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EFFECTS OF REFINED SOFTWOOD:EUCALYPT PULP MIXTURES ON PAPER PROPERTIES

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ABSTRACT

Fibre property, refining requirement, and handsheet strength and optical property interrelations are examined for a eucalypt and several softwood market kraft pulps and blends. Market krafts included in the study are radiata pine pulps of low and medium coarseness, a benchmark pulp from the interior region of British Columbia, and a eucalypt pulp from Brazil. Eucalypt:softwood blends are in proportions of 100:0, 50:50, 80:20, and 0:100, and effects of separate and co-refining are assessed using a laboratory scale Escher Wyss refiner which is considered to be indicative of commercial scale refining operations.

For the softwood pulps, refining at the low 1 Ws/m specific edge load has minimal effects on fibre shortening, fibre collapse, and wall expansion and delamination. Under these conditions fibres are neither rapidly rewetted nor made flexible. The converse occurs with refining at 3 and 5 Ws/m.

Tensile strengths are relatively high and softwood fibre walls are slow to respond with refining at low specific edge load. Such effects are consistent with the retention of fibre stiffness and length, and the development of high bonding potential. The high bonding potential is presumably developed

through selective fibre surface disruption, wetting, and molecular and micro level fibrillation. Light-scattering coefficient/tensile index relations are independent of specific edge load and indicate mutual compensatory responses for these handsheet properties.

For eucalypt:softwood blend proportions of about 80:20, tear/tensile relationships (reinforcement properties) and light-scattering coefficients (optical properties) are roughly the same and independent of the origin or type of softwood used in the investigation. Such results are to be expected since there are only 2–3% by number of softwood fibres included in the 80:20 eucalypt:softwood furnish blends. For 50:50 eucalypt:softwood blends the effects of using softwoods of different fibre quality are also relatively small.

With co-refining reinforcement properties are decreased, and optical properties can be increased depending on specific edge load. It is envisaged with co-refining that the small number of softwood fibres present in the 80:20 eucalypt:softwood blends (<3%) receive disproportionate levels of the refining, and tear strengths decrease for given tensile strengths and energy inputs. Also, such an explanation is consistent with the possibility that light-scattering coefficients can increase with co-refining. Thus, softwood fibres can be expected to be more refined and hardwood fibres less refined for given energy inputs with co-refining than with separate refining before pulp blending.

INTRODUCTION

Different softwood bleached market kraft pulps can respond to refining in very different ways (1, 2). Pulps from the interior region of British Columbia, eastern Canada, and Scandinavia are the most readily refined while those from the southern USA are traditionally the most difficult to refine to a given strength and freeness. Corresponding radiata pine kraft pulps are of good strength and have intermediate refining requirements which are normally markedly less than those of Southern pine pulps, but more than those of the Canadian pulps (1). Furthermore, refining requirements and other properties of radiata pine pulps can vary greatly depending on their fibre qualities. For this reason low, medium, and high coarseness categories of radiata pine market kraft pulp are recognised in New Zealand.

In the present paper the fibre properties of selected eucalypt and softwood market kraft pulps and blends are compared against furnish refining requirements, tensile properties, reinforcement strengths, and optical properties. Market kraft pulps included in the study are radiata pine pulps of low and medium coarseness, a benchmark pulp from the interior region of British Columbia, and a eucalypt pulp from Brazil. Eucalypt:softwood blends are in proportions of 100:0, 50:50, 80:20, and 0:100. Effects of separate and co-refining are assessed using an Escher Wyss refiner which is considered to be indicative of commercial-scale refining operations (3).

Handsheet property evaluations for the various pulps and pulp blends are presented elsewhere (4, 5) and summarised as follows:

- The fibre qualities of unrefined softwood kraft pulps, to a large extent, predetermine their refining potentials and handsheet strength and optical properties. Reinforcement potentials, based on tear/tensile properties, of the medium coarseness radiata pine and interior British Columbia pulps are roughly equivalent. With the low coarseness radiata pine pulp some reinforcement strength is sacrificed for enhanced web closure, improved optical properties, decreased refining energy requirements, and improved sheet formation.

- The influence of softwood fibre quality on pulp properties decreases with decreasing proportions of softwood fibre included in eucalypt:softwood pulp blends. For 80:20 eucalypt:softwood blends refining energy, freeness and tensile strength interrelationships, and handsheet reinforcement and optical properties, are largely independent of the origin of the softwood pulp used.

- Pulps refined separately before blending have higher reinforcement strengths than those which are blended before co-refining. Co-refining of the eucalypt:softwood blends can give slightly higher light-scattering coefficients than separate refining of individual components before blending. Finally, separate refining requires the least energy and develops the highest tensile strengths at given freeness values.

EXPERIMENTAL

Pulp Origins

Radiata pine bleached market kraft pulps of medium and low coarseness were supplied from the Kinleith mill of NZFP Pulp and Paper Limited and are used in New Zealand as standard pulps for comparison against all others. The pulps are designated Std low and Std medium.

The softwood pulp from the interior region of British Columbia was supplied by the McKenzie mill of Fletcher Challenge Canada. Pulp species composition was determined as 88:12 spruce:lodgepole pine. The McKenzie pulp is used as the benchmark for radiata pine kraft since it is recognised by papermakers to be a leading softwood market pulp.

The eucalypt pulp from Brazil was reference material 8496 supplied by Aracruz Cellulose S.A., and distributed by National Institute of Standards and Technology, Standard Reference Materials Program, Building 202, Room 205, Gaithersburg, Maryland 20899, USA.

Pulp Processing and Evaluation

The Escher Wyss laboratory scale conical refiner, of NZFP Pulp and Paper Limited, was used to process the pulps as follows: stock concentration 3.5%, refining speed 1500 rpm, specific edge loads 1, 3, and 5 Ws/m (softwood pulps) and 0.5, 1.5, and 2.5 Ws/m (eucalypt pulp), and refining energies 0, 40, 80, 120, 160, and 200 kWh/t.

For softwood and hardwood pulps which were refined separately before blending, respective specific edge loads were 3 Ws/m (softwood) and 0.5 Ws/m (hardwood). Pulps were blended in eucalypt:softwood proportions 0:100, 50:50, 80:20, and 100:0. Whole-lap including cut edges was used as the refining sample.

Softwood and eucalypt pulps were blended after Escher Wyss processing as follows: stock concentrations for each of the six samples of each Escher Wyss run were determined on the refined residual pulp remaining after processing. Softwood and eucalypt pulps to be blended were thoroughly mixed in a bucket by stirring, and calculated volumes required were removed with plastic containers cut to size based on predetermined stock concentration values.

For the co-refined samples whole-lap samples were blended before disintegration and refined at 0.5 and 1.5 Ws/m. Pulps were blended in eucalypt:softwood proportions 80:20 only.

Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. Physical evaluation data are reported on o.d. bases.

Fibre Dimension Measurement

Relative length weighted fibre length and fibre coarseness were determined using a Kajaani FS-200 instrument and standard PAPRO procedures.

Unrefined and refined fibres were dehydrated, embedded, and sectioned, and the cross-section dimensions of thickness, width, wall area, and wall thickness were measured using procedures described previously (6). Slurry samples were diluted to stock concentrations of <0.1% to minimise the possibility of refined fibre wall structural organisations changing with storage time. Diluted slurry samples were dehydrated and embedded as soon as practicable after refining, normally within 2 to 4 days.

The fibre parameters of width, thickness, and wall area are as indicated in Figure 1 for dried and rewetted fibres. The product fibre width × fibre thickness represents the minimum fibre cross-section rectangle. Also, fibre cross-section wall area is equivalent to fibre wall volume per unit length and correlates with fibre coarseness for dried and rewetted pulps (7). The ratio width/thickness can give an indication of fibre collapse since the greater the width and the lower the thickness of a fibre cross-section, the greater is the extent of fibre collapse.

Relative numbers of fibres per unit mass were calculated using the reciprocal of the products "fibre coarseness × fibre length" or "fibre wall area × fibre length". A base value of 100 fibres per unit mass was taken for the Std low pulp with relative values being calculated for all other furnishes using principles of proportionality.

