SUMMARY

Fibre and pulp qualities are assessed for kraft pulps made from New Zealand grown radiata pine whole tree thinnings logs and toplogs which contained 9, 12, 15 and 18 growth layers at their large diameter end. The chip basic density range for the toplogs was 388 to 413 kg/m³ and for the thinnings was 335 to 367 kg/m³. Kraft fibre qualities and handsheet properties for the toplog and thinnings furnishes are very different. Compared with thinnings fibres, toplog fibres are substantially and significantly longer, coarser and wider with thicker walls and lower relative numbers of fibres per unit mass. For the thinnings furnishes, on the other hand, fibre length decreases with decreasing chip basic density and handsheet apparent density is extremely high (except for the 18 year old furnish). It is the short fibre characteristic of the 9, 12 and 15 year old thinnings furnishes and their related extremely high handsheet apparent densities which apparently determine their unique (for softwoods) handsheet properties.

Radiata pine thinnings and toplog kraft pulp qualities

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The influence of wood age on radiata pine kraft and mechanical pulp fibre qualities has been extensively researched over the last two to three decades(1-4). Unanswered questions still exist, however, particularly with wood chips over the basic density range of 300 to 400 kg/m³. How do fibre qualities vary over this basic density range, and between radiata pine thinnings and toplogs of equivalent age? How do differences in thinnings and toplog fibre qualities over this density range influence kraft and mechanical pulp qualities? What are the energy requirements for mechanical pulping of such a range of wood and fibre qualities?

Previous studies of kraft pulps have shown an abrupt change in pulp quality as wood chip basic densities fall below about 350 kg/m³. Handsheet apparent densities increased abruptly with such a change in wood chip basic density(1,5). The question arises as to whether such a change in pulp quality with decreasing chip basic density can be related to changes in fibre quality, and if so, at what basic density or fibre quality level does this occur? For mechanical pulps, previous studies have also indicated an abrupt change in pulp quality with TMP refining of radiata pine wood chips of basic density about 350 kg/m³(6). Energy consumptions and fibre and fines qualities also appeared to change abruptly. Also, a certain genetic strain of radiata pine of relatively low basic density with relatively long fibres showed very desirable mechanical pulp properties and refining energy requirements(7).

The objective of the present study was to determine and correlate radiata pine kraft fibre quality and handsheet properties for 9, 12, 15 and 18 year old thinnings, and toplogs which contained 9, 12, 15 and 18 annual growth layers from the pith taken from a stand of 38 year old trees. The slabwood sample was prepared from the sawmill slabwood of the base log of the same trees.

EXPERIMENTAL

Sample selection and preparation

The 9, 12, 15 and 18 year old whole tree thinnings, and the stand of 38 year old trees from which the toplog and slabwood material was taken were grown on sites of roughly equivalent site index and given very similar silvicultural treatments.

- The 9, 12 and 15 year old thinnings were planted at initial stockings of 1667 stems per hectare and thinned to waste at age 5 years to 382 (9 year old), 521 (12 year old) and 575 stems per hectare (15 year old). The 9 year old thinnings were low pruned at age 5 and medium pruned at age 6 years. The 12 and 15 year old thinnings were unpruned trees extracted from stands which had been low and medium pruned.
- The 18 year old thinnings were high pruned final crop trees which had been thinned to 282 stems per hectare at age 16. Initial stocking was 2500 stems per hectare which was decreased to 1360 at age 4 and 568 at age 7. The stand was low pruned at age 7, medium pruned at 11 years and high pruned at 12 years.
- The 9, 12, 15 and 18 year old toplogs were cut from a stand of 38 year old trees. Initial stocking 5000 stems per hectare. Thinned at age 9 (2500 stems per hectare), age 11 (530 stems per hectare) and age 21 (210 stems per hectare). Low pruned at age 11, medium pruned at age 12.

