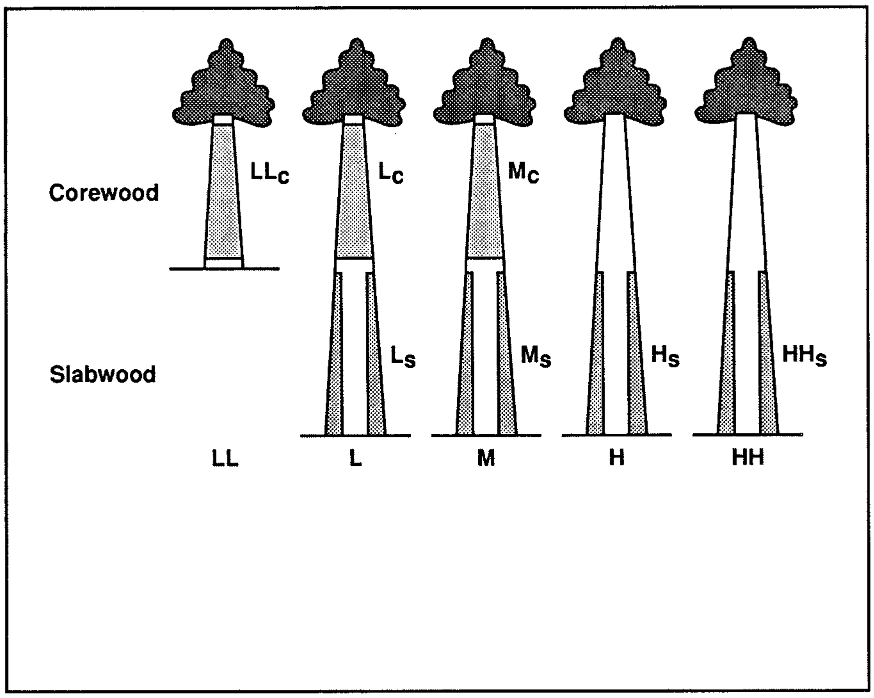
In an earlier study, I examined the influence of radiata pine wood properties on TMP quality (*3*). The density range covered 95 kg/m^3, from 360 kg/m^3 to 455 kg/m^3 within related samples of both juvenile and mature wood. The results showed that the wood type—either corewood or slabwood—was the quality parameter that had the greatest effect on wood properties. When compared on the basis of either pulp freeness, pulping energy consumption, or sheet density, the pulps of the slabwood had superior tear and tensile strength and an inferior scattering coefficient.

A particularly important finding was that the slabwood pulps had higher sheet density, compared at the same freeness value. Relative to wood type, basic wood density had only a slight influence on refining energy demand and the subsequent pulp properties of the different wood subsamples, as compared on the basis of freeness, sheet density, and tensile index. Because the separation of wood into corewood and slabwood divides the wood on the basis of both basic

1. Mean within-tree distributions of basic wood density and tracheid length for typical 50-year-old radiata pine (*1*)



2. Origin of wood samples



density and tracheid length, this finding that basic wood density was of secondary importance after wood age suggested that it was tracheid length (or some factor associated with it) that controlled pulping performance. Because tracheid length was not measured in this earlier study, its specific influence could not be evaluated. Others have studied the influence of wood properties on mechanical pulp quality but have been equally unsuccessful in finding a strong effect related to basic wood density (*4–6*).

The paradox of corewood behavior

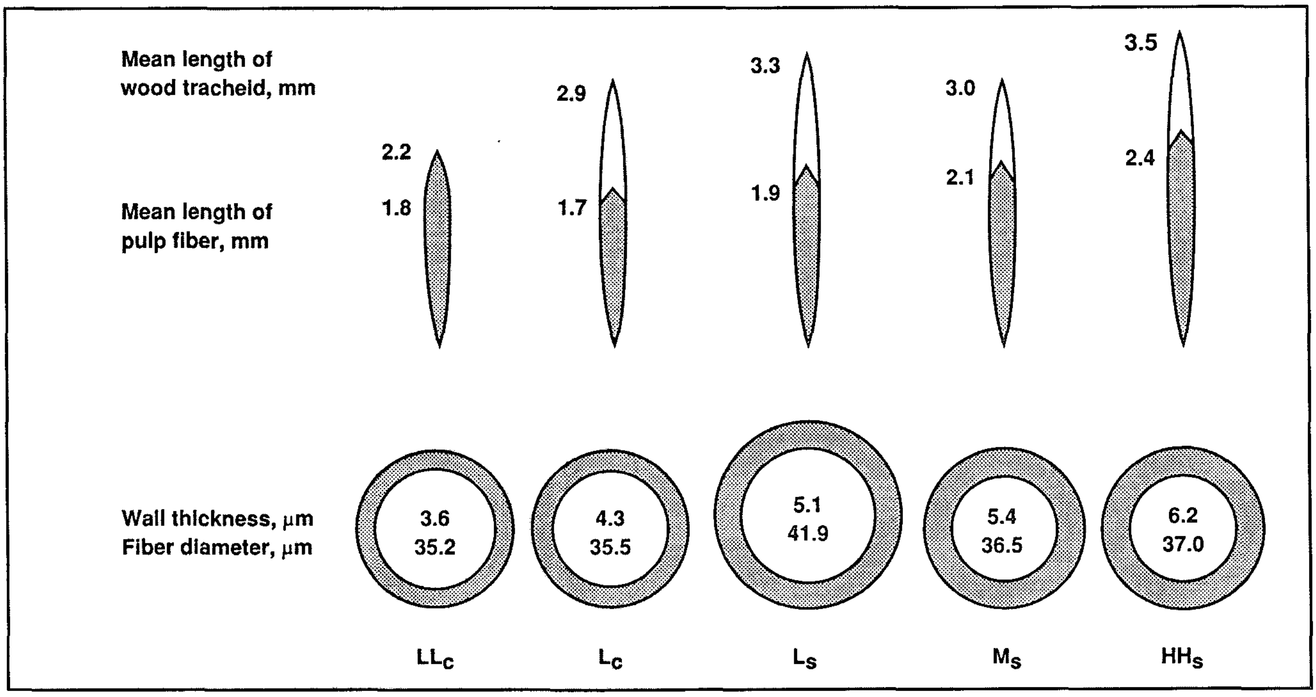
The thin-walled fibers of radiata pine corewood may be expected to have

1. Wood age, wood densities, tracheid lengths and other properties for the corewood and slabwood samples

Code	*Wood age, years*	*Basic density, kg/m³*	*Tracheid length, mm*	*Oven-dry content, %*	*Fiber diameter,* μm*	*Fiber wall thickness,* μm*	*Mean pulp fiber length,* mm*
				Corewood			
LL_c	11	345	2.2	34.3	35.2	3.6	1.8
L_c	11	375	2.9	36.8	35.5	4.3	1.7
M_c	13	425	2.5	41.4	...	...	1.8
				Slabwood			
L_s	26	390	3.3	36.7	41.9	5.1	1.9
M_s	27	465	3.0	41.9	36.5	5.4	2.1
H_s	44	515	3.6	46.1	...	...	2.3
HH_s	46	565	3.5	50.1	37.0	6.2	2.4

*At a freeness of 105 mL CSF.