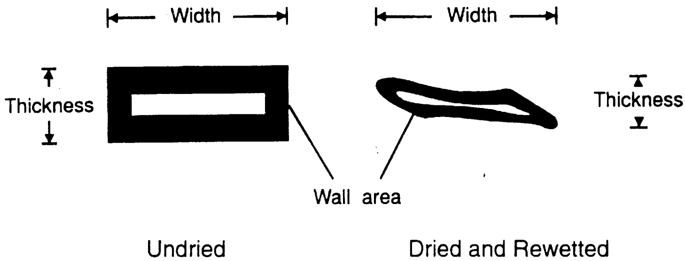

Figure 1: Schematic diagram of fibre cross-section dimensions for undried, and dried and rewetted fibres

RESULTS

Length, Coarseness and Number of Fibres

Length weighted fibre lengths of the unrefined Std medium (2.46 mm) and McKenzie (2.49 mm) pulps are practically identical, although their coarseness values of 0.275 and 0.198 mg/m are very different (Table 1). Also, the length weighted population distributions for the two pulps are almost identical (unpublished data). In contrast, the Std low pulp contains short fibres (2.14 mm) of coarseness (0.243 mg/m) intermediate between those of the Std medium and McKenzie furnishes. As expected, the eucalypt fibres are roughly one-third the length and coarseness of the softwood fibres. Based on fibre length and coarseness, and a value of 100 for the Std low furnish, the calculated relative numbers of fibres per unit mass of each pulp and pulp blend are as noted in Table 1. Relative numbers of fibres per unit mass are generally independent of the softwood used in the 50:50 and 80:20 softwood/eucalypt blends. It is only for the unblended softwood pulps that numbers of fibres per unit mass are substantially lower for the Std medium than for either the Std low or McKenzie pulps. However, the proportion of Std medium fibres in the 80:20 eucalypt:softwood blend is about 2.2% (15 out of 701) and that of the McKenzie fibres about 3.0% (21 out of 707).

Fibre cross-section wall area trends for the eucalypt and softwood fibres generally follow those of corresponding fibre coarseness values, as expected

(Table 1) (7). For the softwood fibres, wall area values are least for the McKenzie and greatest for the medium coarseness radiata pine pulp. Furthermore, relative numbers of fibres in the softwood and eucalypt pulps are roughly comparable when the calculation base is fibre coarseness or fibre cross-section wall area. Relative numbers of fibres in the eucalypt and McKenzie pulps are greater with wall area as the calculation base by about 8% and 15% respectively.

Refining of the softwood pulps shows that at a specific edge load of 1 Ws/m and after 200 kWh/t energy input, the McKenzie fibres are shortened by about 10% whereas the radiata pine fibres are essentially unchanged (Figure 2, Table 2). Extents of fibre shortening increase over the specific edge load range 1–5 Ws/m and with increasing refining. Treatments at 3 and 5 Ws/m shorten the Std medium and McKenzie fibres to roughly similar extents, about 24% and 37% respectively.

Table 1: Relative number of fibres for the unrefined softwood and eucalypt pulps and blends

Pulp	Furnish blend	Fibre coarseness as basis of comparison			Fibre wall area as basis of comparison		
	(%)	Fibre length (mm)	Fibre coarseness (mg/m)	Relative number of fibres)	Fibre length (mm)	Fibre wall area (μm^2)	Relative number of fibres
Eucalypt	100:0	0.74	0.082	857	0.74	58	927
Eucalypt: Std low	0:100	2.14	0.243	100	2.14	186	100
	50:50			478			513
	80:20			706			762
Eucalypt: Std medium	0:100	2.46	0.275	77	2.46	203	80
	50:50			466			503
	80:20			701			758
Eucalypt: McKenzie	0:100	2.49	0.198	105	2.49	130	123
	50:50			480			525
	80:20			707			766

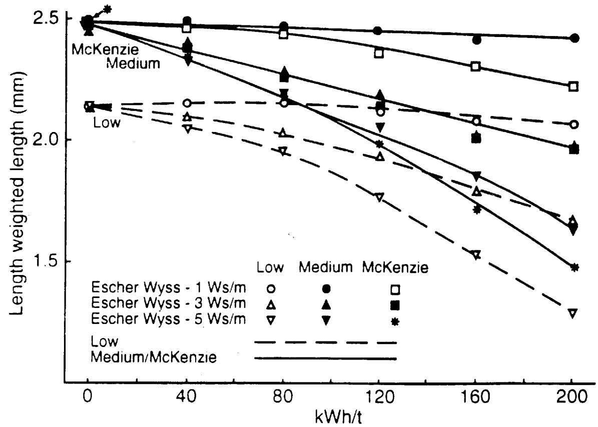

Figure 2: Refining input and softwood mean length weighted fibre length

The eucalypt fibres are also shortened by refining at specific edge loads of 1.5 and 2.5 Ws/m but not at 0.5 Ws/m (Table 2). The levels of shortening are, however, low at 11% and 15% respectively. Corresponding 3 and 5 Ws/m values for the Std low fibres are 22% and 40%.

For pulps blended after separate refining, only the softwood component of a blend contributes to the shortening of fibres since eucalypt fibre lengths are unchanged when refined at 0.5 Ws/m (Table 3).

For co-refined pulps, fibres are shortened only slightly when processed at the low specific edge load of 0.5 Ws/m and by up to 21% at the higher specific edge load of 1.5 Ws/m (Table 4). In contrast, unblended eucalypt fibres are shortened only by up to 11% when refined at 1.5 Ws/m (Table 2) which suggests that the major proportion of the refining load is carried by the softwood component in the co-refined blended furnishes.

Fibre Cross-Section Dimensions

Softwood and eucalypt pulps

The Std medium and McKenzie fibres have very different mean wall area, wall thickness, width, thickness, and cross-section area values (Table 2), but almost identical length weighted length values (Table 1). The McKenzie

Table 2: Mean fibre dimensions for a range of specific edge loads

Pulp	Refining energy (kWh/t)	Specific edge load (Ws/m)	Fibre length (mm)	FS 200 fibre coarseness (mg/m)	Fibre width (μm)	Fibre thick-ness (μm)	Width x thick-ness (μm²)	Wall area (μm²)	Wall thick-ness (μm)	Width/ thick-ness
Eucalypt	0	0.5	0.74	0.080	12.7	6.9	89	60	2.48	1.92
	40		0.75	0.080	13.9	6.9	96	60	2.17	2.13
	80		0.76	0.079	13.0	7.0	92	57	2.11	1.95
	120		0.76	0.081	13.6	7.3	102	61	2.14	1.96
	160		0.75	0.079	13.3	7.4	100	61	2.14	1.88
	200		0.74	0.065	14.0	7.4	105	62	2.10	1.99
Eucalypt	0	1.5	0.75	0.081	13.3	6.5	88	57	2.13	2.14
	40		0.74	0.071	12.9	6.8	89	58	2.26	1.99
	80		0.72	0.073	11.6	6.8	81	53	2.24	1.75
	120		0.71	0.072	13.4	7.1	97	61	2.29	1.96
	160		0.68	0.074	12.7	7.1	91	58	2.23	1.87
	200		0.67	0.073	12.6	7.4	94	61	2.36	1.79
Eucalypt	0	2.5	0.74	0.084	13.2	6.5	88	57	2.22	2.09
	40		0.72	0.087	13.1	6.7	89	58	2.23	2.03
	80		0.70	0.073	13.6	6.8	94	61	2.23	2.07
	120		0.67	0.072	12.9	6.9	91	59	2.33	1.95
	160		0.65	0.072	12.4	6.9	87	56	2.27	1.88
	200		0.63	0.080	13.4	6.7	91	58	2.15	2.07
Std low	0	1.0	2.14	0.253	29.5	11.2	337	186	2.96	2.85
	40		2.15	0.243	28.3	11.4	333	190	3.12	2.66
	80		2.15	0.235	29.7	11.6	350	193	3.07	2.80
	120		2.13	0.226	27.1	11.7	323	186	3.12	2.54
	160		2.07	0.245						
	200		2.06	0.206						
Std low	0	3.0	2.14	0.233	29.5	11.2	337	186	2.96	2.85
	40		2.09	0.248	30.5	11.0	335	184	2.85	3.02
	80		2.03	0.231	28.7	12.1	350	202	3.32	2.60
	120		1.93	0.229	27.5	12.3	339	196	3.31	2.48
	160		1.79	0.223	26.7	12.9	356	200	3.36	2.29
	200		1.66	0.204	27.5	12.4	345	193	3.26	2.47
Std low	0	5.0	2.14	0.242	29.5	11.2	337	186	2.96	2.85
	40		2.05	0.235	30.2	11.3	346	193	3.05	2.89
	80		1.95	0.242	27.7	12.4	348	196	3.31	2.45
	120		1.76	0.240	26.8	12.2	335	191	3.32	2.35
	160		1.53	0.219	27.2	12.6	354	197	3.30	2.38
	200		1.28	0.189	27.1	12.4	347	189	3.14	2.43

Table 2 cont.

