Reinforcement and optical properties of separate and co-refined softwood and eucalypt market kraft pulps

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SUMMARY

The reinforcement strengths, optical properties and refining requirements of a eucalypt and several softwood market kraft pulps and blends are described. Market kraft pulps examined 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 by mass, and effects of separate and co-refining are assessed.

The fibre qualities of unrefined softwood kraft pulps largely predetermine their refining potentials and handsheet strength and optical properties. The medium coarseness radiata pine and interior British Columbia pulps, based on their tear-tensile properties, have roughly equivalent reinforcement potentials. The low coarseness radiata pine pulp has somewhat lower reinforcement strength but has more web closure, improved optical properties, decrased refining energy requirements and improved sheet formation.

Tear-tensile properties of 80:20 eucalypt-softwood blends are roughly the same and independent of the origin or type of softwood used. Pulps refined separately before blending have higher tear-tensile properties than those that are blended before co-refining. The light scattering coefficients are also similar for the 80:20 eucalypt-softwood blends. Co-refining of the eucalypt-softwood blends gives slightly higher light scattering coefficients than does separate refining of individual blend components.

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 very readily refined while those from the southern USA are traditionally very difficult to refine to a given strength and freeness. Radiata pine kraft pulps are of good strength and have intermediate refining requirements, 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 recognized in New Zealand.

The primary objective of this research is to identify optimum refining conditions and treatments for processing radiata pine kraft pulps and pulp blends. Characterization of the mechanical, reinforcement and optical properties of eucalypt-softwood pulp blends is the subject of this paper. Market kraft pulps examined 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. Effects of separate refining and co-refining are assessed using an Escher Wyss refiner which is considered to be indicative of commercial scale refining operations (3).

Earlier research has shown that refining energy demand, freeness, and tensile strengths of the three softwood pulps are predetermined by their unrefined fibre properties (4). Fibre and pulp quality differences present in the unrefined pulps are retained throughout refining processes. Furthermore the relative refining reponse of a given softwood pulp is independent of refining energy and specific edge load. Also the influence of softwood fibre quality differences on the properties of pulp blends decrease as the proportions of softwood fibre included in eucalypt-softwood blends decrease. For 80:20 eucalypt-softwood blends refining energy, freeness and tensile strength values are independent of softwood pulp origin. Similar trends are obtained when furnish components are refined separately or co-refined, although separate refining requires less 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 recognized 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 Mational Institute of Standards and Technology, Standard Reference Materials Program, 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 using these conditions: stock concentration 3.5%, refining speed 1500 r/min, specific edge loads 1, 3 and 5 W.s/m (softwood pulps) amd 0.5, 1.5 and 2.5 W.s/m (eucalypt pulp), and refining energies 0, 40, 80, 120, 160 and 200 kW.h/t.

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

Softwood and eucalypt pulps were blended after Escher Wyss refining. The stock concentration for each of the six samples of each Escher Wyss run was determined from the refined residual pulp remaining after processing. Softwood and eucalypt pulps were blended by thorough mixing in a bucket by stirring. 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 W.s/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 the o.d. bases. Tabulated data for all pulps, blends and refining conditions are presented elsewhere and are available on request.

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

RESULTS

Length, coarseness and number of fibres

Length weighted mean 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). In contrast, the Std low pulp contains shorter fibres (2.14 mm) of coarseness (0.243 mg/m) intermediate between those of the Std medium and McKenzie furnishes. The eucalypt fibres are roughly a third of 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 eucalypt-softwood 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).

Effects of separate and co-refining on the lengths of fibres in individual and blended pulps have been described elsewhere (4) and in summary they are—

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

Unblended eucalypt and softwood pulps

Tensile strength-apparent density relations: The eucalypt, Std medium and McKenzie pulps develop similar tensile strength-apparent density relations with refining (Fig. 1). The McKenzie pulp develops the highest tensile strengths for given energy inputs as discussed elsewhere (4). The Std low pulp gives handsheets of high apparent density (low bulk) compared with the eucalypt and other softwood pulps.