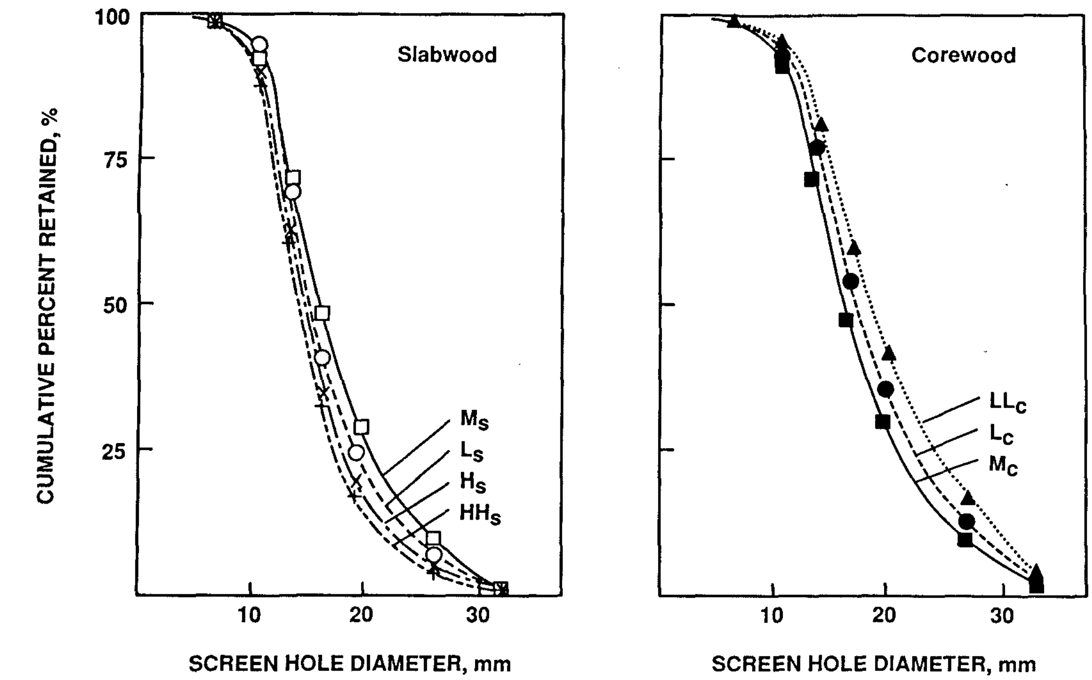
3. Scheme of mean wood tracheid and pulp fiber dimensions of selected samples at 105 mL CSF



advantages over the thick-walled slabwood fibers in refining energy requirements and pulp quality development. Conceptually, the thin-walled fiber should flex easily during refining and develop quality more readily and with less fiber length reduction than the thick-walled fiber (7). Supposedly, the corewood would require less energy to refine to a specific freeness and would have higher sheet density and higher tensile strength. These effects would result from the higher incidence of fiber-fiber contact, from the greater fiber bond area attained by the more pliable fibers, and from the tighter packing of the shorter corewood fibers.

However, this behavior is not observed. Corewood pulps usually have lower sheet densities and never have higher sheet densities than slabwood of equal freeness. Also, corewood requires at least as much energy as slabwood to develop freeness. For thinnings, the corewood requires substantially more energy than does the slabwood.

4. Size distribution profiles of corewood and slabwood chip samples



Project strategy

The purpose of the present project was to identify the relative influence of both basic wood density and tracheid length on TMP quality in a single, integrated refining study of wood samples from selected forest stands. Replicate refining of all samples in a single, randomized series was specified to eliminate potential within-project and between-project variations in refining response. The influences of basic wood density in the range of 345-565 kg/m³ and tracheid length in the range of 2.2-3.6 mm were examined.

When the project was initiated, the scheme was to examine at least two basic wood densities at each of three tracheid lengths: 2.5, 3.5, and 4.5 mm. Additionally, to allow for the comparison of wood types, each sample of corewood was to have the same tracheid length as a corresponding sample of slabwood. An earlier analysis of mean basic densities of the outer wood at breast height of 7500 trees growing on 250 sites suggested that this tight,

II. Thermomechanical pulp quality at 100 mL CSF

	Corewood			*Slabwood*			
	LL_c	L_c	M_c	L_s	M_s	H_s	HH_s
Bauer-McNett classification							
Fraction							
+30	23.3	25.4	29.6	34.5	35.9	39.8	39.5
100/200	7.2	9.4	7.1	8.0	5.9	6.1	6.0
-200	33.6	33.6	31.2	31.3	30.9	31.1	30.1
Handsheet properties							
Physical properties							
Sheet density, kg/m³	368	352	351	373	358	356	348
Air resistance, s/100 mL	42	38	32	65	41	50	51
Strength properties							
Tensile index, N • m/g	34.3	32.6	34.6	39.8	38.2	37.8	37.3
Tear index, mN • m²/g	8.9	7.5	8.5	9.5	10.8	11.2	11.6
Burst index, kPa • m²/g	2.2	2.0	2.2	2.7	2.6	2.6	2.5
Optical properties							
Scat. coef., m²/a.d. kg	52.9	56.7	50.5	51.7	49.5	48.2	49.8
Opacity, %	95.6	96.3	95.4	95.8	96.3	96.2	96.2

Handsheet property values were calculated from regression equations.

III. Comparison of linearized regressions of selected pairs of wood samples, as a function of freeness

Wood samples compared	*Bauer-McNett fraction, %* +30	*Bauer-McNett fraction, %* 100/200	*Bauer-McNett fraction, %* -200	*Sheet density, kg/m³*	*Air resistance, s/100 mL*	*Tensile index, N•m/g*	*Tear index, mN•m²/g*	*Burst index, kPa•m/g*	*Scattering coefficient, m²/a.d. kg*	*Opacity, %*
					Within stem class, between wood type					
L_c vs. L_s	**	**	**	*	**	**	**	**	**	**
M_c vs. M_s	**					**	**	**		**
					Within wood type class, between wood density and tracheid					
L_c vs. M_c	**				**		**		**	**
L_c vs. M_s	*				*	**	**	**	**	*
L_s vs. M_s	*				**		*		*	
L_s vs. H_s	**			*	*		**		**	**
L_s vs. HH_s	*			*	*			**	**	*
H_s vs. HH_s										
					Within tracheid length class, between wood density					
LL_c vs. L_c	**					**		**	**	**
LL_c vs. M_c	**	*	*	*	*				*	*
M_s vs. H_s	*								*	*
M_s vs. HH_s	**									

*Significant difference at 1% level.
**Significant difference at 5% level.