Pulp	Refining energy (kWh/t)	Specific edge load (Ws/m)	Fibre length (mm)	FS 200 fibre coarseness (mg/m)	Fibre width (μm)	Fibre thick-ness (μm)	Width x thick-ness (μm^2)	Wall area (μm^2)	Wall thick-ness (μm)	Width/ thick-ness
Std medium	0	1.0	2.46	0.279	29.9	11.6	348	203	3.29	2.79
	40		2.49	0.280	28.5	12.4	360	212	3.54	2.47
	80		2.47	0.269	28.0	13.4	383	229	3.76	2.24
	120		2.45	0.267	28.4	12.3	357	213	3.54	2.45
	160		2.41	0.271						
	200		2.42	0.242						
Std medium	0	3.0	2.44	0.276	29.9	11.6	348	203	3.29	2.79
	40		2.39	0.272	29.5	12.5	371	221	3.64	2.54
	80		2.27	0.269	28.6	13.4	389	228	3.75	2.29
	120		2.19	0.241	27.8	12.8	361	215	3.69	2.35
	160		2.00	0.246	26.2	13.3	358	217	3.91	2.10
	200		1.88	0.236	26.0	12.7	340	199	3.53	2.21
Std medium	0	5.0	2.49	0.270	29.9	11.6	348	203	3.29	2.79
	40		2.33	0.277	27.6	12.7	357	207	3.55	2.33
	80		2.18	0.286	28.9	13.1	382	224	3.73	2.37
	120		2.05	0.230	26.6	12.9	351	201	3.33	2.23
	160		1.85	0.244	26.0	13.4	355	213	3.79	2.07
	200		1.63	0.227	25.8	12.7	342	195	3.29	2.16
McKenzie	0	1.0	2.48	0.204	25.1	8.9	223	130	2.57	3.04
	40		2.46	0.200	25.1	9.2	233	129	2.44	2.94
	80		2.43	0.193	24.6	9.0	225	129	2.54	2.90
	120		2.36	0.171	24.5	9.8	239	135	2.64	2.73
	160		2.30	0.170	23.6	9.7	229	134	2.77	2.65
	200		2.22	0.168	23.8	9.5	229	131	2.67	2.68
McKenzie	0	3.0	2.49	0.187	25.1	8.9	223	130	2.57	3.04
	40		2.37	0.191	25.6	9.8	253	153	2.91	2.81
	80		2.25	0.184	22.8	9.7	225	134	2.80	2.50
	120		2.14	0.171	24.4	10.1	247	145	2.92	2.63
	160		2.01	0.171	23.7	10.4	246	144	2.97	2.50
	200		1.87	0.165	23.3	10.4	246	142	2.93	2.40
McKenzie	0	5.0	2.49	0.203	25.1	8.9	223	130	2.57	3.04
	40		2.35	0.200	24.1	9.9	242	148	3.05	2.59
	80		2.17	0.176	25.0	10.3	258	151	2.88	2.64
	120		1.98	0.164	24.5	10.5	260	150	2.92	2.52
	160		1.72	0.154	24.3	10.7	262	157	3.09	2.47
	200		1.49	0.153	23.2	10.2	239	140	2.90	2.41
LSD*					1.5	0.7	27	15	0.20	0.20

* Least significant difference between means at the 95% level of confidence

Table 3: Mean fibre length and coarseness for separate refined eucalypt:softwood pulp blends

Furnish blend (%)	Refining energy (kWh/t)	Specific edge load (Ws/m)	Eucalypt:Std low		Eucalypt:Std med.		Eucalypt:McKenzie	
			Fibre length (mm)	Fibre coarseness (mg/m)	Fibre length (mm)	Fibre coarseness (mg/m)	Fibre length (mm)	Fibre coarseness (mg/m)
100:0	0	0.5	0.74	0.080	0.74	0.080	0.74	0.080
	40		0.75	0.080	0.75	0.080	0.75	0.080
	80		0.76	0.079	0.76	0.079	0.76	0.079
	120		0.76	0.081	0.76	0.081	0.76	0.081
	160		0.75	0.079	0.75	0.079	0.75	0.079
	200		0.74	0.065	0.74	0.065	0.74	0.065
50:50	0	0.5/3.0	1.15	–	1.17	–	1.24	–
	40		1.12	–	1.14	–	1.24	–
	80		1.10	–	1.13	–	1.19	–
	120		1.07	–	1.11	–	1.13	–
	160		1.05	–	1.05	–	1.10	–
	200		1.00	–	1.00	–	1.06	–
80:20	0	0.5/3.0	0.88	–	0.86	–	0.90	–
	40		0.88	–	0.90	–	0.90	–
	80		0.88	–	0.89	–	0.91	–
	120		0.88	–	0.86	–	0.88	–
	160		0.85	–	0.86	–	0.87	–
	200		0.83	–	0.82	–	0.85	–
0:100	0	3.0	2.14	0.233	2.44	0.276	2.49	0.187
	40		2.09	0.248	2.39	0.272	2.37	0.191
	80		2.03	0.231	2.27	0.269	2.25	0.184
	120		1.93	0.229	2.19	0.241	2.14	0.171
	160		1.79	0.223	2.00	0.246	2.01	0.171
	200		1.66	0.204	1.88	0.236	1.87	0.165

fibres are slender compared with the radiata pine fibres as indicated by their very different width, thickness, and cross-section area or width × thickness product values (Table 2). Std low fibres are of roughly the same slenderness, but have low wall areas and thin walls compared with the Std medium fibres. Eucalypt fibres are short, slender and of low wall area and coarseness when compared with those of softwood fibres. as expected (Tables1, 2) (8, 9).

Table 4: Mean fibre length for co-refined eucalypt:softwood pulp blends

Furnish blend (%)	Refining energy (kWh/t)	Specific edge load (Ws/m)	Eucalypt: Std low	Eucalypt: Std medium	Eucalypt: McKenzie
			Length weighted fibre length (mm)	Length weighted fibre length (mm)	Length weighted fibre length (mm)
80:20	0	0.5	0.87	0.88	0.91
	40		0.89	0.87	0.91
	80		0.88	0.87	0.90
	120		0.87	0.88	0.90
	160		0.86	0.87	0.90
	200		0.82	0.85	0.86
80:20	0	1.5	0.86	0.88	0.91
	40		0.87	0.87	0.89
	80		0.84	0.83	0.86
	120		0.81	0.82	0.80
	160		0.77	0.77	0.76
	200		0.73	0.75	0.72

Softwood fibre widths decrease and thicknesses and cross-section wall areas increase with refining (Figures 3, 4, 5) (Table 2), as fibre walls delaminate and the collapsed dry lap fibres become progressively wetter and