Table 1
Fibre length and coarseness, and calculated relative number of fibres per unit mass

Pulp	Eucalypt: softwood blend (Eucalypt content) %	Length weighted fibre length mm	Fibre coarseness mg/m	Calculated relative number of fibres per unit mass
Eucalypt	100	0.74	0.082	857
Eucalypt: Std low	0	2.14	0.243	100
	50			478
	80			706
Eucalypt: Std medium	0	2.46	0.275	77
	50			466
	80			701
Eucalypt: McKenzie	0	2.49	0.198	105
	50			480
	80			707

For the three softwood pulps, tensile strengths at given sheet densities and energy inputs can be higher with treatment at 1 W.s/m than at 3 W.s/m (9). This contrasts strongly with wide pulp freeness differences obtained with specific edge load treatments at 1, 3 and 5 W.s/m (4,5). Thus, treatment at 1 W.s/m is marginally most effective in developing handsheet tensile strength but least effective in decreasing pulp freeness. For the present study, the intermediate specific edge load of 3 W.s/m is taken to be the optimum treatment for softwood pulps. Treatment at 5 W.s/m can be harsh and one not normally considered to be applicable for most pulp processing situations (4,6,7,8).

Tear-tensile relations: Tear-tensile relations are indicative of pulp reinforcement potentials and web runnability on paper machines (1). Reinforcement potentials or tear resistances for given tensile indices are higher for the McKenzie and Std medium pulps and lowest for the Std low pulp (Fig. 2) (1). Also, tear-tensile strength relations are marginally greater with treatment at 1 W.s/m than at 3 W.s/m, but at the expense of freeness (4,5).

Optical properties: Light scattering coefficients for each of the three softwood pulps decrease with increasing refining and apparent density (Fig. 3). For given apparent densities, the McKenzie pulp gives the highest and the Std medium pulp the lowest light scattering values. Light scattering properties of the Std low pulp are closer to those of the McKenzie than the Std medium pulp.

Light scattering-tensile strength relations are somewhat different to those obtained when light scattering coefficient is compared against apparent density (Fig. 3,4). With tensile strength as the basis of comparison, the McKenzie pulp again has the highest light scattering properties and the Std medium the lowest, but with those of the Std low pulp closer to the Std medium than the McKenzie pulp.

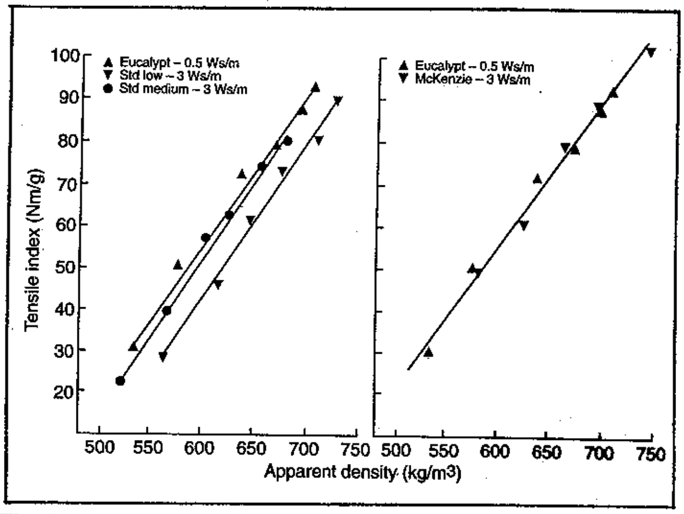

Fig. 1 — Tensile index/apparent density — unblended pulps.

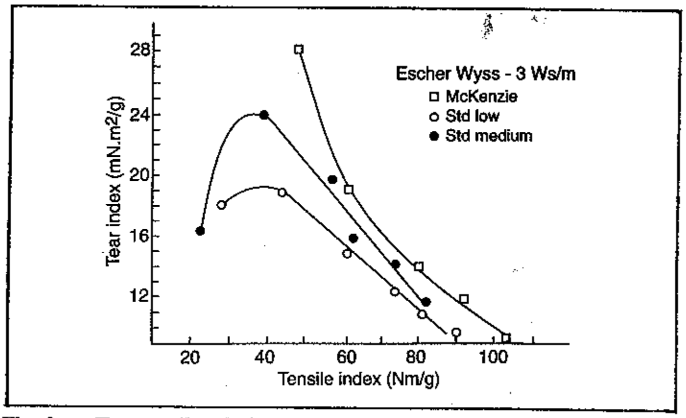

Fig. 2 — Tear-tensile relations for Std low, Std medium, and McKenzie pulps.