Both the thinnings and toplog samples were cut to a 100 mm small end diameter. The number of growth layers at the large end of each log was either 9, 12, 15 or 18. Some 60 to 90 trees were included in each sample to ensure ample material for both the mechanical and chemical pulping trials and evaluations. The whole logs were chipped in a commercial chipper. Chips used in the study passed through a 26 mm screen and were retained on a 13 mm screen of a round hole Williams chip classifier.

Pulping and pulp processing

Kappa number 28 to 29 kraft pulps were prepared from both the thinnings and toplog samples (Table 1) by pulping 200 g o.d. of chips using a 15% effective alkali charge. Further details of pulping procedures can be made available on request (unpublished data). In the present study, pulp fibre dimensions were made on the first series of pulps listed in Table 1. To obtain sufficient pulp for handsheet evaluations further kraft pulps were prepared. These are also listed in Table 1.

Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. Test

Table 1
Kraft pulp samples

Wood sample Age year	Wood sample Type	Chip basic density kg/m³	Pulp Kappa number*	Pulp Kappa number†
9	thinnings	335	28.8	31.5
9	top logs	388	26.4	30.9
12	thinnings	367	28.6	29.1
12	top logs	399	28.5	30.4
15	thinnings	354	28.9	29.5
15	top logs	413	26.2	31.9
18	thinnings	364	28.9	29.5
18	top logs	408	32.3	28.9
	slabwood	431	26.4	–

* Pulps used for fibre dimension analyses.
† Additional pulps prepared for handsheet physical evaluation.

tensile index, stretch, apparent density, tear index and their inter-relationships, values for the four toplog pulps can be treated as being roughly similar (Fig. 4-7). For the four thinnings pulps, on the other hand, very definite differences exist with the 18 year old thinnings pulp having handsheet mechanical properties generally equivalent to those of the toplog pulps. Also, handsheet apparent densities are roughly equivalent for given refining levels for the 9 and 12 year old thinnings pulps (Table 5, Fig. 4). The 15 year old thinnings pulp has apparent density values roughly intermediate between those of the 18 year old thinnings pulp and the 9 and 12 year old thinnings pulps. For given tensile values, apparent densities are essentially identical for the 9 and 12 year old thinnings pulps and very high relative to those of the corresponding 15 year old pulp. Thus, based on tensile/apparent density relationships alone, there is little to distinguish the 9 and 12 year old thinnings pulps. However such coincidence of 9 and 12 year old thinnings handsheet values is not repeated for such properties as stretch and tear index. Handsheet stretch certainly increases with decreasing age of the thinnings logs, although stretch values for the 9

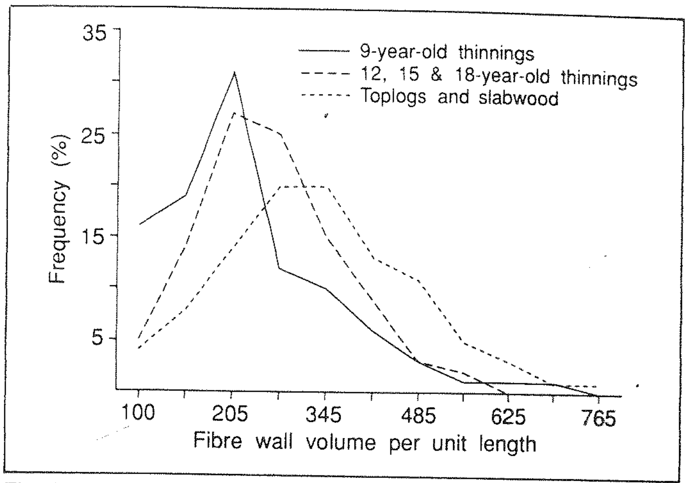

Fig. 3 — Fibre wall volume per unit length population distributions.

