Celso Foelkel

REFINING – MIXED vs. SEPARATE

by Vail Manfredi and Ergilio Claudio-da-Silva Jr.

Research and Technology Center

ARACRUZ CELULOSE S.A.

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SPRING MEETING

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BACKGROUND

Refining is the first unit process in papermaking that affects stock properties in a generalized fashion. Through this mechanical treatment the pulp fibers undergo structural modifications, which have a profound effect on the properties of the paper to be formed.

The pulp refining operation is complex because it involves a number of variables not always under control. Although the refining results on pulp fibers have been identified, and most investigators agree on what the effects on fibers are, there seems to be no generally accepted theory that would indicate to the papermaker how the various controlling variables should be manipulated to achieve a desired output in terms of pulp properties.

Conditions are, therefore, seldom reproducible, and it is difficult to compare the experience of different mills. For a given pulp it is always possible to achieve optimum operating conditions, especially when the fiber characteristics are know and the desired paper properties are more or less set up. The problem starts when one tries to generalize the optimum conditions obtained with one pulp to others. This is particularly difficult when dealing with the various types of hardwood pulps in the market, and how they interact with softwood fibers during papermaking.

Refining Theories

The proposal and utilization of new theories, since 1967, have enabled a better understanding of what happens inside the refiner, and allowed better means for optimization. Fundamental to all the theories is the understanding that the refining result is a function of two major factors, among others:

– the *amount* of applied energy (i.e *net* kwh/t)
– *how* is the energy applied.

It is also well recognized today that the energy is transmitted to the fibers by the *leading edges* of refiner bars (and not the surface of contact), and that the primary stock entities receiving treatment are fiber *flocs,* rather than single fibers (1–4).

The concept of Specific Edge Load (S.E.L.) has provided a significant contribution in the search for an index representing the intensity of the beating performance describing the beating absorption by a pulp, at least with respect to its nature. In this theory an empirical measure of the relative severity and the relative number of impacts that a fiber receives in the refiner is given (5). This concept has been developed into other refining theories by Brecht (6), Danforth (7) and Leider and Nissan (8), all involving the character of the beating (or refining) action as described by the type (or intensity) of refining and the extent of action, which is related to the amount of refining (or work) imposed on the fiber flocs.

In other words, refining action is always a balance between *total net energy* input and the *number* of impacts vs. impact *intensity.* The intensity of treatment is an inverse function of the area of refining, as given by the number and width of bars, and a direct function of the unit pressure exerted between the surfaces. The degree or amount of treatment is directly related to the actual bar-to-bar surface area and the relative speed of the refining surfaces. According to this concept, lower intensity should increase treatment homogeneity, preserve fibre length and induce better fibre bonding, whilst high intensity leads to increased fibre shortening and the excessive generation of fines.

The use of these principles should allow the optimization of energy consumption, while maximising the potential for development of paper properties. In other words, presently there are means to better understand and simulate the refiner *action,* although they do not incorporate all refiner variables (4, 9-11), and there is still a missing link in the comprehension of refining *action* vs. basic primary *effects* on fibers, as indicated by the recent literature (12-14).

Refining Optimization

The limitations above mentioned often contribute to further difficulties in generalizing the results. The SEL theory is undoubtedly much easier to apply (11, 15) than those based on calculations of the severity and number of impacts (7, 8), because it is mathematically much simpler. However, it does not include the effects of bar material, bar angle, flow rate, and most importantly pulp consistency.

Since there is evidence that flocs are always present between refiner bars, and because one of the primary refining effects may proceed via floc behavior under compressive shear forces (16), there may be a stronger influence of parameters related to floc structure (i.e. pulp consistency, fibre length, flexibility, amount of beating, etc.) on the relationship between refining action and refining result than previously recognized.

This is evident in the studies of Arjas (17), who has shown the importance of residence time distribution of fibers in the refining upon the bar clearance. His results indicate that since in any refining process the pulp mat must support the load of the energy applied, the observed reductions in refiner gap in multiple pass refining are strongly related to the increased degree of treatment homogeneity (and hence floc behavior), as opposed to single-pass refining. These observations indicate that studies based on multiple-pass refining may not allow the identification of important parameters influencing refining action vs. effects, as, for instance, pulp consistency (15).

Another important consideration has been clearly exemplified in the work by Levlin (18). When comparing the refining behavior of pine and birch pulps, at differente S.E.L. levels, he observed that they reacted differently to the applied load, and concluded that optimum beating conditions are generally quite differente for softwood and hardwood pulps. His data indicated that bar clearance when refining birch was always half or lower than when refining pine, due to the greater flocculation ability of the latter. From these results it was concluded that separate refining of these two pulps would allow better optimization of paper properties of a mixed furnish.