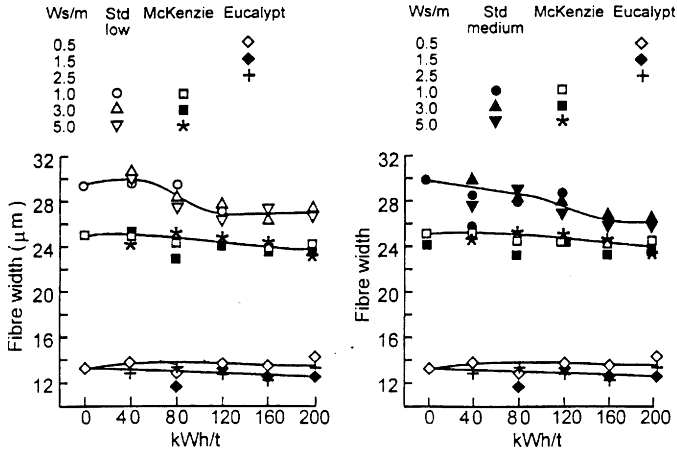

Figure 3: Fibre width and refining energy

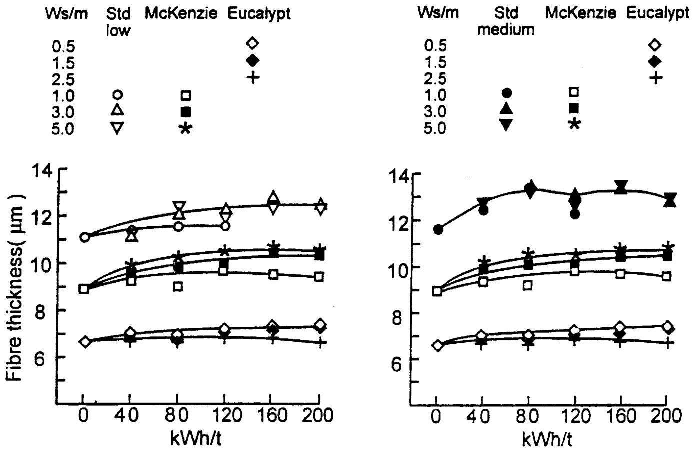

Figure 4: Fibre thickness and refining energy

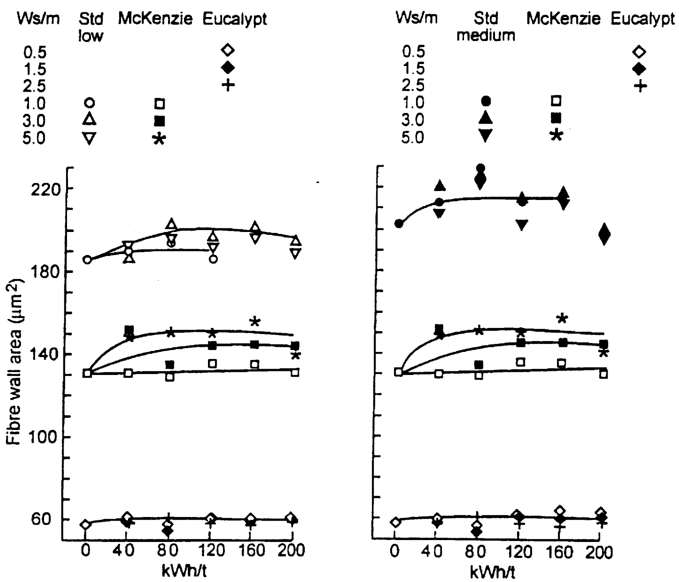

Figure 5: Fibre wall area and refining energy

uncollapsed (9, 10). The decrease in fibre width with refining is least for the McKenzie pulp and greatest for the radiata pine pulps, and independent of specific edge load. For fibre thickness, on the other hand, the increase which occurs with refining is least for pulps refined at low specific edge load and greatest for those processed at the higher specific edge loads, except for the

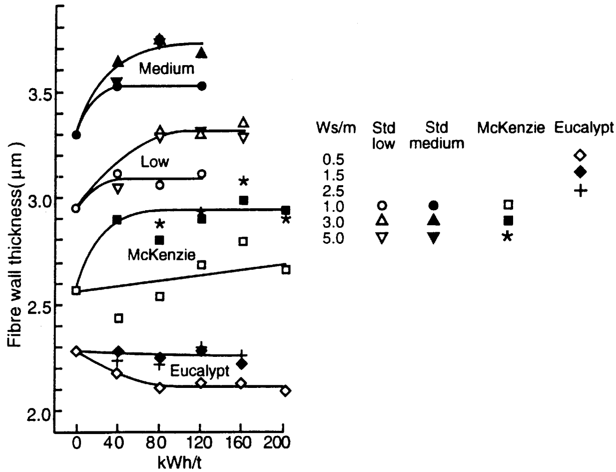

Figure 6: Fibre wall thickness and refining energy

medium coarseness radiata pine pulp. Fibre cross-section dimensions of the McKenzie pulp are most sensitive to changes in specific edge load. Fibre wall thickness trends show a marginal response to refining at low specific edge load for the three softwood pulps (Figure 6). In contrast, softwood fibre walls are substantially expanded when refined at the high specific edge loads of either 3 or 5 Ws/m.

Eucalypt fibres respond very differently to refining when compared with the softwood fibres (Figures 3, 4, 5, 6). Treatment at low specific edge load (0.5 Ws/m) causes eucalypt fibre width, thickness, and overall cross-section area values (width × thickness product) to increase rather than decrease. Eucalypt fibre wall area is unchanged but wall thickness can decrease with refining (Figure 6), as fibre cross-sections expand (Table 2).

Eucalypt:softwood pulp blends

Calculated and experimentally derived "relative numbers of fibres" in the various eucalypt:softwood pulp blends are listed in Table 5. Calculated "relative numbers of fibres" are based on the lengths and wall areas of unblended fibre populations. Experimentally derived values, on the other hand, are based on actual mean length and wall area values of blended eucalypt:softwood fibre populations. Calculated "relative numbers of fibres" are considered to reflect most accurately the real situation since less than 3% of the fibres in an 80:20 eucalypt:softwood blend sample can be of softwood

Table 5: Fibre length and wall area, and relative number of fibres in eucalypt: softwood pulp blends

Pulp	Furnish blend (%)	"Calculated values" Fibre length (mm)	Fibre wall area (μm^2)	Relative number of fibres	"Experimental values" Fibre length (mm)	Fibre wall area (μm^2)	Relative number of fibres
Eucalypt	100:0	0.74	58	927	0.74	58	927
Eucalypt:	0:100	2.14	186	100	2.14	186	100
Std low	50:50			513	1.15	92	376
	80:20			762	0.88	60	754
Eucalypt:	0:100	2.46	203	80	2.46	203	80
Std medium	50:50			503	1.17	99	344
	80:20			758	0.86	65	712
Eucalypt:	0:100	2.49	130	123	2.49	130	123
McKenzie	50:50			525	1.24	77	417
	80:20			766	0.90	67	660

origin (Table 1). For the experimentally derived values of Table 5, "relative numbers of fibres" in the 50:50 and 80:20 blends are generally low which suggests that higher than predicted proportions of softwood fibres were selected for measurement. Thus, mean fibre cross-section dimensions for blended pulps are probably indicative of softwood proportions somewhat higher than those listed (Table 3).

Tensile Strength Development

Softwood and eucalypt pulps

Mean tensile strengths for the unrefined softwood pulps are very different with that of Std medium lowest (23 Nm/g) and that of McKenzie highest (48 Nm/g) (Figure 7). Such tensile strength differences between unrefined pulps continue to exist when the softwood kraft pulps are refined. The more gentle specific edge load treatment (1 Ws/m) is most effective in developing the tensile strengths of the McKenzie and Std low pulps, but not of the Std medium pulp since the 1 and 3 Ws/m curves are indistinguishable. Treatment at 5 Ws/m is least effective in developing tensile strength by refining.

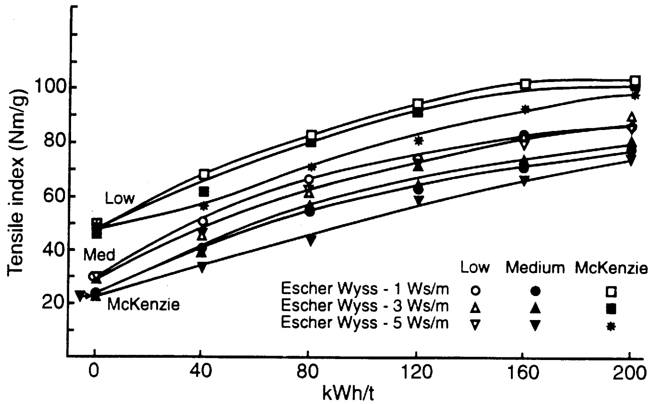

Figure 7: Refining energy/tensile strength relationships for softwood pulps

The tensile strength of the unrefined eucalypt pulp lies between those of the Std low and the McKenzie pulps (4). The same relative difference between the unrefined softwood and eucalypt pulps remains with refining.

Refining at 1, 3, and 5 Ws/m gives similar tensile strength/apparent density relationships for the Std low but not for the Std medium pulp (Figure 8). Treatment at 5 Ws/m causes the Std medium handsheets to be more consolidated and of higher apparent density at a given tensile strength than treatment at 1 and 3 Ws/m.