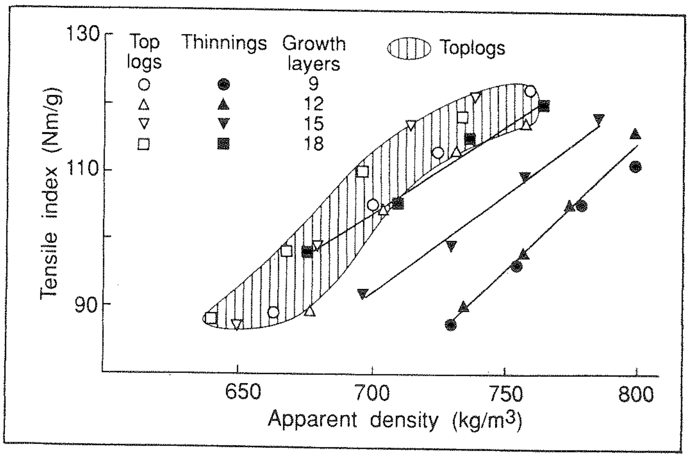

Fig. 4 — Handsheet tensile index and apparent density.

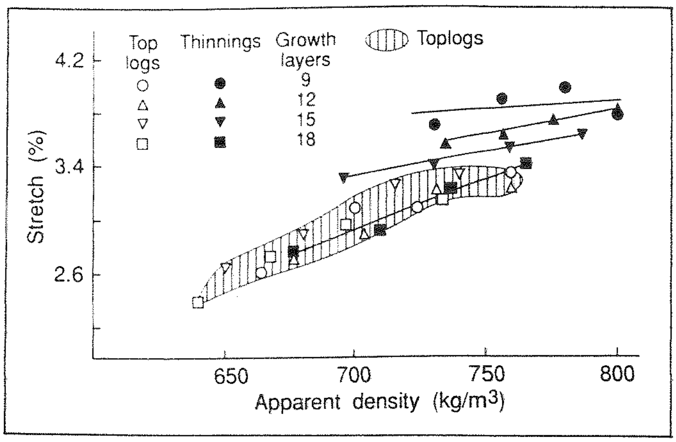

Fig. 5 — Handsheet stretch and apparent density.

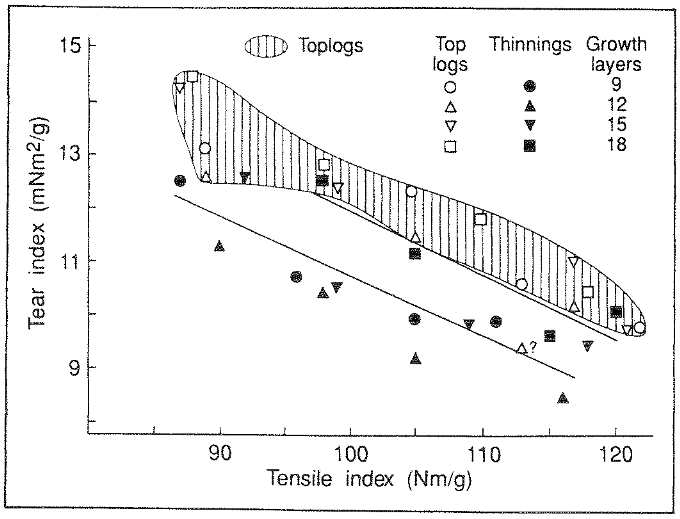

Fig. 6 — Handsheet tear index and tensile index.

Table 3
Fibre width by thickness product population distributions — frequency, %

Sample Age year	Type	Fibre width by fibre thickness classes, μm								
		<200	300	500	700	900	1100	1300	1500	1700
9	thinnings	18	28	29	10	9	5	1		
9	top logs	9	16	26	26	12	7	3	1	
12	thinnings	6	18	37	23	10	4	2		
12	top logs	9	13	20	18	21	13	3	3	
15	thinnings	6	23	38	18	10	4	1		
15	top logs	4	19	29	30	9	5	4		
18	thinnings	7	24	32	22	11	2	2		
18	top logs	3	15	30	25	13	9	3	1	1
	slabwood	3	18	30	24	18	4	2	1	

Table 4
Fibre wall volume per unit length population distributions — frequency, %