Eucalypt-softwood pulp blends

Reinforcement potential — tear-tensile relations: Tearing resistance for given tensile strength decreases as eucalypt blend proportions increase from zero to 100% (Fig. 2,5,6) (5). For the unblended softwood and hardwood pulps typical tear-tensile relations are obtained with refining (4). Tearing resistance increases with refining to maximum values for the eucalypt pulp, and decrease to minimum values of about 9 mN.m²/g for the softwood pulps. Also, typical tear index peaks at tensile index values of 40—50 N.m/g are obtained with the softwood pulps.

As proportions of softwood fibre included in pulp blends are progressively decreased, the influence of softwood fibre quality differences also decreases with tear-tensile properties roughly the same for the 80:20 eucalypt-softwood blends (Fig. 5,6). For the corresponding 50:50 blends, tear-tensile differences between the three softwoods are very much decreased but remain slightly higher for the McKenzie and Std medium furnishes.

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 (Fig. 7). For the 80:20 eucalypt-McKenzie blend, on the other hand, web reinforcement properties are roughly the same with either separate or co-refining (Fig. 8).

However reinforcement properties of the eucalypt-McKenzie blends lie between those of corresponding separate and co-refined radiata pine blends. Tear-tensile properties are generally equivalent for blends co-refined at 0.5 or 1.5 W.s/m (5).

Optical properties: 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 (Fig. 3,4,9,10). For the eucalypt-softwood pulp blends, light scattering coefficients increase with increasing proportions of eucalypt fibre in a furnish with values for the McKenzie blend marginally higher than those of the Std

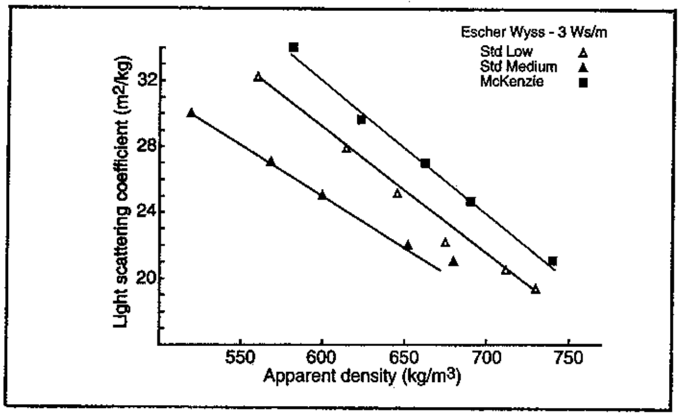

Fig. 3 — Softwood light scattering-density relations.

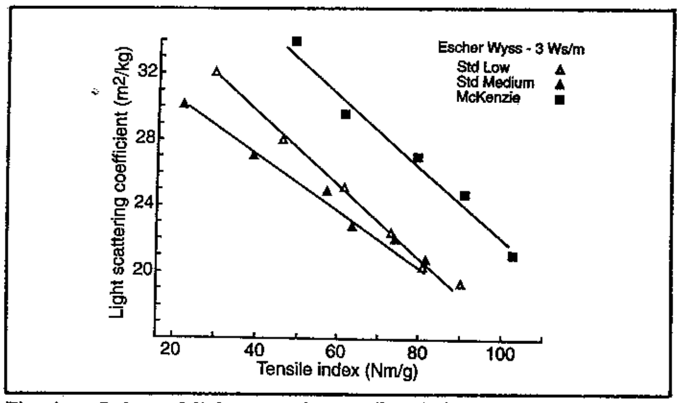

Fig. 4 — Softwood light scattering-tensile relations.