Other authors have arrived at similar conclusions (10, 19, 20) especially when refining eucalyptus (21-23), while Arjas (24) has observed little difference between the results from mixed vs. separate refining. It is noticeable, however, that these studies have not included pulp consistency (as directly influencing the flocculation degree) as a major variable in the evaluation of results. Fiber types, which also influence floc characteristic and behavior, have also been usually limited by the number of pulps used. A recent study by Gess (25) on some of the refining effects has indicated that the type of pulps in a blend may lead to results following one or another direction.

The present study is an attempt to bring more information, which may help to clarify this matter, as separate beating always involves a more complex stock preparation system and higher investments, and in many cases the mill refining capacity is significantly limited.

EXPERIMENTAL

Refining Pilot Plant

The investigation was performed in a pilot plant specifically designed for research purposes. It includes a 12 inch PILÃO refiner, powered by a 55 kw motor, a positive displacement (mono) pump, which allows good control of flow rates through the refiner, as well as automatic control valve which enables control of feed pressure to the refiner, and temperature and power registers. The total control of these variables, as well as consistency is of fundamental importance for the reproducibility and representativeness of the results (11).

Refining Operation

The pulps were reslushed at the desired consistency in 1.8 m^3 chests, using mill tap water (total hardness 19 ppm $CaCO_3$, conductivity 15 $\mu S/cm$). For each refining curve, approximately 1.5 m^3 of suspension were used.

To ensure complete suspension homogeneity, the stock was pumped through the refiner for five minutes before refining, also allowing for measurement of "no-load" or "backed-off" power in each case (pulp type, consistency, plate used). At this point samples representing the unbeaten pulps were taken.

Every refining curve was performed at constant S.E.L. level, and varied throughput. This means that motor load and speed was constant in each case, and variations is stock flow rate produced different levels of net applied energy. Bar clearance was adjusted manually to keep motor load when varying throughput. This procedure characterizes single-pass refining at all refining levels, in contrast to obtaining different levels of net energy input by multiple passes through the refiner.

Although single-pass refining has its limitations, due to available motor power in the pilot plant, pulp consistency, and the level of flow rate, it is expected to be more representative of actual refining than operation in multiple pass, according to the residence time distribution (24). One-stage refining is certainly more heterogeneous and may allow a better evaluation of the effects of different refining variables. Furthermore, industrial refining is seldom performed in more than three passes.

In this study single-pass refining was always applied, except when working at 5% consistency and with very low flow rate, due to limitations in the system. In this case the highest applied energy for each beating curve was obtained by refining in two passes, with 3.75 m^3/hr throughput in each.

All refining curves were performed in triplicate, and the results from testing of pulp and paper properties are expressed as averages.

Pulp Samples

Dry lap bleached kraft market pulps were used throughout this study. Initially one northern softwood pulp — mostly western Canadian *spruce* (Northwood) —, two northern hardwoods — *aspen* (Terrace Bay) and *maple* (Pontiac regular) —, and one *eucalypt* pulp (Aracruz) were used. In the final stages of this work other softwood pulps were introduced and used in mixtures with the eucalypt pulp: Scandinavian Pine (Stora 32) and Southern Pine (Mead Brunswick) — mostly slash pine, with some loblolly pine.

Experimental Design

The influence of two refining variables was studied simultaneously, in addition to pulp types: The S.E.L. level and stock consistency. The first was applied at 0.5 and 2.0 w.sec/m, through calculated motor load (Table I). Refiner speed was maintained at 1200 rpm, which is equivalent to a peripheral speed of ca. 18.8 m/sec.

TABLE I — Characteristics of plate patterns used.

PLATE PATTERN	BAR WIDTH mm	GROOVE WIDTH, mm	BAR ANGLE DEG.	GROOVE DEPTH, mm	CUTTING LENGTH, km/rev.	MOTOR LOAD AT 1200 rpm kw	S.E.L. w.sec/m
5 X 5/5	5	5	5	7.9	0,247	12.5	2.0
3 X 3/5	3	3	5	7.9	0,624	9.0	0.5

It is important to stress that by changing refiner plates the number of contacts per unit time was also changed, but the motor load was adjusted to reach the desired level of S.E.L. These loads, at each S.E.L. level, were kept *constant* throughout refining, in order to keep unchanged the intensity of every impact.