Sample Age year	Type	Fibre width by fibre thickness classes, μm²										
		<100	135	205	275	345	415	485	555	625	695	765
9	thinnings	16	19	31	12	10	6	3	1	1	1	
9	top logs	7	8	15	25	16	15	8	4	1	1	
12	thinnings	5	13	22	31	13	10	5	1			
12	top logs	5	9	12	16	17	14	14	8	3	1	1
15	thinnings	4	15	33	20	14	10	3	1			
15	top logs	3	9	18	20	23	11	7	6	2	1	
18	thinnings	6	13	25	25	18	7	3	3			
18	top logs	2	9	10	22	23	14	11	4	4	1	
	slabwood	2	7	15	20	23	14	12	3	3	1	

values were recorded on o.d. basis. The load applied during pulp refining with the PFI mill was 3.4 N/mm. Pulps were refined at 10% stock concentration.

Fibre dimension measurement

Relative weighted average fibre length and fibre coarseness were determined using a Kajaani FS-200 instrument. Cross-section fibre dimensions of thickness, width, wall area and wall thickness were measured using procedures of image processing described previously(8).

The fibre dimensions of width, thickness and wall volume per unit length are as indicated in Figure 1. The product fibre width by fibre thickness represents the minimum fibre cross-section rectangle and indicates overall changes in cross-section fibre dimensions. Also, fibre cross-section wall area is equivalent to fibre wall volume per unit length (Fig. 1) and is a relative measure of fibre coarseness(2). The ratio width:thickness can give an indication of fibre collapse since the greater the width and lower the thickness of a fibre cross-section, the greater is the extent of fibre collapse.

Relative number of fibres per unit mass was calculated using the reciprocal of the product 'fibre wall volume per unit length by fibre length' with an assumed wall substance density value of 1.0. A base value of 100 fibres per unit mass was taken for the 9 year old thinnings pulp with relative values being calculated for all other furnishes using principles of proportionality.

RESULTS

Fibre dimensions and qualities

Chip basic densities of the thinnings were consistently lower than those of corresponding toplog samples and as expected lower than that of the slabwood chips (Table 1). Chip basic densities were lowest for the 9 year old thinnings sample and roughly the same for corresponding 12, 15 and 18 year old samples. For all toplog material, on the other hand, chip basic densities are roughly the same or increase very slightly with age. The slabwood sample chip basic density is the highest of all samples, as expected(1).

Fibre qualities of the thinnings pulps are consistently and significantly different from those of corresponding toplog furnishes and the slabwood pulp (Table 2). The thinnings fibres are shorter, of lower coarseness, more slender (lower width by thickness product), and have lower wall volumes per unit length. Also relative numbers of fibres per unit mass for the thinnings fibres are very much greater than those of

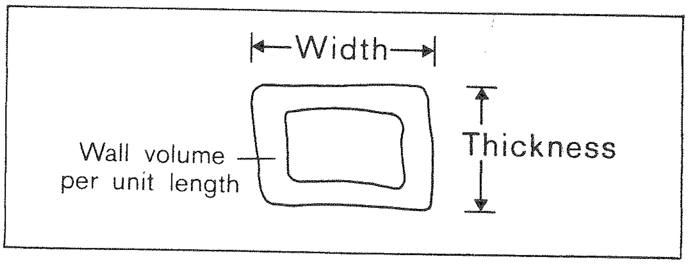

Fig. 1 — Schematic diagram of fibre cross-section dimensions.

corresponding toplog furnishes and of the slabwood pulp. With the exception of fibre length which consistently increases with increasing thinnings age, fibre slenderness (width by thickness product), wall volumes per unit length and relative numbers of fibres per unit mass are all roughly the same for the 12, 15 and 18 year old thinnings furnishes. It is only the 9 year old thinnings furnish which has width by thickness products, wall volumes per unit length and number of fibres per unit mass significantly different from those of all other thinnings pulps. Overall the mean fibre length of the 9 year old thinnings is not disproportionately lower than corresponding values for the 12, 15 and 18 year old thinnings pulps. Width by thickness products, wall volumes per unit length and number of fibres per unit mass, on the other hand, are disproportionately different from those of the other thinnings furnishes.