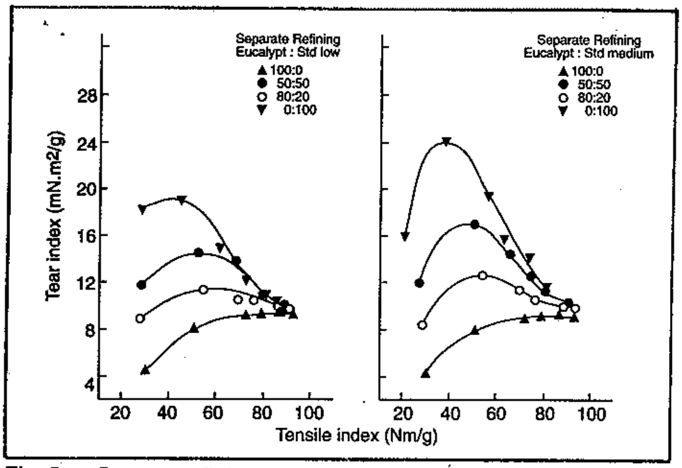

Fig. 5 — Separate refining — blend reinforcement strengths for Std low and Std medium pulps.

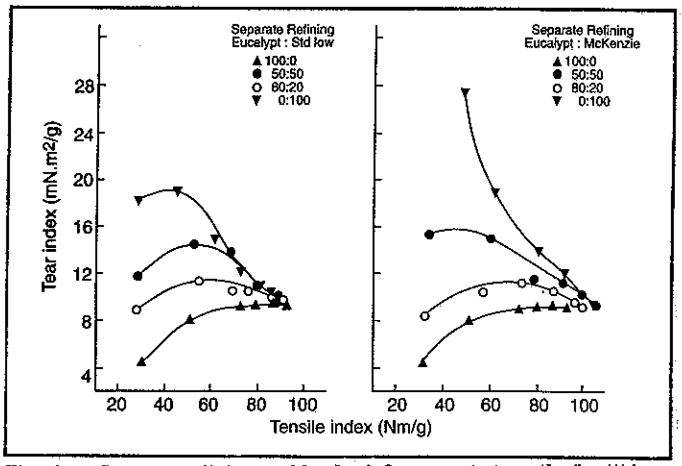

Fig. 6 — Separate refining — blend reinforcement strengths for Std low and McKenzie pulps.

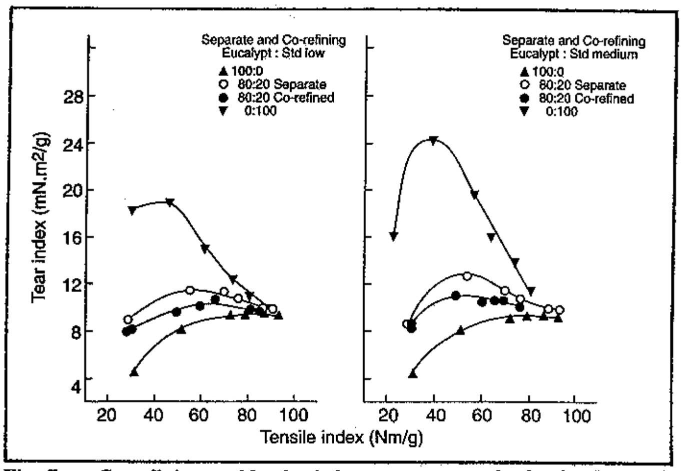

Fig. 7 — Co-refining — blend reinforcement strengths for Std low and Std medium pulps.