Two levels of pulp consistency were used: 2.0 and 5%, simulating low consistency and medium consistency refining respectively, which are levels that can normally be used at most refining installations. Table II summarizes the combination of variables:

TABLE II — Combination of refining variables in the experimental design.

REFINER SPEED rpm	SPECIFIC EDGE LOAD, w.sec/m	PULP CONSISTENCY %	PLATE PATTERN
1200	0.5	2	3 X 3 / 5°
		5	3 X 3 / 5°
	2.0	2	5 X 5 / 5°
		5	5 X 5 / 5°

Those four combinations of conditions were applied to all pulps, in pure form and after blending. Six types of blends were studied:

- 60% eucalypt / 40% spruce
- 80% eucalypt / 20% spruce
- 80% aspen / 20% spruce
- 80% maple / 20% spruce
- 80% eucalypt / 20% scand. pine (only 5% consistency and 0.5 w.sec/m)
- 80% eucalypt / 20% southern pine (only 5% consistency and 0.5 w.sec/m)

These blends were prepared both before and after refining, the latter by mixing pure pulps, in the desired proportion, which had been subjected to equivalent levels of net refining energy. It was assumed that this procedure would allow a good basis for comparison of mixed vs. separate refining, since total applied power is one of the most important variables in the refining operation, and in mixed refining one can expect that the energy will be distributed proportionally among the components. In this way it is possible to evaluate the effects of same total net energy when applied to both components at once, or separately to each of them.

Pulp and Paper Testing

Wet pulp samples were analysed with respect to slowness, (degree Schopper-Riegler – ^{o}SR), Water Retention Value – WRV, and Dynamic Drainage Time (DDT). The former followed the procedure in the SCAN Standard, while WRV was measured at 900 X g for 30 minutes.

The DDT measurement was included as a better indication of the drainage resistance of pulp on the wire of papermachines than the ^{o}SR. It incorporates two operating variables of primary importance during dewatering, which are neglected in the freeness/slowness test: the suction present in table rolls and foils, and the turbulance of the stock coming from the headbox. The method followed the procedures proposed earlier (13), and involves measurement of time elapsed for drainage of a pulp suspension from 0.2 to 4% consistency, under 100 rpm and 10 inches of Hg vacuum in a modified Britt's Jar.

Morphological analyses were also performed on wet pulps. Fiber length was determined by the Kajaani FS-100 fiber analyser. A suspension of 0.001% consistency was prepared by diluting 0,15 grams oven dry pulp to fifteen liters with demineralized water. The consistency was determined by the average result of three replicates, using 3 liters of the suspension each. For hardwoods, a sample of 25 ml was run in the fiber analyser. For softwoods, between 50 ml to 100 ml were used so as to obtain, in both cases, a total of ca. 5000 fibers counted. Three determinations were obtained for each pulp. The corrected consistency, total number of fibers in each run minus no. of fibers counted up to 0,1 mm, and the arithmetic average fiber length were used in the calculation of coarseness, and number of fibers per gram of pulp. The weighted average fiber length was calculated by the Kajaani analyser.

Primary fines contents were determined using TAPPI T261-pm 79. Suspension pH and conductivity measurements were made according to ISO Standards 6588/81 and 6587/80 respectively.

Ash content and mineral analysis were performed by gravimetry, followed by acid dissolution and spectrophotometric/atomic absorption measurements. For pentosan analysis TAPPI T 223 ts-63 was used, while for DCM extractives the procedures in TAPPI Standard T 204-os 76 were followed. Determinations of pulp viscosity followed SCAN Standard C15:62.

At a later stage of this study it became necessary to make an estimate of the relative tendency of flocculation of the different pulps. This evaluation was made through the measurement of "terminal volumes" of pulp suspensions (31) which are also in agreement with equivalent methods to measure the "sedimentations concentrations" (C_s) – "the lower concentration limit, under which the fibers cannot form a continuous network" (32). Each pulp was suspended in mill tap water at 0.1% consistency. The deaerated suspension at 25 ^{o}C was allowed to settle for six hours, in a two liter graduated cylinder, and the volume of sedimented pulp was measured.

Handsheets were prepared, conditioned and tested following SCAN Standards. The results represent averages from three refining curves, with coefficients of variation lower than 5 per cent.

RESULTS AND DISCUSSION

The experimental design used in this investigation has produced a significantly large amount of data, which makes it unpractical to report completely. The major stress in the following discussion is, thus, to present and analyse the major trends and phenomena observed.