For toplog pulps little difference between the 9, 12, 15 and 18 year old pulps is apparent with mean fibre lengths, fibre coarseness, width by thickness products, wall volumes per unit length and relative number of fibres per unit mass (Table 2). However fibre lengths, coarseness, width by thickness products and wall volumes per unit length are generally highest and number of fibres per unit mass generally lowest for the 18 year old pulp. The slabwood pulp contains the longest fibres with other properties very similar to those of the 18 year old toplog pulp. Examination of fibre width by thickness product and wall volume per unit length fibre population distributions show trends very similar to those indicated by mean values listed in Table 2 (Fig. 2, 3, Tables 3, 4). For both the width by thickness product and wall volume per unit length, the 9 year old thinnings population distribution curve is unique when compared with all others. The 12, 15 and 18 year old thinnings values can be grouped together, as can those of the four toplog pulps and the slabwood pulp (Tables 3, 4).

Handsheet properties

Handsheet strength and optical properties for the various pulps and different refining levels are listed in Table 5. For

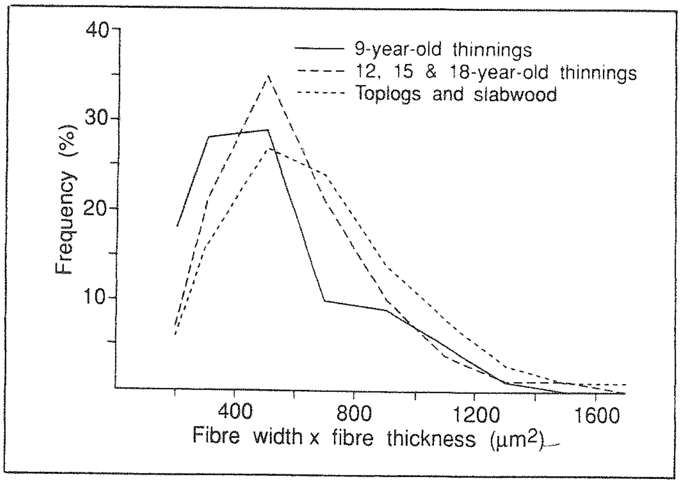

Fig. 2 — Fibre width by fibre thickness product population distributions.

Table 2
Relative fibre dimensions and related properties

Sample: Age year	Type	Fibre length mm	Fibre coarseness mg/m	Fibre cross-section dimensions: Width μm	Thickness μm	Width × thickness μm^2	Wall volume per unit length μm^2	Wall thickness μm	Width/thickness	Relative number of fibres per unit mass
9	thinnings	2.01	0.180	28.0	15.7	472	229	3.35	1.84	100
9	top logs	2.58	0.225	30.8	19.1	618	309	4.05	1.71	58
12	thinnings	2.15	0.195	29.8	18.4	568	268	3.71	1.67	80
12	top logs	2.50	0.228	31.8	20.7	694	350	4.28	1.58	53
15	thinnings	2.28	0.207	29.7	17.8	547	255	3.61	1.75	79
15	top logs	2.64	0.225	30.9	19.0	605	315	4.29	1.69	55
18	thinnings	2.47	0.216	30.5	17.1	537	267	3.72	1.91	70
18	top logs	2.74	0.251	31.4	20.8	675	340	4.44	1.58	49
	slabwood	2.90	0.256	30.1	20.4	634	336	4.56	1.54	47
LSD*				1.9	1.1	58	26	.21	.12	

* LSD Least significant difference between means at the 95% level of significance.

year old thinnings pulp are not increased greatly with refining (Fig. 5). Handsheet tear indices are low for all the thinnings pulps with the 18 year old pulp having tearing properties roughly similar to those of the toplog pulps (Fig. 6,7). It is noteworthy that relative to the toplog tear index relationships, those of the thinnings vary depending on whether the basis of comparison is tensile index or apparent density. This can be related to relationships shown in Figure 4 where tensile indices of the 9, 12 and 15 year old thinnings pulps are low compared with those of the 18 year old thinnings and toplogs pulps. Apparent densities, however, are extremely high for the 9, 12 and 15 year old thinnings at relatively low tensile values. This trend confirms previous results for kraft pulp made from whole tree thinnings of low wood basic density(1,5).