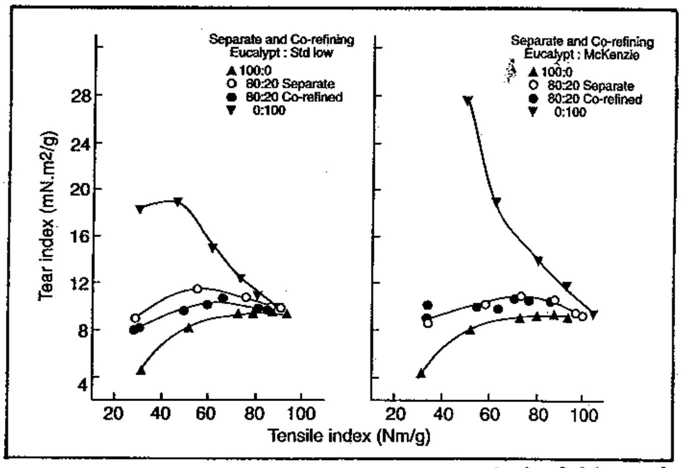

Fig. 8 — Co-refining — blend reinforcement strengths for Std low and McKenzie pulps.

low and Std medium blends. The high tensile strength and light scattering coefficient typical of unrefined McKenzie pulp is evident from Figure 10 (4). 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 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 (Fig. 11,12)—

- For the three 80:20 eucalypt-softwood blends light scattering coefficients are roughly the same and therefore independent of softwood fibre quality differences.
- Eucalypt-softwood 50:50 blend proportions are reflected in unrefined light scattering values with apparent density as the basis of comparison (Fig. 11,12). 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 (Fig. 10,11). This effect is particularly evident for the McKenzie blend.

For the 80:20 eucalypt-softwood blends, light scattering coefficients are slightly higher (at given tensile strengths) with co-refining at 0.5 W.s/m than with separate refining (Fig. 13,14). Co-refining at 1.5 W.s/m, on the other hand gives light scattering coefficients 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 W.s/m (5).

Tensile strength and apparent density values for given energy inputs are lower with co-refining at 0.5 W.s/m than at 1.5 W.s/m or with separate refining before blending (5). The slow tensile strength development with co-refining at low specific edge load (0.5 W.s/m) is also reflected in the light scattering-tensile index relations of Figures 13,14. Furthermore, tear-tensile relations are lower with co-refining than with separate refining (Fig. 7,8) which is the converse of the effects on handsheet optical properties (Fig. 13,14).

DISCUSSION

Unblended softwood pulp properties

For a given softwood pulp, tensile strengths at given sheet densities and energy inputs, and tearing resistances at given tensile indices, can be marginally higher with treatment at 1 W.s/m than at 3 W.s/m (5,9). This contrasts strongly with wide pulp freeness differences with specific edge load treatments at 1, 3 and 5 W.s/m (4). Treatment at 1 W.s/m is most effective in developing handsheet tensile and tear, and least effective in decreasing freeness. Thus, if manufacturing constraints and priorities demand paper machine runnability and/or high product strength, then refining at low specific edge load needs to be considered. Alternatively, if manufacturing constraints relate to energy requirements to a given freeness, then refining at an intermediate specific edge load needs to be considered.

Different softwood market kraft pulps can have very different reinforcement properties as measured by their tear-tensile relations (1,2). Tear-tensile properties are high for the McKenzie and Std medium pulps and relatively low for the Std low pulp (Fig. 2), and in agreement with previous findings (1). 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 tearing resistances for given tensile indices. With the Std low pulp some reinforcement strength is sacrificed for enhanced web closure (5), improved optical properties (Fig. 3,4), decreased refining energy requirements (4), and an expected improvement in sheet formation.

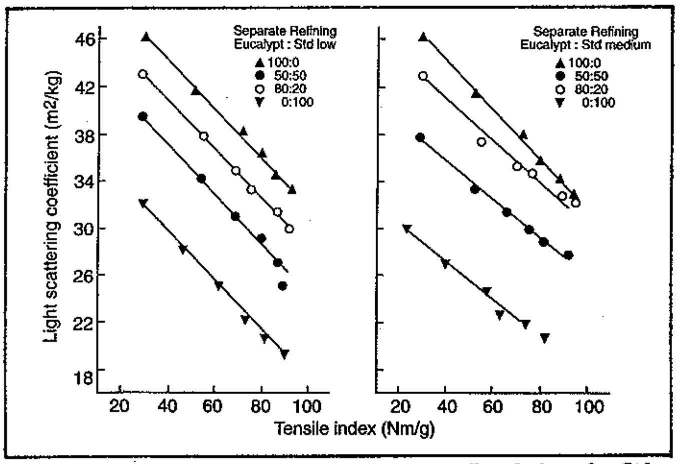

Fig. 9 — Separate refining — light scattering-tensile relations for Std low and Std medium pulps.