For values of wood density and tracheid length, see Table I.

three-level experiment was feasible (*8*).

It was only after the selected wood samples had been chipped that important deviations in the target and actual tracheid lengths could be identified. In particular, the tracheid lengths of the slabwood samples were generally lower than expected. Also, the tracheid lengths of the corewood and slabwood of the low-density sample (denoted as L_c and L_s) were higher than expected. These variations indicate the difficulties involved in selecting wood samples with specific properties in the large quantities required for pilot-scale refining.

Experimental procedures

Wood samples

Seven wood samples were extracted from compartments within Kaingaroa and Tairua Forests in the Bay of Plenty region of the North Island of New Zealand. The sampling scheme is shown in **Fig. 2**. Related subsets of corewood and slabwood were obtained from each of two sets of trees. In the sample coding, the samples were classified by basic density within subgroups of corewood and slabwood. Basic density classifications were:

LL = lowest density
L = low density
M = medium density
H = high density
HH = highest density.

Low-density, short-tracheid wood was obtained from both young trees (LL_c) and the tops of older trees (L_c and M_c). High-density, long-tracheid wood was obtained from the slabwood of old trees (H_s and HH_s). Wood, tracheid, and fiber properties are presented in **Table I** and **Fig. 3**. The fibers are those of the +30 Bauer-McNett fraction of selected pulps of 105 mL CSF.

Enough logs were obtained to prepare 5 metric tons (oven-dry equivalent) of chips for each wood sample (from 10 logs to 50 logs).

Chip preparation

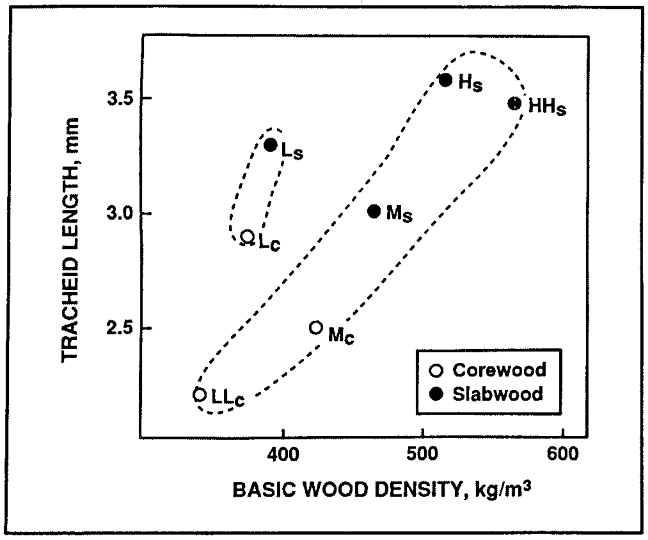
During chip screening, oversized chips of 40+ mm were rejected back to the disc chipper, and undersized material of 10- mm was rejected to waste. Within both the corewood and the slabwood categories, there were consistent trends for chip size to increase with decreasing basic wood density, as shown in **Fig. 4**.

Refining

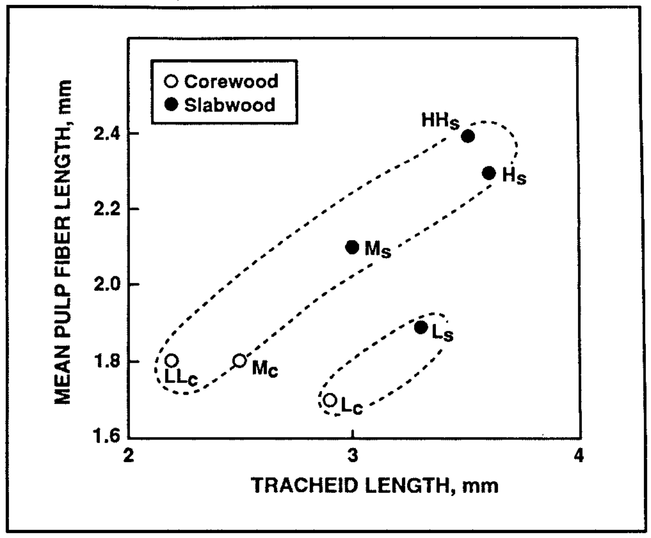
Refining began within two weeks after the trees were felled, and it continued for three weeks. Thermomechanical pulps were produced in PAPRO's atmospheric, 1000-mm, 400-kW, double-disc, Bauer 410 refiner. The chips were batch preheated for 5 min at 125°C immediately prior to refining.

To acquire adequate data for regression analysis, we performed 6–10 multi-stage refining sequences for each wood sample, to produce pulps in the target freeness range of 50–250 mL CSF. In all, 163 pulps were evaluated for their pulp and handsheet properties. Representative pulp properties at 100 mL CSF are presented in **Table II**.

5. Tracheid length vs. basic wood density, showing long tracheid characteristic of Sample *L*



7. Mean pulp fiber length at 100 mL CSF vs. wood tracheid length, showing loss of pulp fiber length for Sample *L*



Fundamental evaluation

Two sets of pulps, either with a common freeness of 105 mL CSF or with a common consumption of refining energy, were chosen to determine the effects of wood quality on the fundamental characteristics of the individual fractions. The results from the series of common freeness are presented here.

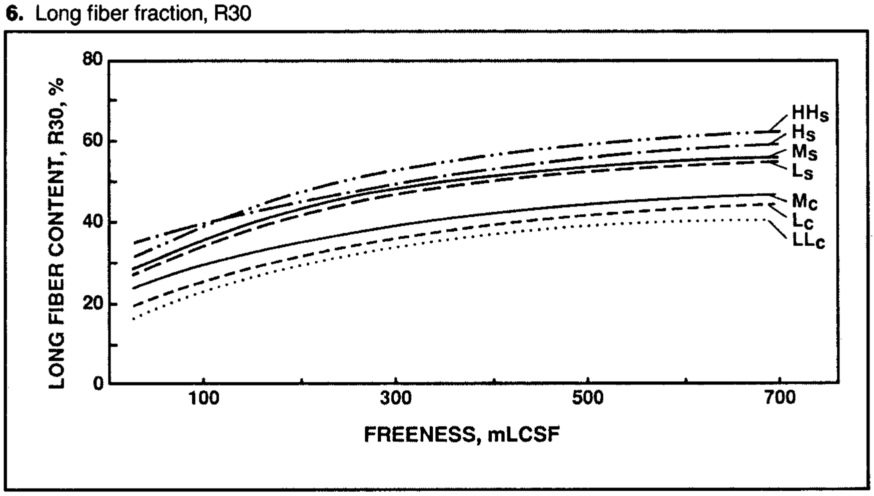
Statistical analysis

Pulp quality has been examined as a function of pulp freeness, consumption of refining energy, sheet density, and tensile index. Here, the variations observed with respect to freeness are discussed. Only the individual influences of basic wood density and tracheid length are considered.