For the Std low and Std medium pulps the 1 and 3 Ws/m treatments give almost identical tensile strength/apparent density relationships, although

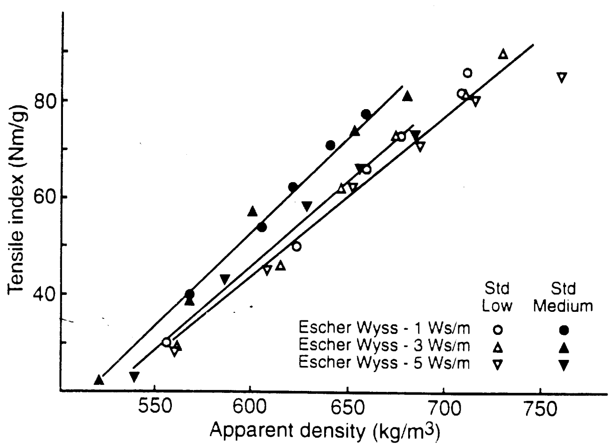

Figure 8: Tensile index/apparent density for Std low and Std medium pulps

separate regressions are obtained for the two pulps with the Std low giving handsheets of high apparent density or low bulk when compared with the Std medium furnish (Figure 8). Std low handsheets are also of high apparent density when compared with McKenzie handsheets of equivalent tensile index (Figure 9). Also, separate tensile index/apparent density regressions are obtained for the three specific edge loads with the McKenzie pulp, an effect not clearly obtained with either the Std low or Std medium pulps. Finally, unrefined tensile strengths and apparent densities are particularly high for the McKenzie furnish, as noted elsewhere (4, 5).

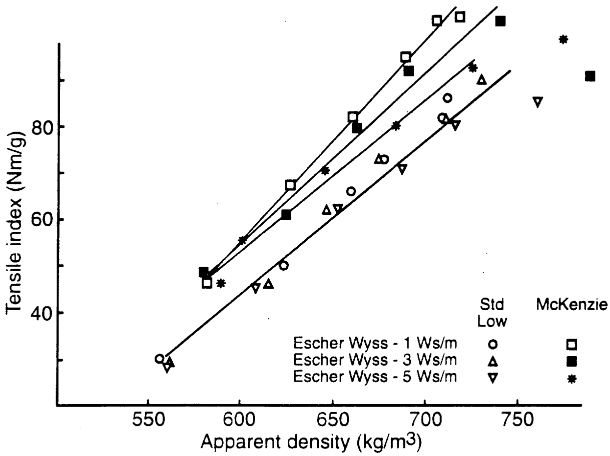

Figure 9: Tensile index/apparent density for Std low and McKenzie pulps

The eucalypt, McKenzie, and Std medium pulps have similar tensile strengths at given sheet densities with the most obvious difference between the pulps being the high tensile/density values of the unrefined McKenzie furnish (5). In contrast, the Std low handsheets are of high sheet density for given tensile strengths (Figures 8, 9).

For the three softwood pulps, tensile strengths at given sheet densities (Figures 8, 9) and energy inputs (Figure 7) can be marginally higher with treatment at 1 Ws/m than at 3 Ws/m. This contrasts strongly with wide pulp freeness differences obtained with specific edge load treatments at 1, 3, and 5 Ws/m (4). Thus, treatment at 1 Ws/m can be marginally more effective in developing handsheet tensile strength but least effective in decreasing pulp freeness. For the eucalypt:softwood blending studies, the more middle-of-the-road specific edge load of 3 Ws/m is taken to be the optimum treatment for softwood pulps.

Tear/Tensile Strength Relationships

Softwood and eucalypt pulps

Tear/tensile strength relationships are indicative of pulp reinforcement potentials and web runnability on papermachines (4, 5). For the Std medium pulp tear strength is higher than that of the Std low pulp when compared at the same tensile strength, except for the 5 Ws/m Std medium treatment (Figure 10). Treatment of the Std medium pulp at 5 Ws/m developed tear strengths equivalent to those of the 3 Ws/m treatment but at substantially lower tensile strengths. The marked shift in tensile strength of the Std medium pulp at 5 Ws/m is unexplained. For the McKenzie pulp tear strengths are high for given tensile indices relative to the Std low pulp (Figure 11), but roughly equivalent to those of the Std medium 1 and 3 Ws/m treatments (Figure 10). Examination of individual 1 Ws/m data points in Figures 10 and 11 shows that this treatment is most effective in developing the tear strength, at given tensile values, of the three softwood pulps. Also, tensile strengths consistently decrease with increasing specific edge loads, albeit only marginally for some pulps and/or treatments.

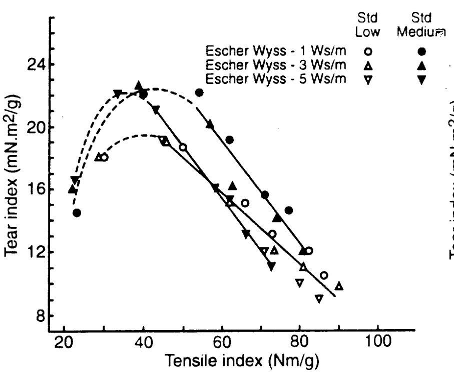

Figure 10: Tear/tensile strength of Std low and Std medium pulps

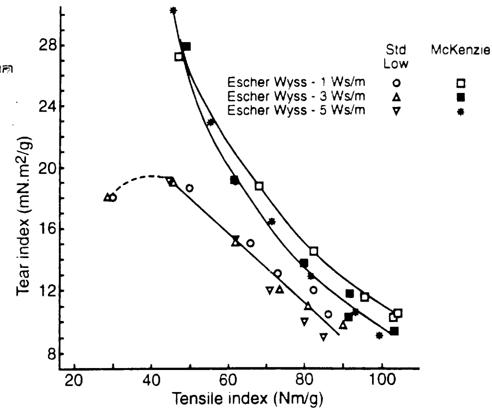

Figure 11: Tear/tensile strength of Std low and McKenzie pulps

Eucalypt:softwood pulp blends

Tear strengths for given tensile strengths decrease as eucalypt blend proportions increase from zero to 100% (Figure 12) (5). For the unblended softwood and hardwood pulps typical tear/tensile strength relationships are obtained with refining. Tear strengths increase with refining to maximum values for the eucalypt pulp, and decrease to minimum values of about 9 mN.m^2/g for the softwood pulps. Also, typical tear index values at tensile index values of 40–50 Nm/g are obtained with the softwood pulps.

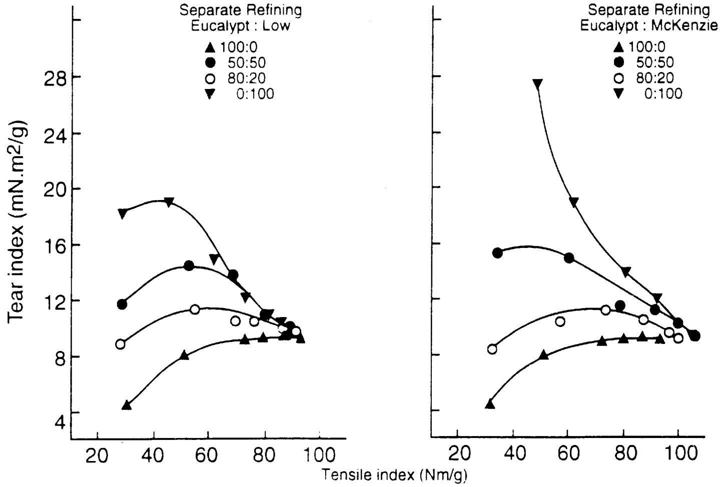

Figure 12: Separate refining—blend reinforcement strengths for Std low and McKenzie pulps

Unblended Std medium and McKenzie pulps have excellent tear/tensile strengths with those of the Std low pulp somewhat lower (Figures 10, 11) (5). As proportions of softwood fibre included in pulp blends are progressively decreased, the influence of softwood fibre quality differences also decreases with tear/tensile strengths roughly the same for the three 80:20 eucalypt:softwood blends. For the corresponding 50:50 blends, tear/tensile strength differences between the three softwoods are very much decreased but remain slightly higher for the McKenzie and Std medium furnishes (5).