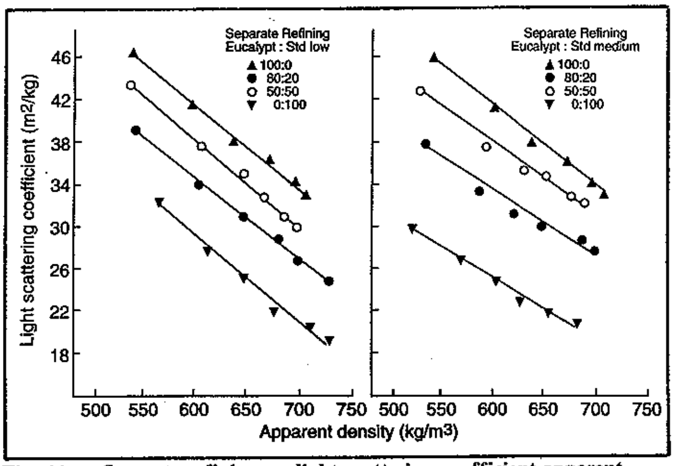

Fig. 11 — Separate refining — light scattering coefficient-apparent density relations for Std low and Std medium pulps.

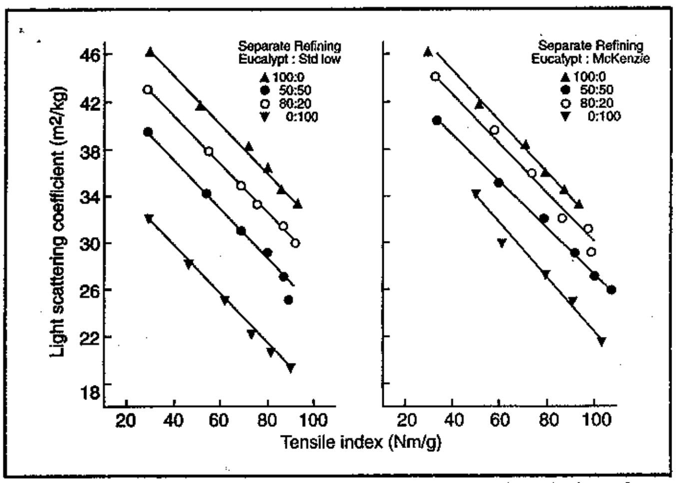

Fig. 10 — Separate refining — light scattering — tensile relations for Std low and McKenzie pulps.

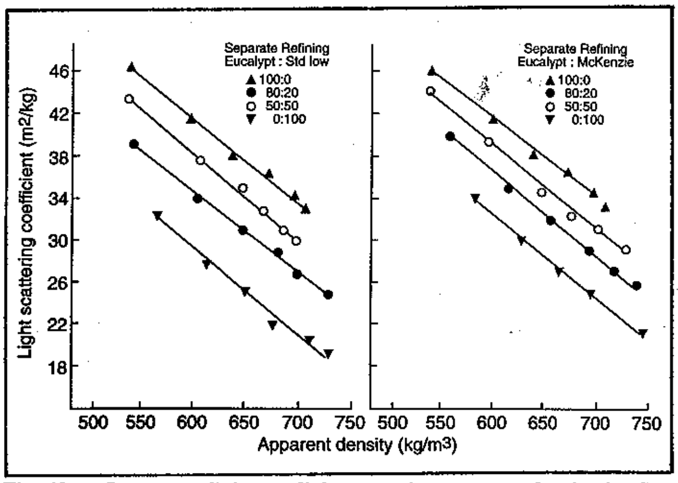

Fig. 12 — Separate refining — light scattering-apparent density for Std low and Mckenzie pulps.