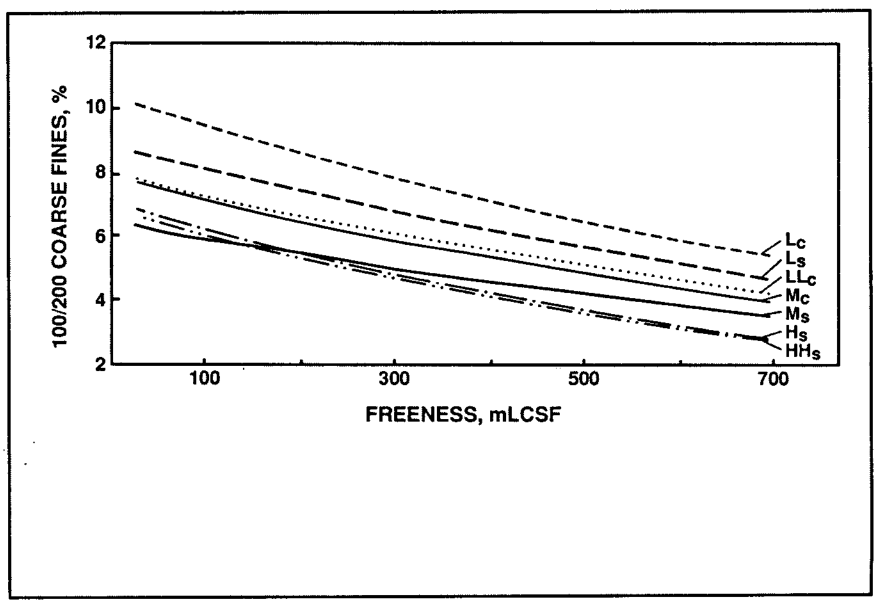
The various influences of the wood properties on the pulp properties were determined by comparing regressions between the dependent variable (e.g., the +30 fraction) and the independent variable (freeness) for selected pairs of wood samples, as presented in **Table III**. This table shows the instances in which statistically significant differences exist between the properties of pulp of the various wood samples (e.g., between L_c and L_s).

The data of Table II and the general pulp property curves presented here were plotted from the calculated regression equations. Differences between individual pulp property curves may be examined with respect to the information of Table III. Multiple regression analysis was not used

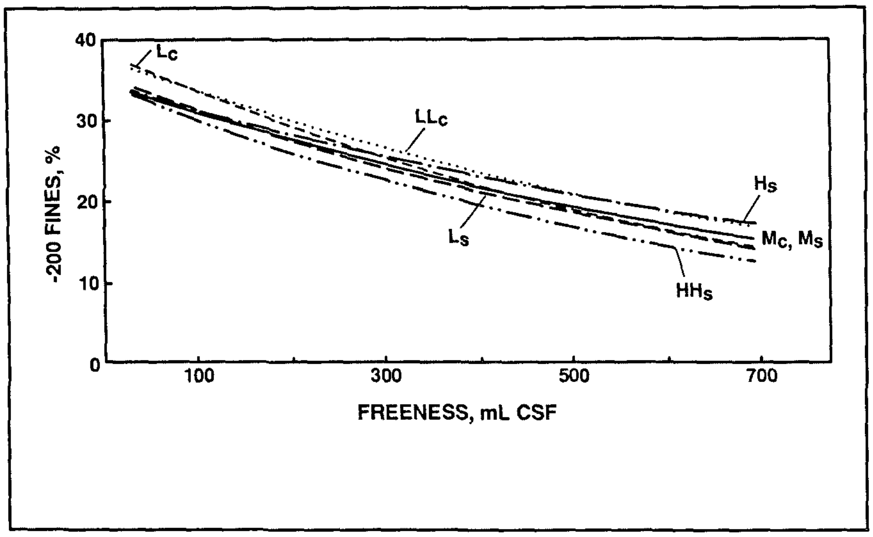
6. Long fiber fraction, R30



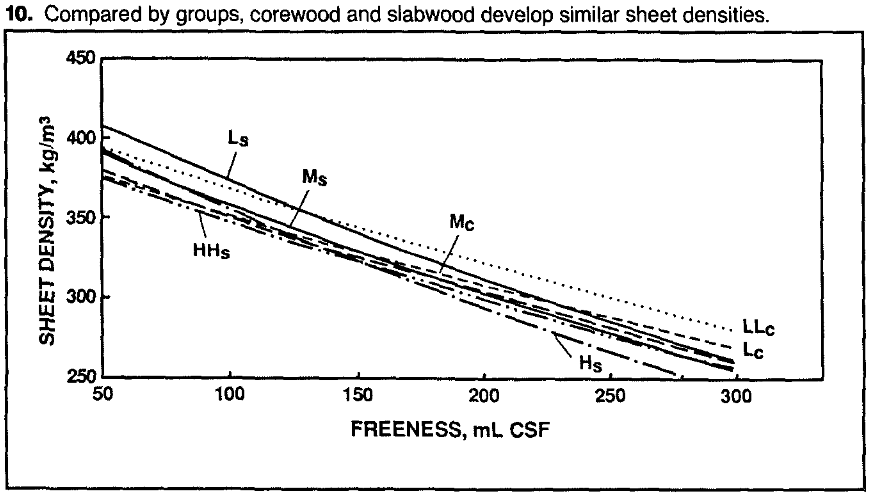
8. Relative magnitudes of the coarse fines fraction (100/200)



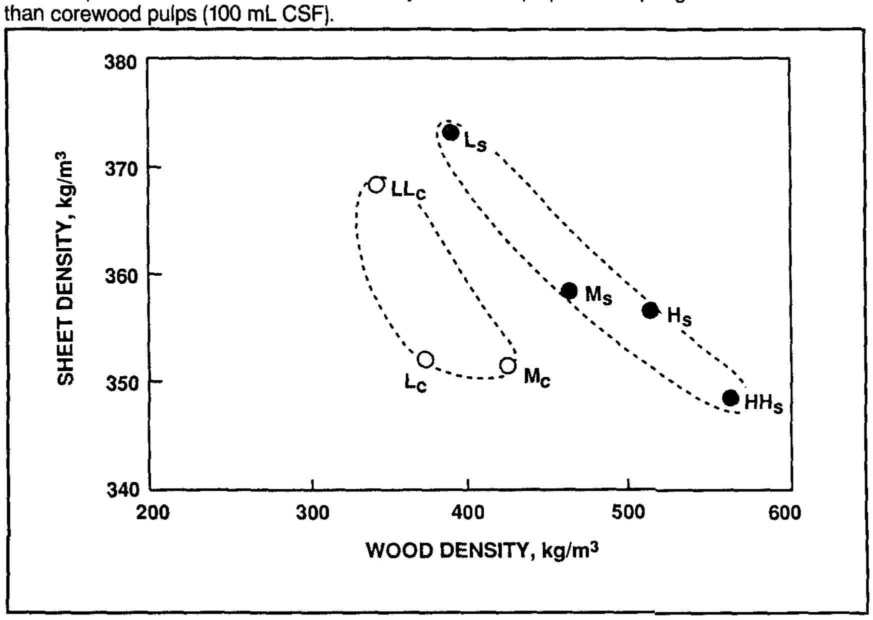
9. Similarity of the magnitude of the fines fraction (-200)



10. Compared by groups, corewood and slabwood develop similar sheet densities.



11. Compared on the basis of wood density, slabwood pulps develop higher sheet densities than corewood pulps (100 mL CSF).



because earlier experience had shown that the individual pulp properties are dominated by the influence of wood type (corewood or slabwood) (*3*).