Refining of Pure Pulps

As described earlier, the bulk of this study was concentrated on three hardwoods and one softwood pulp, and their mixtures. In a later part of the investigation two other softwood pulps were used (Scandinavian pine and Southern pine), in mixtures with the eucalypt pulp. Some information about the properties of all pulps in their unbeaten state is presented in Table III.

It can be noticed that the spruce pulp is the strongest among the softwoods analysed, with long fibers and low fines content, high values of initial strength, handsheet density and air resistance. These properties also indicate a high degree of flexibility of spruce fibers, which when associated with their average length and chemical properties, should have an important influence on floc size and behavior inside the refiner. Southern pine fibers are longest but appear to be the stiffest among the softwoods, as indicated by handsheet density, air resistance and initial strength. Scandinavian pine has properties in-between the other two softwoods, being closer to southern pine.

Among the hardwood pulps eucalypt has the shortest and more numerous fibers, while aspen's are longest and occur in lower number per gram of pulp. Also noticeable are the elevated primary fines and pentosans contents of maple pulp, and the high initial light scattering coefficient of eucalypt pulp.

The fiber length distributions for the different pulp samples (Figure 1) may bring additional information to the simple figures of average fibre length. It can be seen that southern pine fibers are very heterogeneous in length, although their average length is the highest among softwoods. The high proportion of short fibers in the scandinavian pine is also noticeable, especially when compared to spruce. Hardwood fibers are much shorter, but significantly more uniform in length, particulary the eucalypt. Those features may also help in the evaluation of the tendency for formation of fiber networks, to be discussed later.

TABLE III — Unbeaten Pulp Properties

PROPERTIES	PULP SAMPLES					
	Eucalypt	Aspen	Maple	Spruce	Scand. Pine	So. Pine
ANATOMICAL PROPERTIES						
Weighted Average Fiber Length, mm	0.65	0.88	0.81	2.50	2.13	2.70
No. Fibres/gram. (x 10^6)	21.6	14.3	15.9	4.0	4.2	2.6
Fiber Coarseness, mg/100 m	8.6	10.3	10.7	15.8	18.3	26.5
Fines Content (200 mesh), %	6.1	7.4	10.8	2.6	3.9	6.8
HANDSHEET PROPERTIES						
Apparent Density, kg/m^3	556	629	592	562	517	501
Tensile Index, Nm/g	20.6	20.7	20.6	21.2	18.4	17.6
Tear Index, Nm^2/kg	4.0	5.0	5.7	17.0	12.2	13.7
Light Scattering Coeff., m^2/kg	47.6	37.0	40.4	35.5	32.5	27.2
Air Resistance — Gurley, sec/100 ml	1.4	3.0	1.5	1.0	1.5	0.2
WET PULP PROPERTIES						
Water Retention Value, %	155	131	144	130	121	120
Dynamic Drainage Time, sec	6.1	6.0	6.1	5.1	5.2	5.0
Degree Schopper-Riegler, °SR	20.0	18.0	19.5	14.0	13.0	11.5
PHYSICO-CHEMICAL ANALYSIS						
PULP						
DCM Extractives, %	0.13	0.31	0.11	0.12	0.02	0.01
Pentosans, %	16.5	16.5	18.7	8.6	8.5	7.8
Viscosity, dm^3/kg	866	803	717	848	799	747
Ash Content, mg/kg	1,629	8,114	2,130	2,318	478	2,375
Silica, mg/kg	16	6,366	740	1,519	38	967
Iron, mg/kg	3.3	23.4	13.1	15.3	11.2	11.3
Magnesium, mg/kg	20.8	58.0	168.1	153.2	20.3	329.1
Aluminium, mg/kg	9.6	4.0	8.2	6.5	8.6	5.6
Calcium, mg/kg	55.1	127.2	93.2	208.5	98.0	447.4
Sodium, mg/kg	340.9	70.4	278.2	68.5	78.9	73.7
PULP SUSPENSION (demineralized water)						
Conductivity, μS/cm	15.0	9.8	17.1	14.7	12.0	19.0
pH	5.7	6.5	6.0	5.4	6.2	6.6