Co-refining is less effective than separate refining in developing the tear/tensile properties of 80:20 eucalypt:Std low and eucalypt:Std medium blends (Figure 13) (5). For the 80:20 eucalypt:McKenzie blend, on the other hand, web reinforcement properties are roughly the same with either separate or co-refining. However, reinforcement properties of the eucalypt:McKenzie blends lie between those of corresponding separate and co-refined radiata pine blends. Tear/tensile strengths are generally equivalent for blends co-refined at 0.5 or 1.5 Ws/m (5).

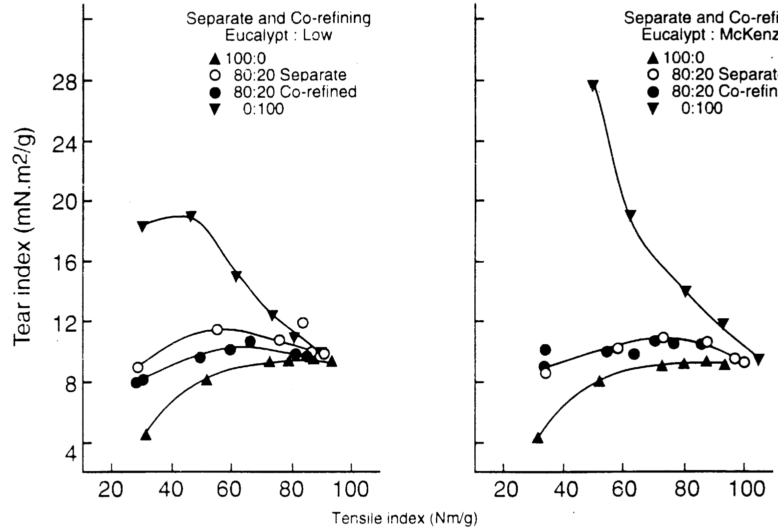

Figure 13: Co-refining—blend reinforcement strengths for Std low and McKenzie pulps

Optical Properties

Eucalypt and softwood pulps

Light-scattering coefficient/tensile strength relationships for each of the three softwood pulps are linear and decrease with increasing refining and tensile strength (Figure 14). Light-scattering coefficients are independent of specific edge load with the McKenzie pulp having the highest light-scattering properties and the Std medium the lowest. Also, light-scattering coefficients of the Std low pulp are closer to those of the Std medium than the McKenzie pulp. This is the reverse of trends obtained when apparent density is the basis of comparison (Figure 15).

Light-scattering/apparent density relationships are somewhat different to those obtained when light-scattering coefficient is compared against tensile index (5). Refining at 1 Ws/m can give marginally lower light-scattering coefficients when compared with pulps processed at 3 Ws/m. Also, light-scattering properties of the Std low pulp are closer to those of the McKenzie than the Std medium pulp.

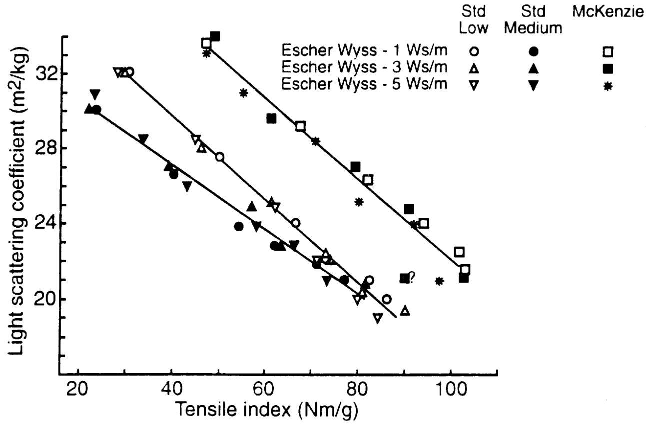

Figure 14: Softwood light scattering coefficient/tensile strength relationships

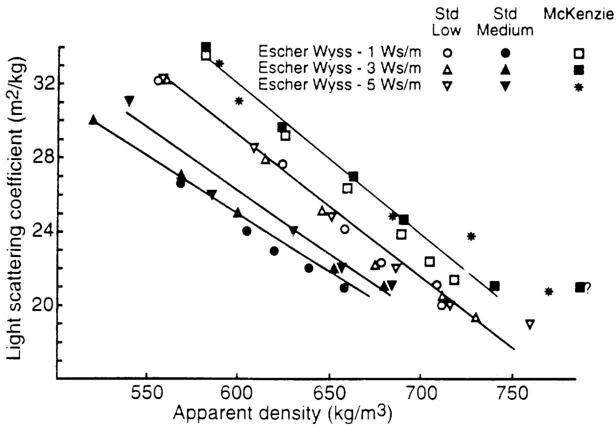

Figure 15: Softwood light scattering coefficient/apparent density relationships

Eucalypt:softwood pulp blends

For given tensile strengths the eucalypt pulp has by far the highest light-scattering potential followed by the softwood pulps in the order McKenzie, Std low, and Std medium (Figure 16) (5). For the 80:20 and 50:50 eucalypt:softwood pulp blends, light-scattering coefficients increase with increasing proportions of eucalypt fibre included in a furnish with values for the McKenzie blend marginally higher than those of the Std low and Std medium blends. The high tensile strength and light-scattering coefficient

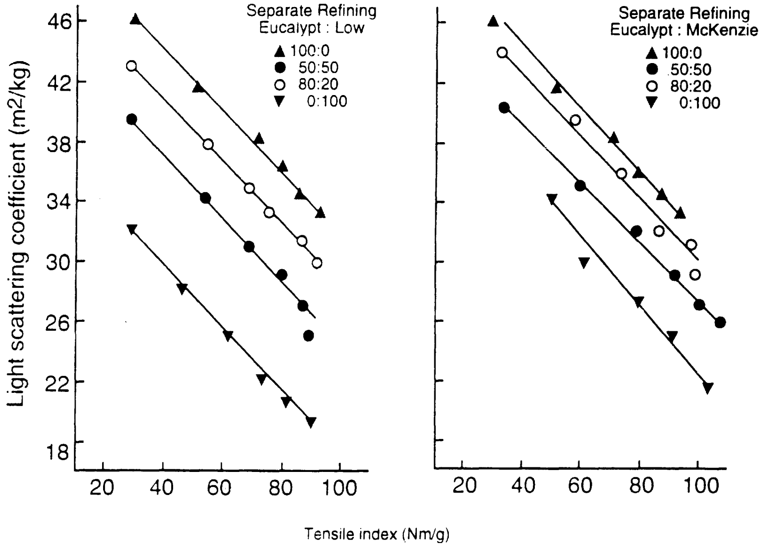

Figure 16: Separate refining—light scattering/tensile strength relationships for Std low and McKenzie pulps. Specific edge load: eucalypt 0.5 Ws/m and softwood 3 Ws/m.

typical of unrefined McKenzie pulp is evident from Figure 16 (4, 5). Furthermore, the high number of eucalypt fibres in the 50:50 blend, 428 out of 480 (Table 1), determines the tensile strength of the blend. For the unrefined 50:50 eucalypt:McKenzie blend the tensile strength is equivalent to that of the eucalypt component alone.

Light-scattering coefficient/ apparent density trends are generally similar to those obtained with tensile strength as the basis of comparison, with the following exceptions (5):

1. For the three 80:20 eucalypt:softwood blends light-scattering coefficients are roughly the same and therefore independent of softwood fibre quality differences.

2. Light-scattering coefficients of the unblended McKenzie and Std low pulps are much closer than those of the Std medium and Std low pulps, and contrast with trends obtained when tensile strength is the basis of comparison (Figures 14, 15)

3. With apparent density as the basis of comparison, blend proportions are generally reflected in unrefined apparent density and light-scattering values. With tensile strength as the basis of comparison, on the other hand, unrefined tensile strengths of 50:50 blends are often determined by the eucalypt component (Figure 16). This effect is particularly evident for the McKenzie blend.

For 80:20 eucalypt:softwood blends, light-scattering coefficients are slightly higher (at given tensile strengths) with co-refining at 0.5 Ws/m than with separate refining (Figure 17) (5). Co-refining at 1.5 Ws/m, on the other hand, gives light-scattering coefficients which are similar to those obtained with separate refining (5). With apparent density as the basis of comparison, light-scattering coefficients are roughly the same for separate refining and for co-refining at 0.5 and 1.5 Ws/m (5).