Wood, fiber, and pulp characteristics

Despite the range of basic wood density covered, the comparisons made by Kibblewhite et al. (*9*) of the fiber cross-sectional diameters, fiber wall thicknesses, and width-to-thickness ratios of the collapsed fibers showed few significant differences between the various wood samples, particularly when compared within wood types. Specifically, the fibers of L_s had larger diameters than those of the related L_c. Furthermore, the fiber walls of HH_s were thicker than those of the other wood samples, while those of LL_c were thinner than those of other samples.

As expected, tracheid length increased with basic wood density, as shown in **Fig. 5**. The tracheid lengths of L_c and L_s were, however, longer than those of the other samples. Indeed, the pulps of wood L were not always consistent in their behavior relative to the other samples. The reasons for this different response are currently being sought.

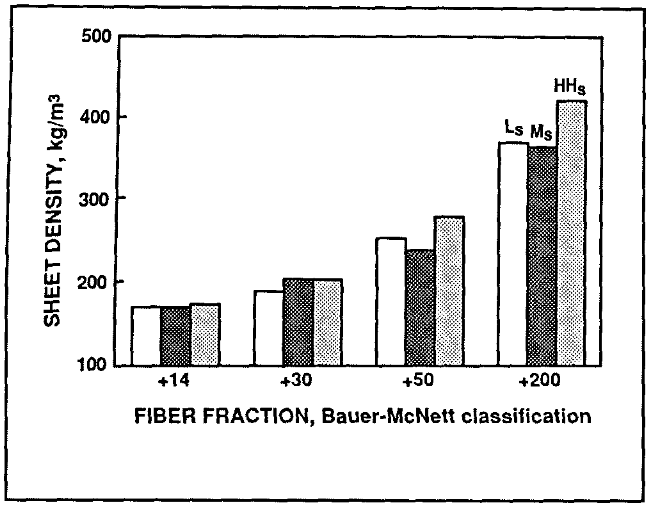
There was less variation in some pulp properties than might have been reasonably expected from the range of wood basic densities and tracheid lengths involved. In particular, there were only slight differences in the -200 fraction, sheet density, and tensile strength characteristics, when compared against freeness. Conversely, important differences in pulp energy consumption, long fiber content, 100/200 fraction, tear index, and scattering coefficient were obtained. These behavior patterns are discussed in the following sections. Wood density and tracheid length influences are discussed for those situations in which they were found to play an important role.

Fiber and fines fractions

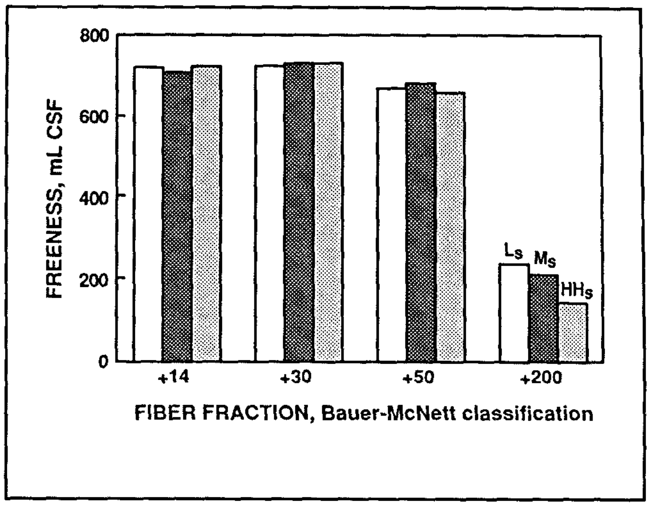
Long fiber

Within each wood type, whether corewood or slabwood, the long fiber content (R30) is strongly ranked by wood density and tracheid length, as **Fig. 6** shows. This influence of wood density may be attributed in part to

12. Sheet density characteristics of fractions of selected slabwood pulps of 105 mL CSF, based on their fines-free furnishes



14. Freeness characteristics of fractions of selected slabwood pulps of 105 mL CSF, based on their fines-free furnishes



the wood age relationship between basic wood density and tracheid length (Table I). Also, for an equal number of fibers, those fibers from wood of higher basic density will have a greater mass per unit length than fibers from wood of lower density. This difference will cause a proportionate increase in the weight fraction of fibers with thicker walls and will influence the Bauer-McNett result (*6*). Generally, however, it is tracheid length and wood type—and not basic density—that control the long fiber content.

The long fiber contents of both the corewood and the slabwood of Sample *L* are not retained during refining. These samples lose proportionately more fiber length than do the other samples, as **Fig.** 7 shows. This finding cannot be attributed to their low density and thin fiber walls, because LL_c does not undergo a similar reduction in length.

100/200 coarse fines

Although the relative magnitude of the 100/200 coarse fines is small, this fraction makes an important contribution to pulp behavior. As a group, the corewood pulps have more of this fraction than do the slabwood pulps, as **Fig.** 8 shows. There is a trend for the magnitude of this fraction to increase with decreasing wood density and, hence, with decreasing wall thickness.

The one exception to this trend is the reduced contribution of the sample of lowest density, LL_c. This exception may be due to the high values of L_c and L_s.

-200 fines fraction

The magnitudes of the -200 fines fractions of all samples are generally similar, as **Fig. 9** shows.