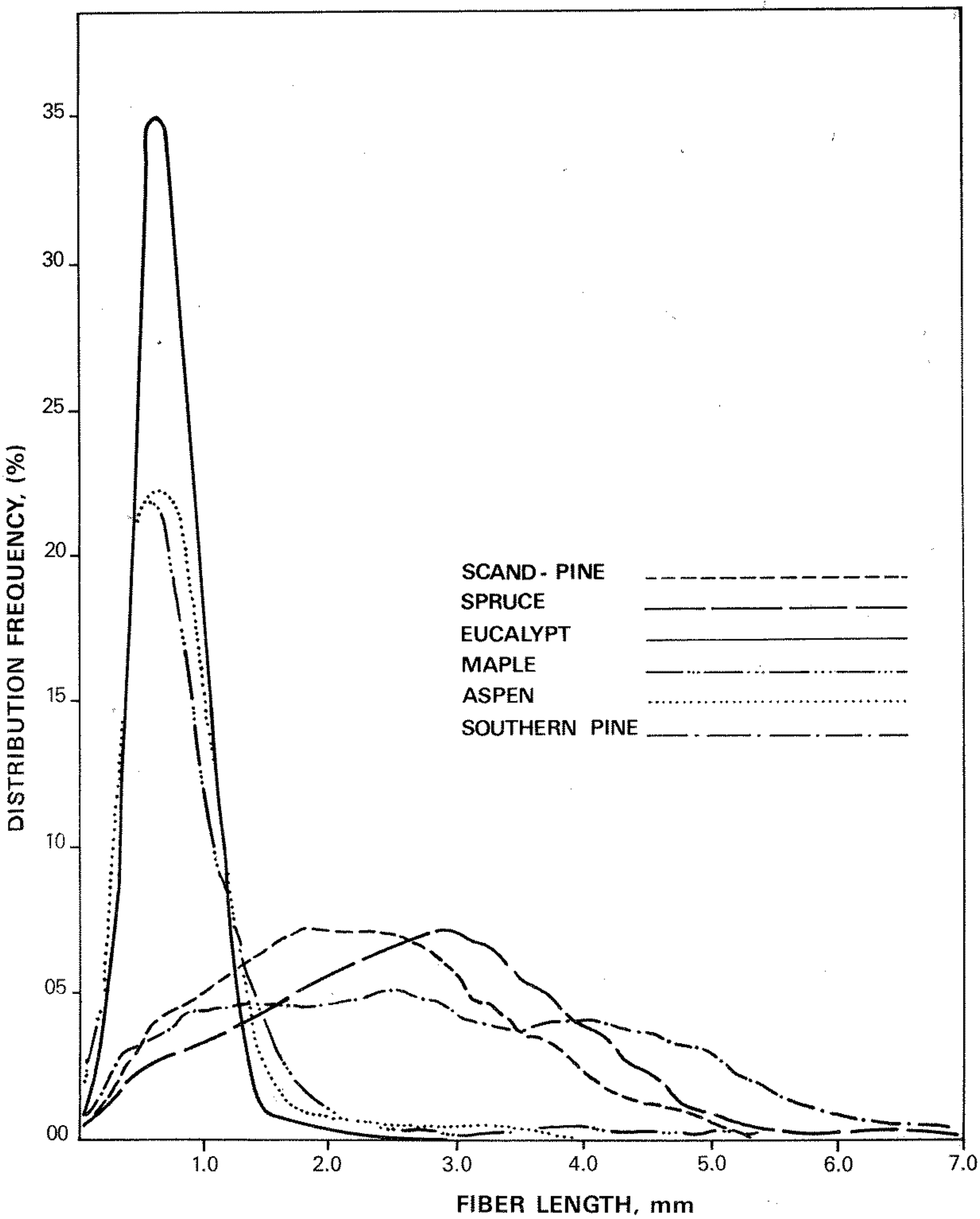
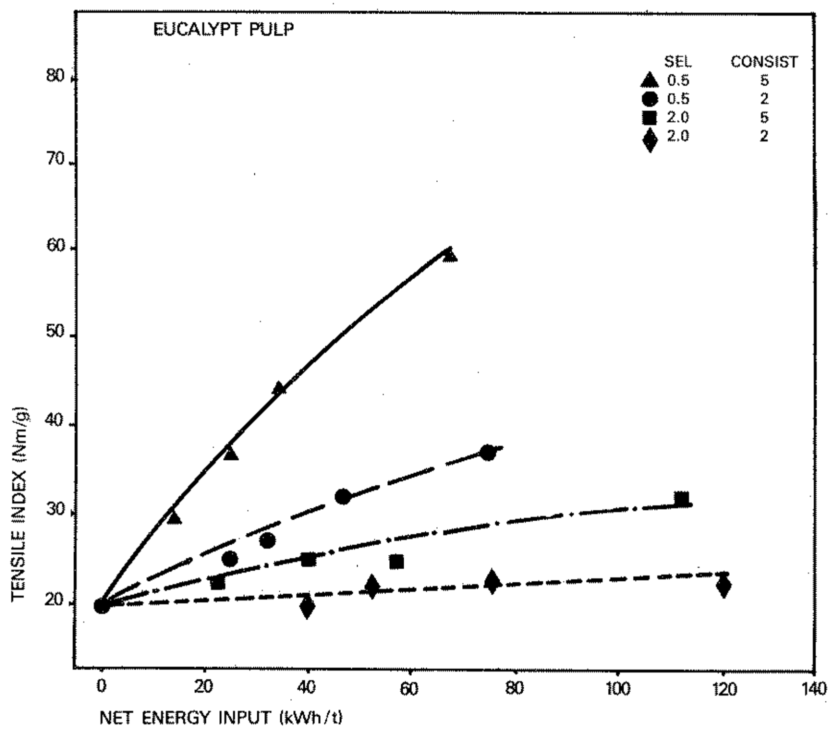
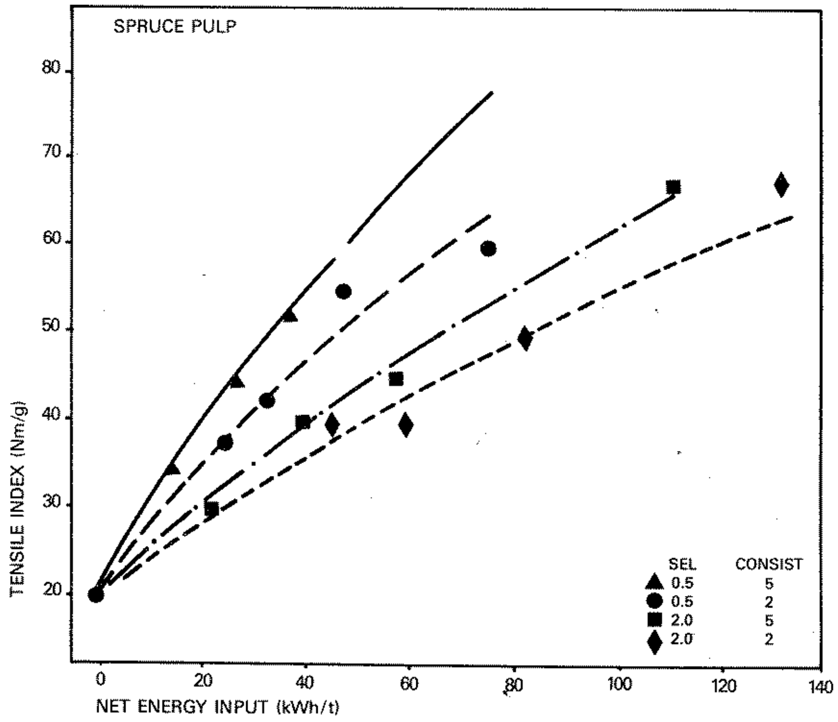