Tensile strength and apparent density values for given energy inputs are lower with co-refining at 0.5 Ws/m than at 1.5 Ws/m or with separate refining (4, 5). The slow tensile strength development with co-refining at low specific edge load (0.5 Ws/m) is also reflected in the light-scattering/tensile index

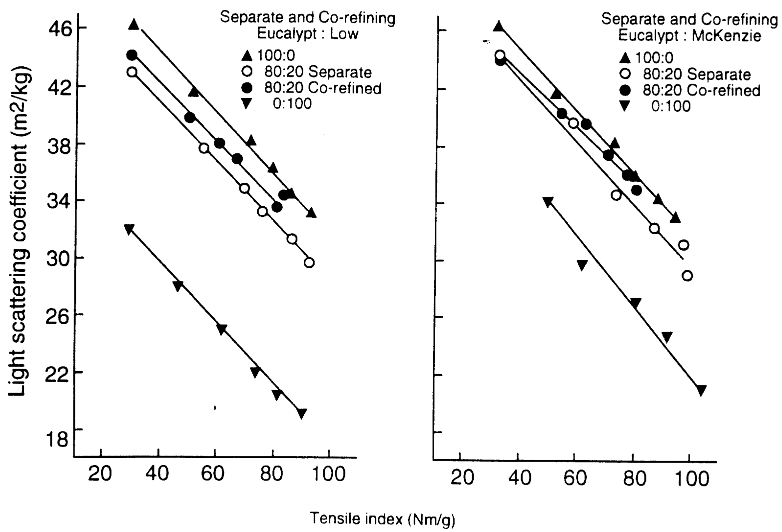

Figure 17: Co-refining—light scattering/tensile strength relationships for Std low and McKenzie pulps. Specific edge load: co-refined 0.5 Ws/m, and separate refined eucalypt 0.5 Ws/m and softwood 3 Ws/m.

relationships of Figure 17. Furthermore, tear/tensile relationships are normally lower with co-refining than with separate refining (Figure 13) which is the converse of the effects on handsheet optical properties (Figure 17) (5).

DISCUSSION

Fibre Property and Refining Interrelations

McKenzie fibres show the largest, and Std medium fibres the smallest, response to refining at different specific edge loads (Figures 4, 5, 6). It is only for the wall thickness property that separate specific edge load relationships are indicated for the Std medium fibres. Refining at the low 1 Ws/m specific edge load has minimal effects on fibre shortening, fibre collapse, and wall delamination and expansion (Table 2, Figures 4, 5, 6). Thus, fibres are not rapidly rewetted or made flexible with treatment at 1 Ws/m and pulp freeness values remain high (4). In contrast, fibre thickness, wall area, and wall thickness are increased substantially with refining at 3 and 5 Ws/m (Figures 4, 5, 6), fibres are shortened (Figure 2), and pulp freeness values are decreased (4). Effects of refining at 3 and 5 Ws/m on fibre cross-section dimensions are similar for the Std low and Std medium pulps but consistently different for the McKenzie furnish.

The selective response or sensitivity to specific edge load of the McKenzie fibres is noteworthy. The McKenzie furnish is typical of market pulps from the interior region of British Columbia. Such pulps can be expected to have highly uniform fibre populations, high numbers of fibres per unit mass, and relatively slender fibres of low coarseness (1, unpublished data). A combination of these factors probably accounts for the selective response to specific edge load obtained with the McKenzie pulp.

Eucalypt fibre cross-section dimensions are consistently higher when processed at 0.5 Ws/m than at 1.5 or 2.5 Ws/m (Figures 3, 4, 5, 6). Hence, the response of the eucalypt fibres to refining is the opposite to that of the softwood fibres, as expected (10). Furthermore, eucalypt fibre width and thickness, and the width × thickness product increase with refining while wall area is unchanged. The measured decrease in wall thickness with treatment at 0.5 Ws/m is therefore to be expected (Figure 6). The fact that wall area is unchanged and general wall delamination is absent in the refined eucalypt fibres is unexpected and remains unexplained. In an earlier study the wall areas of dried and rewetted eucalypt fibres increased when refined at 0.5 Ws/m (10).

Tensile Strength Development

Wall and cross-section dimensions of fibres in the McKenzie pulp are most sensitive, and those in the Std medium pulp least sensitive, to changes in the specific edge load used during refining (Figures 3, 4, 5, 6). This sensitivity of the McKenzie fibres to specific edge load is also reflected in their handsheet tensile properties (Figures 7, 9). The low specific edge load which is apparently least effective in increasing fibre wall area, delamination, wetness, and flexibility, is most effective in developing tensile strength for given energy inputs and apparent densities. It is unlikely that the separate tensile strength/ apparent density relationships for the three McKenzie pulps can be explained by the fibre shortening which occurs with increasing specific edge load (Table 2). Fibres in the Std medium, Std low, and McKenzie pulps are proportionately shortened to roughly the same extent with each specific edge load. The Std low pulp shows similar trends although the presence of a higher tensile strength with the low specific edge load treatment is more marginal than with the corresponding McKenzie furnish. The absence of a specific edge load effect on the cross-section properties of Std medium fibres (Figures 3, 4, 5, 6) is supported by the tensile strengths of the pulps processed at 1 and 3 Ws/m (Figures 7, 8). Finally, the development of high tensile strength at high bulk with refining at low specific edge load is consistent with the retention of fibre stiffness and length, and the development of high bonding potential. The high bonding potential is presumably developed through selective fibre surface disruption, wetting, and molecular and micro level fibrillation.

Reinforcement Strength–Tear/Tensile Relationships

Softwood pulps

Different softwood market kraft pulps can have very different reinforcement properties as measured by their tear/tensile strength relationships (1, 2, 5). Tear/tensile strengths are high for the McKenzie and Std medium pulps and relatively low for the Std low pulp (Figures 10, 11). The Std low pulp which is short fibred and of low coarseness relative to the Std medium pulp, and short fibred and of intermediate coarseness relative to the McKenzie pulp, has relatively low tear strengths for given tensile indices. With the Std low pulp some reinforcement strength is sacrificed for enhanced web closure, improved optical properties, decreased refining energy requirements, and an expected improvement in sheet formation (4, 5).

It is noteworthy that tensile strengths for given tear strengths are marginally greater with treatment at 1 Ws/m than at 3 Ws/m for all three softwood pulps (Figures 10, 11). Such selective development of tensile strength through refining at low specific edge load is more obvious when tear index rather than energy or apparent density is the basis of comparison (Figures 7, 8, 9, 10, 11). Furthermore, the explanation that selective tensile strength is developed at specific tear indices through maximum surface and minimal wall disruption, is in accordance with general understanding of the influence of fibre bonding and failure on paper tear strength (13).

Eucalypt:softwood pulp blends

For eucalypt:softwood blend proportions equal to or greater than 80:20, tear/tensile relationships or furnish reinforcement strengths are roughly the same and independent of the origin or type of softwood used (Figure 12). Thus, softwood fibre quality differences have minimal effects on the web reinforcement properties of 80:20 eucalypt:softwood blends. Such a result is to be expected since the numbers of softwood fibres included in 80:20 eucalypt:softwood furnish blends are 2–3% only (Table 1). For the 50:50 eucalypt:softwood blends, effects on tear/tensile strength relationships of using softwoods of different fibre quality are relatively small.

Based on the trends shown in Figure 12 it is of interest to speculate as to the interactive influences on web reinforcement properties of softwood fibre quality parameters (length, coarseness, slenderness, and relative number of fibres), blend proportions and numbers of eucalypt and softwood fibres, web grammages, and machine MD/CD effects, etc. For example, how do softwood fibre quality differences influence the tear/tensile properties of low grammage 80:20 eucalypt:softwood papers? Trends for 60 gsm handsheets only are shown in Figure 12.