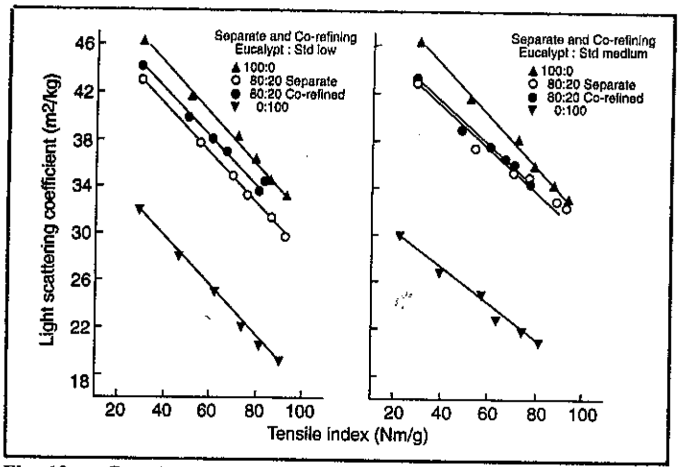

Fig. 13 — Co-refining — light scattering-tensile relations for Std low and Std medium pulps.

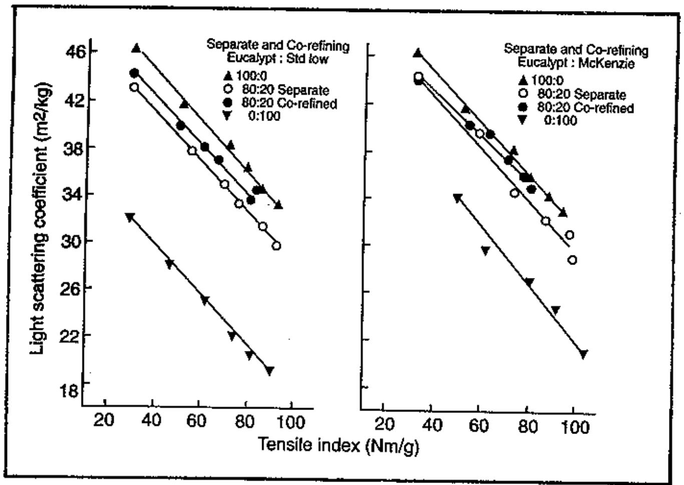

Fig. 14 — Co-refining — light scattering-tensile relations for Std low and McKenzie pulps.

The high apparent density and relative number of fibres per unit mass of the Std low pulp, relative to that of the Std medium pulp, is reflected in higher light scattering values for the Std low pulp (Fig. 3,4). With apparent density as the basis of comparison, light scattering differences between the McKenzie and Std low pulps can be related to roughly similar numbers of fibres (Table 1), higher packing densities and bonding of the short and wide Std low fibres (Fig. 1, Table 1) (1), and more light scattering surfaces with the long and slender McKenzie fibres. 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 (Fig. 3,4).

Eucalypt-softwood pulp blends

Tensile strength-apparent density relations for the eucalypt and softwood pulps and pulp blends are roughly the same, except for the Std low pulp. The Std low pulp has high apparent sheet densities for given tensile strengths when compared with the eucalypt, McKenzie and Std medium pulps. This difference decreases with decreasing Std low proportions in pulp blends, as expected. The high apparent densities of the Std low pulp are not reflected in the 80:20 eucalypt-Std low blend reinforcement and optical properties.

For the 80:20 eucalypt-softwood blends, tear-tensile relations or furnish reinforcement strengths are roughly the same and independent of the origin or type of softwood used. Thus, softwood fibre quality differences have minimal effects on the web reinforcement properties if 80:20 eucalypt-softwood blends.

With separate refining before blending at selected specific edge loads, pulp processing treatments can be optimized for specific fibre types, energy requirements and pulp properties. In contrast, optimization of co-refining treatment conditions for hardwood-softwood blends is complex and expected to be less effective than separate refining. For separate refining, optimum treatments can be selectively applied to the softwood and hardwood components. With co-refining at either 0.5 or 1.5 W.s/m, reinforcement properties are normally decreased compared with separate refining (Fig. 7,8) (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 input, and tearing resistance decreases for given tensile strength and energy input (9). With co-refining, therefore, it can be expected that softwood fibres are more refined and hardwood fibres less refined for given energy input, and tearing resistance is decreased.