Figure 1 — Fiber length distributions of unbeaten pulps.



(2a)



(2b)

Figure 2 — Tensile index development of pure pulps under four combinations of refining conditions

The results from refining separately the three hardwoods and spruce pulp were followed by measurements on wet pulp and dry handsheets. Paper properties evaluated were apparent density, tensile index, tear index, light scattering coefficient and Gurley – air resistance.

The adequate characterization of the refining result is obviously of utmost importance to the understanding of the observed phenomena. Since the properties of a given pulp may be modified in different ways in relation to each other, depending on refining conditions, it is difficult to combine the results in a way applicable to all cases. Certainly it is better to combine properties which are of importance to the paper grade to be manufactured from the pulp.

In most refining studies the freeness/slowness measurement is used as a basis for comparison, despite increased recognition of the limitations of the method (12, 13, 26, 27). Slowness development is highly related to the formation of fines during refining, while the process is usually aimed at improving paper properties which are strongly related to the degree of interfiber bonding and fiber flexibilization (14). Consequently, when results are evaluated mostly as a function of SR/CSF, the conclusions may be based too strongly upon fines development, which is only one of the refining effects.

Furthermore, the freeness/slowness value can hardly be used as an indication of the drainage resistance of chemical pulps, and new methods have been proposed for such an estimate, by incorporation of testing conditions more akin to those on the wire of paper machines (13, 25). Consequently, it was decided for the present study to follow the refining results throught the development of tensile strength, and to use this property as a basis for comparison of other properties, including the dynamic drainage time.