Optimal treatments can be selectively given the softwood and hardwood components of a blend with separate refining but not with co-refining. Co-refining at either 0.5 or 1.5 Ws/m causes reinforcement properties to be decreased (albeit slightly for the McKenzie blend) when compared with separate refining (Figure 13) (5). In such situations it is envisaged that with co-refining the small number of softwood fibres present in the 80:20 eucalypt:softwood blends (<3%–Table 1) receive disproportionate levels of the refining, and tear strengths decrease for given tensile strengths and energy inputs. With co-refining, therefore, softwood fibres can be expected to be more refined and hardwood fibres less refined for given energy inputs, and for tear strengths to decrease (5). Tear index values are determined by the softwood component whereas tensile strengths are apparently determined by both the eucalypt and softwood components (Figures 12) (5). Numbers of fibre-to-tackle interactions and contacts are envisaged as being substantially greater for the long and broad softwood fibres than for the short and slender eucalypt fibres, irrespective of the numbers of each type present (Table 1) (5). Conversely, numbers of fibre-to-fibre contacts are envisaged as being relatively low and unimportant with Escher Wyss refining at a stock concentration of 3.5%. Finally, the tensile strengths and apparent densities of eucalypt pulps are increased more readily with treatment at 0.5 Ws/m than at 1.5 Ws/m. The converse holds for 80:20 eucalypt:softwood blends co-refined at 0.5 and 1.5 Ws/m which strongly suggests selective treatment of the softwood component (4, 5).

Optical Properties

Eucalypt and softwood pulps

The absence of an effect of specific edge load on handsheet light-scattering coefficient/tensile index relations (Figure 14) suggests mutual compensatory responses for the two handsheet properties. For the low specific edge load treatment at 1 Ws/m, high tensile strengths for given apparent densities and tear indices (Figures 8, 9, 10, 11) and low light-scattering coefficients at given sheet densities (Figure 15) are in agreement with such a conclusion. Such a combination of handsheet properties is consistent with the 1 Ws/m treatment selectively producing stiff fibres with compact wall structures (Figures 5, 6), and fibre surfaces of high bonding potential.

The high apparent density and high number of fibres per unit mass of the Std low pulp, compared with the Std medium pulp, are reflected in high light-scattering values for the Std low pulp (Table 1) (Figures 8, 9, 15). With apparent density as the basis of comparison, the different light-scattering coefficients of the McKenzie and Std low pulps can be related to roughly similar numbers of fibres, higher packing densities and bonding of the short and wide Std low fibres, and more light-scattering surfaces with the long and slender McKenzie fibres (5). In contrast, when the basis of comparison is tensile strength rather than apparent density, light-scattering values of the Std low pulp are lower and closer to those of the Std medium than those of the McKenzie pulp (Figures 14, 15).

Eucalypt:softwood pulp blends

Light-scattering coefficients for 80:20 eucalypt:softwood blends are slightly higher with co-refining at 0.5 Ws/m (at given tensile strengths) than with separate refining (Figure 17) or co-refining at 1.5Ws/m (5). Similar explanations hold for the optical properties as for the reinforcement properties of the eucalypt:softwood pulp blends, although light-scattering trends are the converse of those of the tear/tensile properties. It is envisaged with co-refining that the softwood component of a blend is selectively refined more heavily than the hardwood component. Hence, light-scattering coefficients of co-refined blends are higher than obtained with separate refining since optical properties are primarily determined by the hardwood component which is refined proportionately to a lesser extent with co-refining.

CONCLUSIONS

Softwood Pulps

McKenzie fibres show the largest, and Std medium fibres the smallest, response to refining at different specific edge loads. The sensitivity to specific edge load of the McKenzie fibres is explained by uniform fibre populations, high numbers of fibres per unit mass, and relatively slender fibres of low coarseness.

Refining at the low 1 Ws/m specific edge load has minimal effects on fibre shortening, fibre collapse, and wall delamination and expansion. Thus, fibres are neither rapidly rewetted nor made flexible with treatment at 1 Ws/m and pulp freeness values remain high. In contrast, fibre walls are readily expanded and rewetted with refining at 3 and 5 Ws/m, fibres shortened, and pulp freeness values decreased.

The slow response of softwood fibre walls to refining at low specific edge load is also reflected in their handsheet tensile properties. Refining at low specific edge load is least effective in increasing fibre wall area, delamination, wetness and flexibility, is most effective in developing tensile strength for given energy inputs, apparent densities, and tear strengths. Finally, the development of high tensile strength at low apparent density and low tear index, with refining at low specific edge load, is consistent with the retention of fibre stiffness and length, and the development of high bonding potential. The high bonding potential is presumably developed through selective fibre surface disruption, wetting, and molecular and micro level fibrillation. The absence of an effect of specific edge load on handsheet light-scattering coefficient/tensile index relations indicates mutual compensatory responses for these two handsheet properties.

Eucalypt:Softwood Pulp Blends

For eucalypt:softwood blend proportions of about 80:20, tear/tensile relationships (reinforcement properties) and light-scattering coefficients (optical properties) are roughly the same and independent of the origin or type of softwood used (5). Such results are to be expected since the numbers of softwood fibres included in 80:20 eucalypt:softwood furnish blends are 2–3% only. For 50:50 eucalypt:softwood blends effects of using softwoods of different fibre quality are relatively small.

Optimal treatments can be selectively given the softwood and eucalypt components of a blend with separate refining but not with co-refining. Co-refining causes reinforcement properties to be decreased when compared with effects of separate refining (5). In such situations it is envisaged that with co-refining the small number of softwood fibres present in the 80:20 eucalypt:softwood blends (<3%) receive disproportionate levels of the refining, and tear strengths decrease for given tensile strengths and energy inputs. With co-refining, therefore, softwood fibres can be expected to be more refined and hardwood fibres less refined for given energy inputs, and for tear strengths to decrease.

Light-scattering coefficients for 80:20 eucalypt:softwood blends can be slightly higher with co-refining, depending on specific edge load (5). Similar explanations hold for the optical properties as for the reinforcement properties of the eucalypt:softwood pulp blends, although light-scattering trends are the converse of those of the tear/tensile properties.

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Transcription of Discussion

EFFECT OF REFINED SOFTWOOD/EUCALYPT PULP MIXTURES ON PAPER PROPERTIES

P Kibblewhite, PAPRO, New Zealand

Dr R Popil, MacMillan Bloedel Research, Canada

Your early figures show that fibre width decreases with refining energy and that fibre thickness as well as fibre area actually increase with refining energy. What is the physical explanation for that?

P Kibblewhite

I didn't emphasise that the top curve showed that width decreased more quickly for radiata than it did for McKenzie pulp. This is related to the coarser thicker walled radiatia fibres in the furnish. These fibres have been squashed down somewhat but they haven't been collapsed in the lap pulp. When rewetted such fibres are able to bounce back to a circular shape early in refining. The width that we generated when we partly collapsed the fibre then disappears. If we consider the McKenzie fibres or the thinner walled radiata fibres more of these collapse in the diamond mode. In other words from the two ends of opposite corners the width doesn't change very much when either dried or refined.

Prof H Kropholler, UMIST, UK

You used once dried pulps I believe, did you measure curl at all?

P Kibblewhite

No, the pulps are not significantly curled. The radiata fibres aren't curled and neither are the Mackenzie fibres and so we didn't measure curl.

A Chatterjee, University of Toronto, Canada

When you made handsheets for your tear and tensile measurements were they recirculated handsheets, ie did they contain fines?

P Kibblewhite

No, we just used normal Tappi standard handsheet procedures. We didn't take any precautions in that respect.

A Chatterjee

At high specific edge load did you expect increasing fines to have an effect? I was wondering how the properties would change at high specific edge loads if they were made as recirculated handsheets?

P Kibblewhite

I don't think it would make any difference if we had the same quantity and type of fines at both specific edge loads. I did not measure the fines but these are not low freeness pulps - about 300 CSF is the minimum.

Prof J Lindsay, IPST, USA

In looking at eucalyptus and southern hard woods recently we were quite unhappy with the results we got measuring cell wall thickness and one of the things I seemed to note was that the microscopic methods for measuring cell wall thickness was sensitive to who was making the measurement and to some of the methods of preparation. Could you describe briefly the method you used and how confident you are in those measurements of cell wall thickness and cell wall area.

P Kibblewhite

We dehydrated the fibres first by solvent exchange which has a few problems if you are looking at absolute values but for relative values I am really confident in the differences in the unrefined pulps. We section the fibres, stain them and have an image processing system which we developed for measuring them. The wall area and the dimensions are both primary measurements. The wall thickness is derived from the wall area which we divide by the centre line. The wall thickness is a derived property.