A similar explanation holds for the optical properties of the eucalypt-softwood blends, although light scattering trends are the converse of those obtained for the tear-tensile relations. The development of light scattering coefficient by co-refining the 80:20 eucalypt-softwood blends (Fig. 13,14) is explained by selective treatment of the softwood component (9). Hence, light scattering coefficients of co-refined blends are generally higher for a given tensile index since optical properties are primarily determined by the hardwood component which is refined proportionately to a lesser extent with co-refining than with separate refining.

CONCLUSIONS

Unblended softwood pulps

Pulp refining at low specific edge load (1 W.s/m) is most effective in developing handsheet tensile strength and tearing resistance, and least effective in decreasing pulp freeness.

Reinforcement potentials, based on tear-tensile properties, of the refined Std medium and McKenzie pulps are roughly equivalent. 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 tearing resistance for a given tensile index.

Optical properties as measured by light scattering coefficient are highest for the McKenzie pulp and lowest for the Std medium pulp; an effect primarily explained by high numbers of fibres per unit mass in the McKenzie furnish.

Eucalypt-softwood pulp blends

The influence of softwood fibre quality differences on handsheet property inter-relations decreases with increasing proportions of eucalypt fibre included in eucalypt-softwood pulp blends.

For 80:20 eucalypt-softwood blends, tear-tensile relations or furnish reinforcement strengths are roughly the same and independent of the origin or type of softwood used. Thus, softwood fibre quality differences have minimal effects on the web reinforcement properties of 80:20 eucalypt-softwood blends. Pulps refined separately before blending have higher reinforcement strengths than those which are blended before co-refining.

For the eucalypt-softwood pulp blends, light scattering coefficients increase with increasing proportions of eucalypt fibre included in a furnish. Furthermore, light scattering coefficients are similar for the three 80:20 eucalypt-softwood blends although somewhat dependent on whether the basis of comparison is apparent density or tensile index. With apparent density as base light scattering values of the three blends are roughly the same with both separate and co-refining. With tensile index as base, on the other hand, light scattering values are generally the same with separate refining and can be marginally higher with co-refining. Thus, reinforcement properties can be decreased, and optical properties increased, with co-refining.

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ratio for the nylon fibres almost always lay below unity over the range of velocities measured. The heat transfer reduction for the nylon fibres was much less than for the pulp over most (u > 1 m/s) of the velocities investigated. This may be explained by the fact that the nylon fibres have a thermal conductivity approximately two to three times greater than the wood pulp fibres. The higher conductivity may offset some of the heat transfer reduction as a result of the increased thermal conduction within the fibres themselves.

SUMMARY

Frictional pressure drop and heat transfer coefficients have been measured for nylon fibres with a wide range of aspect ratios. At low aspect ratios ($r < 60$) the pressure drops and heat transfer coefficients of the suspensions were similar to those of water, the differences being due to the turbulence-damping effect of the fibres. Pressure drop results showing drag reducing flow were obtained for fibres with high aspect ratios ($r > 60$) and three regimes of flow were identified. The heat transfer coefficient for the longer fibres followed similar trends to those observed for wood pulp fibres, and the existence of two additional flow regimes was suggested. Both frictional pressure drop ratio and heat transfer ratio curves were shifted to higher velocities as the concentration was increased. The influence of the aspect ratio on the pressure drop ratio was shown, and explained in terms of the network strength. Both nylon and wood pulp fibre suspensions demonstrated similar drag reduction maxima indicating that the network strength was not the key parameter for this. Differences between the two results for different fibres were explained in terms of the dissimilar fibre mechanical properties. The nylon fibres reduced the heat transfer coefficient much less than the wood pulp fibres. At low fibre concentration and high bulk velocities some heat transfer enhancement was measured for suspensions which had the same pressure drop as water.

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