Handsheet optical properties measured in terms of light scattering coefficient show very definite trends for the toplogs and for the various thinnings pulps (Fig. 8,9). Depending on the bases of comparison, tensile index or apparent density, the four toplog pulps can be treated as having similar or very different light scattering coefficient relationships. When tensile index is the basis of comparison all toplog furnishes can be grouped together (Fig. 9). The four thinnings pulps again show separate relationships with the highly

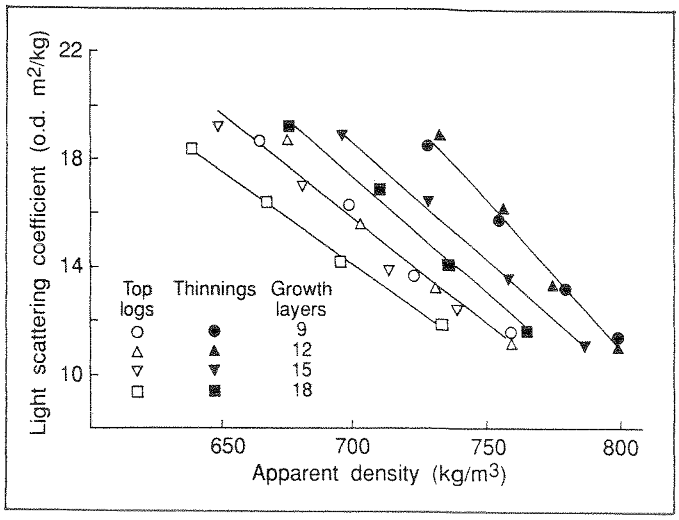

Fig. 8 — Handsheet light scattering coefficient and apparent density.

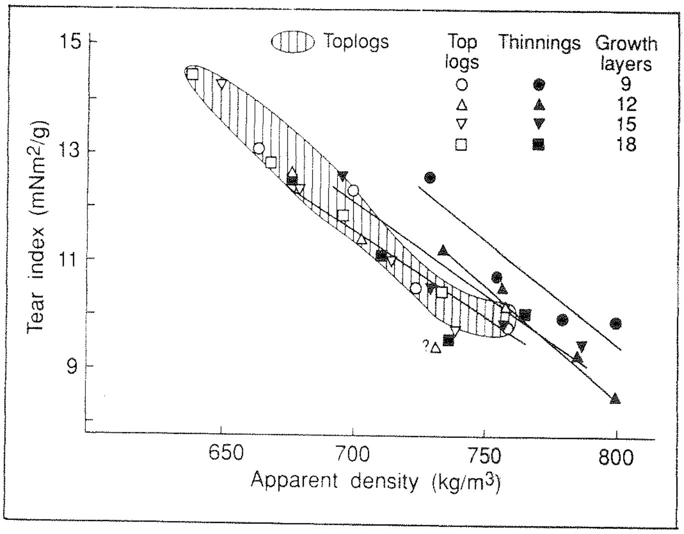

Fig. 7 — Handsheet tear index and apparent density.