Sheet consolidation

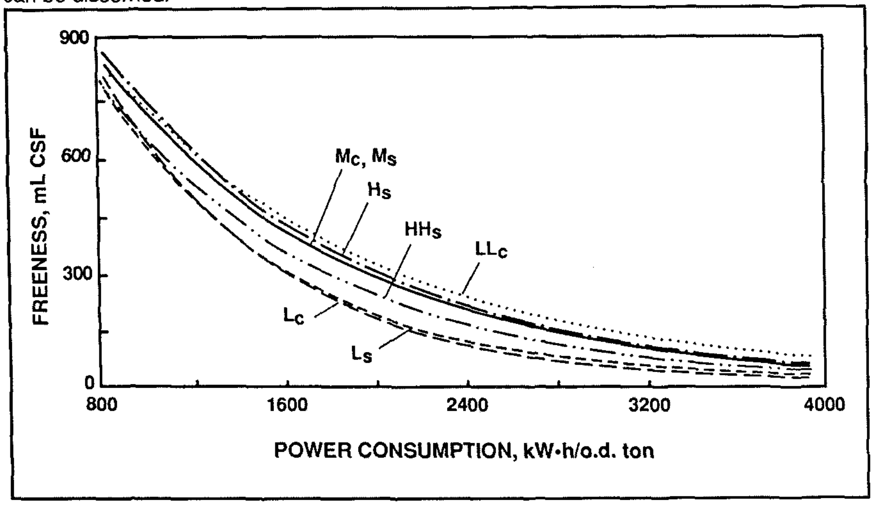
The pulps of both the corewood and slabwood develop similar sheet densities when compared as groups, as **Fig. 10** shows. The slabwood pulps develop higher sheet densities than do the corewood pulps when compared on the basis of wood density or pulp of long fiber content (and hence, tracheid length), as **Fig. 11** shows. This result confirms that of the previous study (*6*). Within each wood type, sheet density is inversely proportional to basic wood density, tracheid length, long fiber content, and mean pulp fiber length.

We may gain insight to the complex mechanisms controlling the development of sheet density by evaluating the fundamental papermaking characteristics of the individual fiber fractions. These fractions were determined by comparing the papermaking characteristics of the +14,+30,+50, and +200 fractions of representative pulps of 105 mL CSF. To do so, furnishes and handsheets were made up of these fractions in mixtures containing up to 50% of a standard fines material (*10*). For simplicity, only the behavior of the fines-free sheets of the individual fractions are presented here.

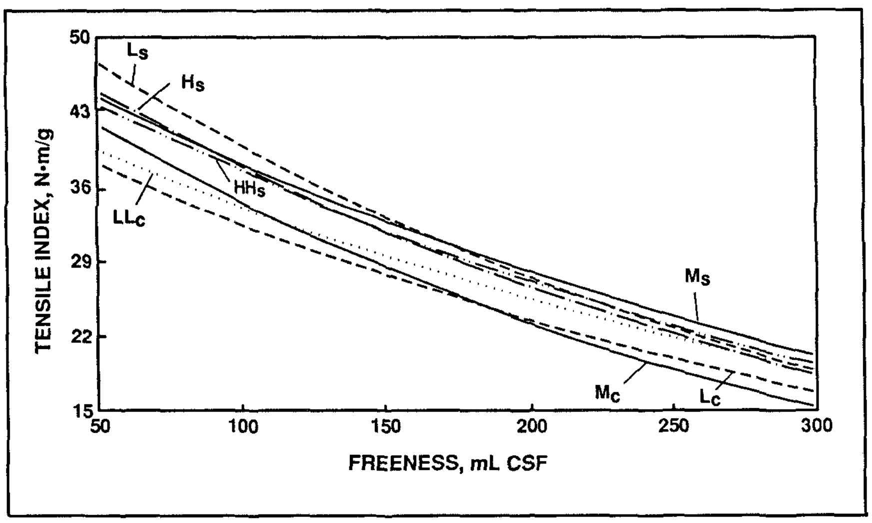
The behaviors of the two corewood pulps, LL_c and L_c, were similar across the range of long (+14 and +30) and short (+50) fiber and the coarse fines (+200). The behavior patterns of the slabwood material (L_s, M_s, and HH_s) were more interesting, as **Fig. 12** shows. Within the +14 and +30 fractions, the fiber behavior was seemingly independent of wood quality. The thicker-walled fibers of the high-density wood (HH_s) consolidated to the same sheet density as did the supposedly more pliable fibers of the thinner-walled wood (L_s and M_s). In the +50 and +200 fractions, the fibers and fibrils of the wood of highest density (HH_s) develop the highest sheet density.

Several complementary mechanisms may be proposed to explain this behavior. Within the pulps of the high-density wood, sheet density appears to be enhanced by the higher mass per cross-section of the thick-walled fibers and by the superior packing density of the coarse fines fraction, and it is by the high long fiber content. For wood of low basic density, sheet density appears to be enhanced by the better compliability of the thin-walled fibers and the low content of long fiber, and it is reduced by the poorer consolidating ability of the coarse fines. For wood of intermediate basic density, sheet density would thus be developed by a balance of these influences.

13. For regression curves for freeness and energy consumption, there are no direct trends between energy consumption and basic wood density or tracheid length, but several patterns can be discerned.



15. Compared at common freeness, the large differences in wood density or tracheid length do not result in proportionately large differences in tensile index.



The relationship between freeness and refining energy

The regression curves for freeness and energy consumption are presented in **Fig. 13**. There are no direct trends between energy consumption and either basic wood density or tracheid length. However, several patterns are notable.

Within the slabwood group, both wood of low and highest basic density required less energy than did wood of intermediate basic density (M_c and H_s). In the corewood category, the wood of lowest density required the most energy of any of the seven samples, and the wood of low density (L_c) required less energy than did the medium-density sample. In the corewood group, a higher tracheid length equates with reduced energy consumption, but this situation is contradicted by the reverse relationship within the slabwood group. There was no simple relationship between chip size distribution and energy consumption.

The shorter mean length of pulp fiber and the higher quantities of 100/200 coarse fines of the pulps of Sample *L* may explain some of the more rapid freeness development with refining energy of this wood, relative to other wood types. This conclusion does not, however, explain the higher energy consumption of LL_c relative to the other wood types.

The differences between LL_c and L_c are of special interest. Both wood samples have the same anatomical wood age. They also have similar fiber diameter, fiber wall thickness, and oven-dry content. Thus, they could be expected to behave similarly during refining. The lower energy requirement of HH_s may be attributed, at least in part, to the low freeness characteristics of its +200 coarse fines relative to those of the other slabwood pulps, as illustrated in **Fig. 14**. One notable characteristic of the different freeness development curves was that all required similar amounts of energy for defibration (that is, energy to reach 700 mL CSF), but they varied in the energy required for fiber development (that is, energy for reduction from 700 mL CSF to low freeness).