As indicated in Figure 2 the four combinations of SEL and consistency had pronounced effects on the rate of tensile strength development. For the eucalypt pulp there was a significant improvement in tensile index when consistency was increased from 2 to 5% at high SEL, but most important was the effect of low SEL on the rate of increase, especially for the combination: 0.5 w.sec/m – 5% consistency.

The behavior displayed by eucalypt was very similar of those of aspen and maple. For spruce the same tendencies were observed, although the differences were not as large when comparing the four sets of conditions. This can be better visualized in Figure 3, where tensile index values of spruce and eucalypt are compared at 80 kwh/t net applied energy, for the four sets of refining conditions.

These results show clearly the strong influences of pulp consistency and characteristics of the impacts during refining upon the result of the mechanical treatment. All pulps responded better to a large number of gentle impacts, rather than a reduced amount of high intensity ones, which is in agreement with earlier results (18), at least for the hardwoods.

The influence of stock consistency seemed to be higher for the hardwood pulps. At 2% consistency there was hardly any development in strength when the refining intensity was high, and it was experimentally confirmed that those conditions induce severe fiber shortening and fines formation. As the experience with refining of hardwoods (in particular with eucalypts (23)) indicates, consistencies higher than 4% are indicated for better property development. If one considers that during refining the pulp mat must support the load applied between the bars, the differences in the degree of flucculation of the pulps in the refiner gap may help to explain the observed phenomena.

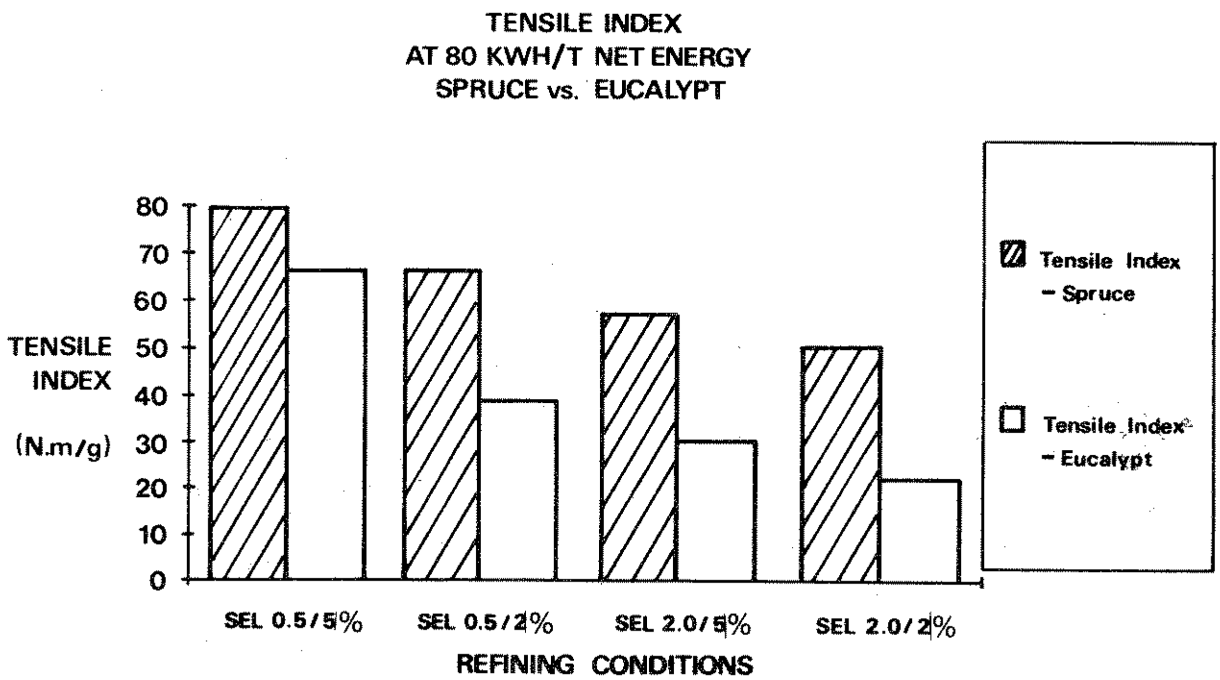


Figure 3 – A comparison of Tensile index of spruce and eucalypt pulps at constant energy input.