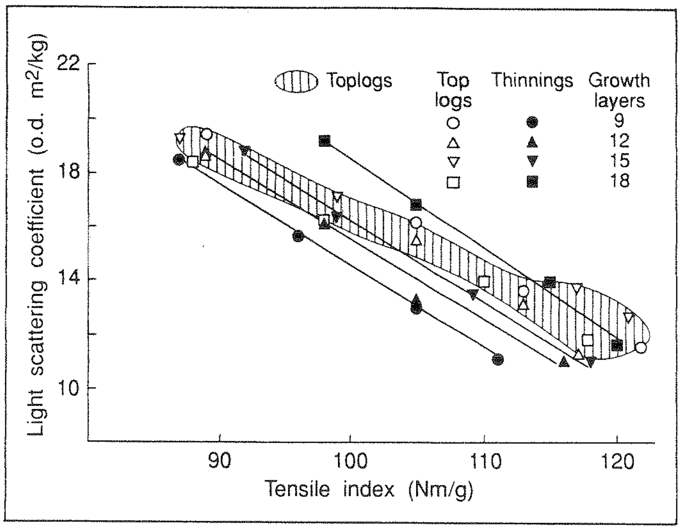

Fig. 9 — Handsheet light scattering coefficient and tensile index.

Table 5
Handsheet physical evaluation data

Sample Age year	Type	PFI mill rev	Freeness CSF	Tear index mN.m²/g	Burst index kPa.m²/g	Apparent density g/cm³	Air resistance s/100 mL	Tensile index N.m/g	Stretch %	T.E.A. J/m²	Young's modulus MN/m²	Light scattering coefficient o.d. m²/kg
9	thinnings	1000	701	12.5	6.5	0.731	34	87	3.73	140	6400	18.5
		2000	672	10.7	7.3	0.755	48	96	3.91	161	6700	15.7
		4000	583	9.9	7.9	0.779	121	105	4.01	178	7400	13.1
		8000	415	9.9	8.7	0.800	625	111	3.81	177	8200	11.2
9	toplogs	1000	720	13.1	6.7	0.664	7	89	2.61	96	6200	18.6
		2000	683	12.3	8.0	0.700	13	105	3.12	131	6700	16.2
		4000	621	10.5	8.9	0.724	29	113	3.12	141	7400	13.6
		8000	400	9.8	10.1	0.759	287	122	3.38	164	8000	11.5
12	thinnings	1000	697	11.2	7.0	0.734	40	90	3.58	137	6600	18.9
		2000	663	10.4	7.7	0.757	59	98	3.65	151	6900	16.1
		4000	612	9.2	8.0	0.775	105	105	3.77	166	7300	13.3
		8000	432	8.5	9.0	0.799	594	116	3.83	184	8000	11.0
12	toplogs	1000	720	12.6	6.6	0.677	7	89	2.71	100	6300	18.7
		2000	686	11.4	7.8	0.703	13	105	2.90	123	7000	15.5
		4000	611	9.4	8.9	0.732	32	113	3.24	148	7300	13.2
		8000	404	10.2	9.4	0.758	242	117	3.25	151	7600	11.3
15	thinnings	1000	714	12.6	6.7	0.697	15	92	3.33	128	6000	18.8
		2000	686	10.5	7.5	0.730	26	99	3.43	141	6800	16.3
		4000	617	9.8	8.3	0.758	62	109	3.56	160	7500	13.5
		8000	401	9.4	9.1	0.787	493	118	3.66	177	8200	11.0
15	toplogs	1000	700	14.2	6.4	0.650	5	87	2.67	95	5900	19.2
		2000	700	12.3	7.5	0.681	8	99	2.92	117	6500	17.1
		4000	630	11.0	8.7	0.715	17	117	3.28	153	7200	13.8
		8000	433	9.7	9.2	0.739	96	121	3.36	162	7800	12.3
18	thinnings	1000	703	12.5	6.9	0.677	11	98	2.79	110	6500	19.2
		2000	698	11.1	7.6	0.711	17	105	2.94	125	7300	16.8
		4000	630	9.6	8.8	0.737	39	115	3.25	150	7500	14.0
		8000	414	10.1	9.2	0.765	316	120	3.43	165	8100	11.6
18	toplogs	1000	723	14.4	6.1	0.639	3	88	2.41	87	6100	18.4
		2000	703	12.8	7.2	0.668	6	98	2.74	108	6600	16.3
		4000	657	11.8	8.1	0.696	13	110	2.98	131	7000	14.1
		8000	437	10.4	9.0	0.734	127	118	3.19	150	7700	11.8