Strength parameters

Tensile strength

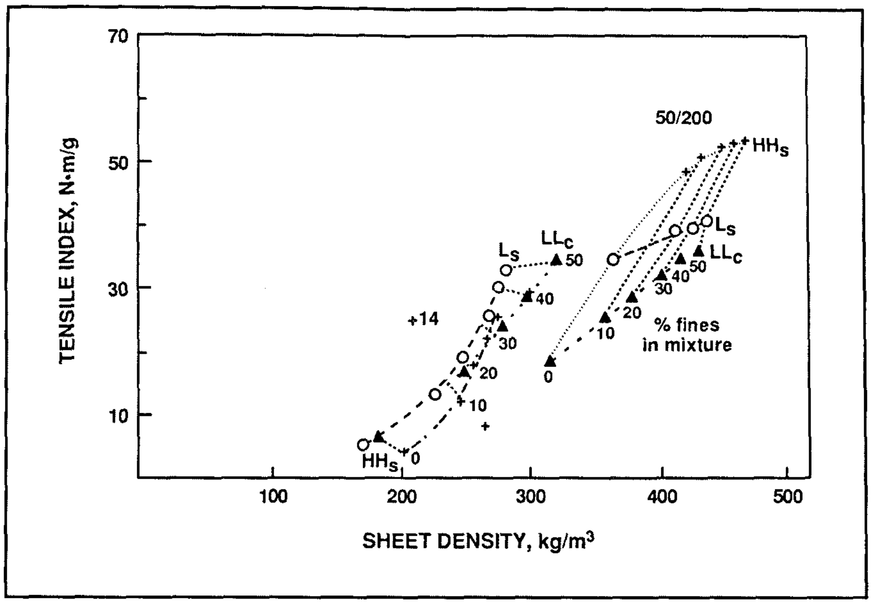
The large differences in basic wood density or tracheid length do not result in proportionately large differences in the parameters of tensile index, stretch, tensile energy absorption index, or Young's modulus, when compared at a common freeness, as in **Fig. 15**.

As a group, the slabwood pulps exhibit higher levels of these parameters than do the corewood pulps. Within each wood type, there was a trend for these parameters to increase with an increase in sheet density and hence a decrease in basic wood density. The one exception to this was the corewood sample L_c.

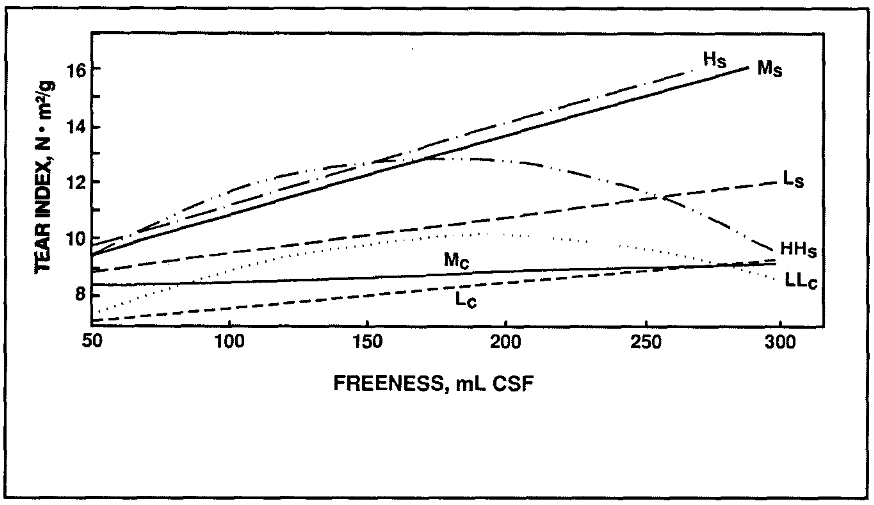
Thus, the factors proposed to describe the influence of sheet density could also influence tensile strength behavior. It is feasible, however, that it could be the length of the fibers, rather than their cross-sectional dimensions, that influences the contribution of the fiber fraction. Within the sheets of the thinner-walled fibers, the better degree of fiber collapse will give more bond contact area and higher incidence of fiber-fiber content than found in the sheets of the thicker-walled fibers. This action will compensate the shorter mean fiber length of the pulps of the wood of lower density. Conversely, within the pulps of the woods of higher densities, the higher mean fiber length will assist in the development of tensile strength.

The behavior of the coarse fines (100/200) fraction again warrants special mention. As shown, the coarse fines refined from the thick-walled fibers of the high-density woods have excellent sheet consolidation ability. They also develop proportionately better tensile strength than do those of the pulps of the low-density wood and even better tensile strength at a common level of sheet density, as presented in **Fig. 16.** (For experimental convenience, the 50/200 fraction was evaluated rather than the 100/200 fraction.)

16. Tensile index of furnishes of the +14 and 50/200 fractions in mixtures with standard fines, with respect to their sheet densities



17. Tracheid length exerts the dominant influence on tear index.



Tear strength

Figures 17 and 18 show that the dominant influence on tear index is exerted by mean fiber length and, hence, tracheid length. Mean fiber length gives a better correlation than does the R30 fraction. Because of the fiber length loss of the pulps of Sample *L*, tracheid length does not give as good a correlation as fiber length.

Scattering coefficient

As **Fig. 19** shows, scattering coefficient cannot be ranked directly by basic wood density, nor can it be ranked by tensile index or -200 fines content, which is as expected. However, there is a loose inverse relationship with basic wood density, augmented by a shorter tracheid length and pulp long fiber content. Again, insight to its development is afforded by the study of the individual fiber and fines fractions within the pulps.

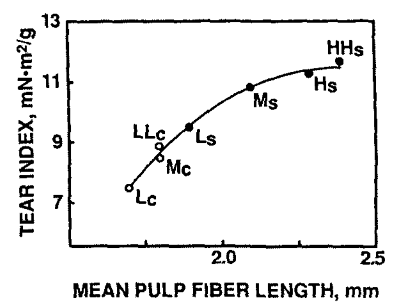
At low basic wood density, the direct ranking with basic wood density is prevented by either the superior performance of L_c and possibly L_s or the weaker performance of LL_c. A scanning electron microscope examination of the sheets of LL_c showed them to be more open than those of L_c and M_c (*9*), despite their high measured sheet density. This finding, plus the lower scattering coefficient of the -200 fines of LL_c, as presented in **Fig. 20** [determined by testing them in mixtures with kraft fibers as reference (*10*)] may account for much of the difference between the whole pulp scattering coefficients of L_c and LL_c.

At high basic wood density, the ranking of scattering coefficient with basic wood density is prevented by the better behavior of HH_s relative to H_s. Because the fractions of H_s were not included in the fundamental study of the pulp fractions, it is not possible to compare them with those of HH_s. However, the behavior of the fractions of HH_s relative to those of M_s provides a valuable guide to the performance of this sample. This analysis of HH_s showed that its short fiber fraction (+50) and coarse fines fraction (+200) were similar to those of M_s, as presented in **Fig. 21.** As Fig. 20 shows, its fines were better than those of M_s. Despite the higher long fiber content of HH_s relative to the other slabwood pulps, its well-consolidated sheet and the nature of its fines material are apparently sufficient for it to achieve better light-scattering coefficient than would be predicted by ranking by wood density alone.

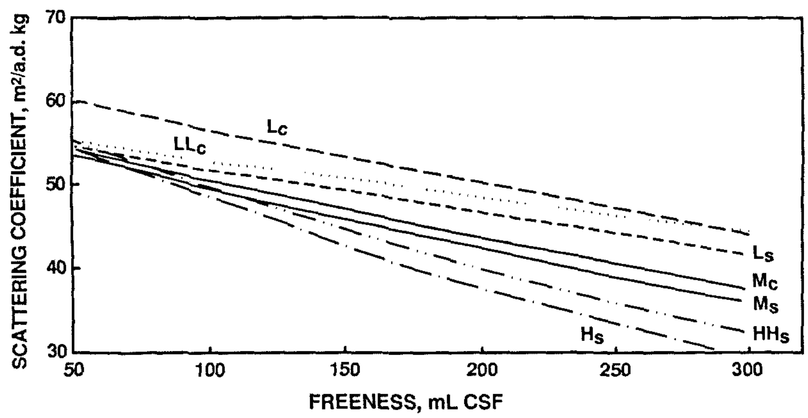
Conclusions

This study offers valuable new information on the TMP qualities that may be obtained from radiata pine over a broad range of basic wood densities and tracheid lengths. Arguably, the most important observation is the generally small differences in sheet properties of the pulps of the alterna-

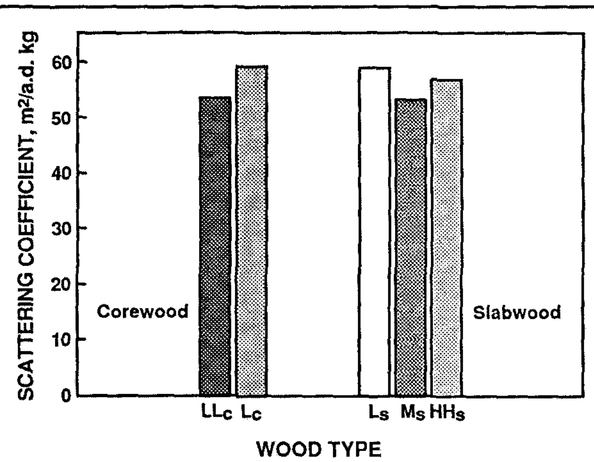
18. Tear index is controlled by pulp fiber length (100 mL CSF).



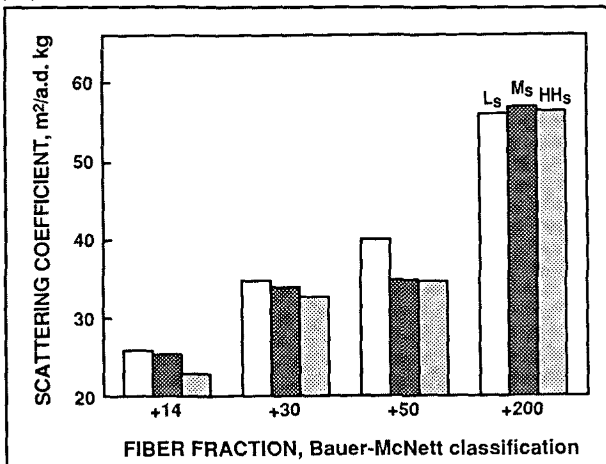
19. Scattering coefficient cannot be ranked directly by basic wood density.



20. Scattering coefficient behavior of selected fines, of pulp of 105 mL CSF, in sheets with standard kraft as a 50:50 mixture



21. Scattering coefficient behavior of fractions of selected slabwood pulps of 105 mL CSF, based on their fines-free sheets



tive wood samples that occur despite their wide differences in basic wood density. Additionally, basic wood density was not found to have the dominant effect on such properties as refining energy consumption as others had proposed earlier.

The sheet density values achieved confirm that this parameter is affected by the origin of the pulp from either juvenile wood (corewood) or mature wood (slabwood). Within either group, basic wood density is inversely proportional to sheet density and its wood-age-related tracheid length.

Strong equalizing mechanisms are apparent in the development of sheet density and tensile strength. The relative compliability and degree of collapse of the fiber are balanced by the consolidation and bond-reinforcing influences of the fines fractions, particularly the 100/200 coarse fines. Although it is not desirable that high-density wood should be sought to obtain the superior performance of its fines, the thick-walled fibers that are characteristic of high-density wood may be isolated from the pulp of wood of lower basic density by an effective screening system.

Pulp energy consumption is influenced by the factors that affect the related parameters of freeness and sheet density development. However, a knowledge of basic wood density, tracheid length, or subsequent mean pulp fiber length is insufficient to predict refining energy requirements.

A high tracheid length results in high long fiber content, in high tear strength, possibly in high tensile index, and in reduced sheet density.

The simple classification of radiata pine juvenile wood as corewood does not account for its disparate energy consumption behavior with regard to wood of equal age in either biologically young trees (thinnings) or the tops of biologically older trees (top logs).

The possibility of some morphological difference between both types of juvenile wood prevents the easy discussion of the differences between the thinnings (LL_c) and the top log material (L_c and M_c). If all three wood types—thinnings, top logs, and slabwood—have discrete, characteristic behavior, then the observed differences may be accounted for. Conversely, if not, the reasons for the superior behavior of the wood of low density (L) must be sought. Until this matter is resolved, the classification of juvenile wood as "thinnings" and "top logs" will serve for studies of this type.

It is the behavior of the pulps of the wood of low density, L, that is of the most immediate practical interest. The excellent levels of light-scattering coefficient that are achieved at lower-than-normal power consumption show that radiata pine can compete strongly with spruce in this regard (*11*). This behavior of low-density wood is achieved by its faster than usual loss of long fiber during refining and its concurrent good development of the fiber and fines characteristics. Fiber cutting alone would not give this result (*12*).

The scale of this study has highlighted the necessarily complex nature of any analysis of the relationships between wood and TMP pulp properties. The heterogeneous nature of wood within and between stems, the need for large quantities of wood for pilot-scale refining, and the probabilities of the response of wood to TMP refining all require that this work be done in replicate and on a large scale to ensure statistically significant results. More limited studies risk the identification of erroneous trends.

In summary, this comprehensive study has yielded important information on the role of both basic wood density and wood tracheid length. While the work has been performed on radiata pine, the results may be relevant to other morphologically similar pines. The study has afforded clarification on the role of wood density within wood of various classes of age. It has also raised new questions of potential differences between thinnings and top log material and for wood that may be morphologically different in both its juvenile and mature forms.□

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The considerable contributions of Shane Foster and Mike Ryan for wood procurement, chipping, refining and pulp quality testing, John Richardson for refiner operation, Michael Hong and Tania Gilmore for statistical analysis, and Wendy Holden for graphics are gratefully acknowledged.

Received for review Jan. 23, 1991.

Accepted Feb. 6, 1991.

Presented at the TAPPI 1991 International Mechanical Pulping Conference.