consolidated and bonded sheets (high apparent density) of the 9 and 12 year old thinnings furnishes having low light scattering properties, and sheets of the 18 year old thinnings having exceptionally high light scattering properties. Such an effect is probably related to the high number of fibres per unit mass and the relatively long fibres of the 18 year thinnings pulp (Table 2). When apparent density is the basis of comparison, the very high apparent densities of all the thinnings pulps becomes evident (Fig. 8). A feature of interest is the low light scattering coefficient (at a given apparent density) obtained with the 18 year old toplog pulp. This may be related to the greater length of the 18 year old toplog fibres together with high values for fibre coarseness, width by thickness product and wall volume per unit length when compared with the other toplog pulps (Table 2).

Silviculture treatment effects

Silviculture treatment given the four stands of thinnings is not expected to account for differences in their fibre qualities (Table 2), although the possibility cannot be totally discounted. Compared with the 12, 15 and 18 year old thinnings, the corresponding 9 year old material consisted of trees which had been low pruned at age five and medium pruned at age six; treatments which might be expected to influence tree growth and fibre qualities in at least the growing season following treatment. For the four thinnings pulps, a significant effect of pruning on the fibre quality of the 9 year old sample is considered unlikely since fibre length decreases progressively with decreasing age, fibre wall volumes per unit length and fibre width by thickness products are consistently low compared with those of the toplog furnishes, and handsheet mechanical and optical properties show consistent trends (Table 2, Fig. 4-9). Also fibre quality and handsheet trends are similar to those indicated in previous studies (1,5,6).

DISCUSSION

An abrupt change in radiata pine kraft fibre quality occurs below chip basic densities of about 350 to 360 kg/m³. Fibres are much shorter, slender and less coarse (lower wall volume per unit length and thinner walled) than fibres from chips of basis density greater than about 350 to 360 kg/m³. These substantial and abrupt changes in fibre quality are also reflected in corresponding abrupt and significant increases in handsheet apparent densities. Evidence to date suggests that the observed abrupt increase in handsheet densities is most probably related to the short lengths of the 9, 12 and 15 year old thinnings furnishes—less than about 2.3 to 2.4 mm (Table 2, Fig. 4). It is of interest that fibre length is the only fibre quality determinant measured which correlates with the observed changes in handsheet apparent density for the 9, 12, 15 and 18 year old thinnings furnishes. Chip basic density (Table 1), width by thickness product, wall volume per unit length, coarseness, wall thickness and relative number of fibres per unit mass (Table 2) are only significantly different for the 9 year old thinnings furnish. In many respects the very high handsheet apparent densities of the 9, 12 and 15 year old thinnings pulps could be interpreted as indicating that these furnishes have lost some typical softwood kraft fibre properties. For example, handsheet stretch and apparent density are very high and tensile index low, particularly for the 9 and 12 year old thinnings.

Kraft fibre qualities and handsheet properties for the toplog and thinnings are very different (Table 2). Compared with thinnings fibres, toplog fibres are substantially and significantly longer, coarser and wider with higher wall volumes per unit length, thicker walls and lower numbers of fibres per unit mass. Also, fibre length and all other fibre quality determinants measured are essentially unchanged for the 9, 12, and 15 year old toplog furnishes. Again, these trends are consistent with the very similar handsheet properties of the 9, 12, 15 and the 18 year old toplog pulps (Fig. 4-9).

CONCLUSIONS

The fibre quality of radiata pine thinnings and toplogs of equivalent age or number of growth layers over the basic density range 330 to 400 kg/m³ can be very different and need to be considered when formulating kraft pulp and/or paper furnishes. Abrupt changes in radiata pine kraft fibre qualities can occur at chip basic densities below about 350 to 360 kg/m³ resulting in some selective changes in their papermaking qualities.

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