It is known that flocculation tendency increases with fiber length and fiber flexibility (28). Certainly the short and stiff eucalypt fibers have a much greater difficulty to form coherent networks (which accounts for the excellent paper formation) than the long and flexible spruce fibers, especially at low consistency. The same must be true for the other hardwoods, although to a lesser extent. Consequently, an increase in pulp consistency is benefitious to increase the layer of fiber mat between the refining surfaces (thus decreasing the amount of flocs in the grooves), and hence improves the impact frequency and intensity distribution, with better results. Higher consistency also increases the retention time of the flocs in the refiner. The bottom line is that increased consistency and reduced specific edge load may have a synergistic effect on the final refining result, by allowing wider bar clearances (3,4), and thus increasing the amount of fibers being impacted.

Other pulp and paper properties followed the same trends as in Figure 2, including slowness and dynamic drainage time, although for the latter the differences among the results for the four combinations of conditions were not as large. In the case of spruce all data followed a single line relationship between the logarithm of dynamic drainage time and net applied energy. The plot of other properties is omitted, for the sake of clarity. Some of them showed distinct behaviors when compared at constant tensile index.

In figures 4a and 4b it can be observed that treatment at 0.5 w.sec/m – 5% consist. produces paper with higher bulk and porosity at a given tensile strength than refining at the other three combinations of variables (the same behavior was also observed for the other two pulps, in each case). Those were shown to yield single lines for apparent density and air resistance vs. tensile index, as an indication that strength development has been obtained through the same combination of refining effects.

The low load/high consistency combination, though, seems to enable the increase in interfiber bonding, with less fines formation. This aspect was confirmed when the plots of DDT vs. tensile index and air resistance vs. apparent density were examined, also indicating a distinct behavior for the 0.5 SEL/5% consistency treatment. It is possible that these conditions have a more pronounced effect in terms of internal fibrillation and fiber flexibilization than as external fibrillation and fines formation, or fiber cutting. Other properties, such as tear index and light scattering coefficient produced single-line relationships when plotted against tensile index, for the four combination of refining variables (Figures 4c and 4d).

Another interesting fact was the observed *increase* in bulk through refining when treating eucalypt pulp at 2% consistency (Figure 4b). Similar results had already been reported when refining eucalypt under those conditions (29), and are indicative that this pulp is particularly sensitive to consistency conditions within the refiner, due to its minute flocs with low degree of cohesion, which tend to hide from refining action in the grooves. The main result is extensive cutting and fines formation, which is certainly not desirable.

Refining of Pulp Blends

The blends were prepared, in the desired proportions, both before refining – to characterize *mixed* refining, and after each individual pulp had been refined separately – characterizing *separate* refining. As described earlier, blends from separately refined pulps were made from samples which had received equivalent levels of net applied energy. The following codes will be used in the following discussion:

Pulp Blend	Code
60% Eucalypt / 40% Spruce	E60/S40
80% Eucalypt / 20% Spruce	E80/S20
80% Aspen / 20% Spruce	A80/S20
80% Maple / 20% Spruce	M80/S20

As the comparisons among refining conditions for the pure pulps indicated two extremes in terms of results – low SEL/high consistency and high SEL/low consistency, the analysis of mixed vs. separate refining will be based upon only those two sets of conditions. The E60/S40 mixture was introduced to evaluate how a higher softwood proportion in the furnish would influence the results, comparatively to a high hardwood/low softwood mixture (E80/S20).

Refining Result – The Influence of Flocs

It is apparent, from figure 5, that the same trends observed for pure pulps were repeated for all mixtures, i.e. the low refining intensity/high consistency combination allowed a faster development of tensile strength, or a better utilization of the energy applied. In contradiction to most published results, however, the results also indicated that mixed refining produces stronger paper at the same net energy input, at least for the pulps studied here. Similar trends were reported in a recent investigation (30), also using spruce and the other three hardwoods, although with a different experimental design.

The differences between mixed and separate refining seem to be larger for the low SEL/high consistency, and under those conditions the improvements of mixed over separate are slightly larger for eucalypt mixtures, followed by maple's, and finally aspen's. Earlier discussion about fiber properties and their possible influence on flocculation behavior may help in analysing the results.

Spruce fibers are long and flexible, and should entangle easily, thus forming strong and coherent flocs. When these fibers are mixed with hardwood fibers, the formation of coherent networks is more likely to happen than for pure hardwood fibers. This may be particularly important for the short and stiff eucalypt fibers, as compared to the longer and more flexible aspen fibers. Hence, in the presence of flexible softwood fibers, the hardwoods may be allowed to stay for longer periods between the refining surfaces, therefore increasing the chances of being impacted and therefore increasing the homogeneity of treatment, according to earlier discussions.

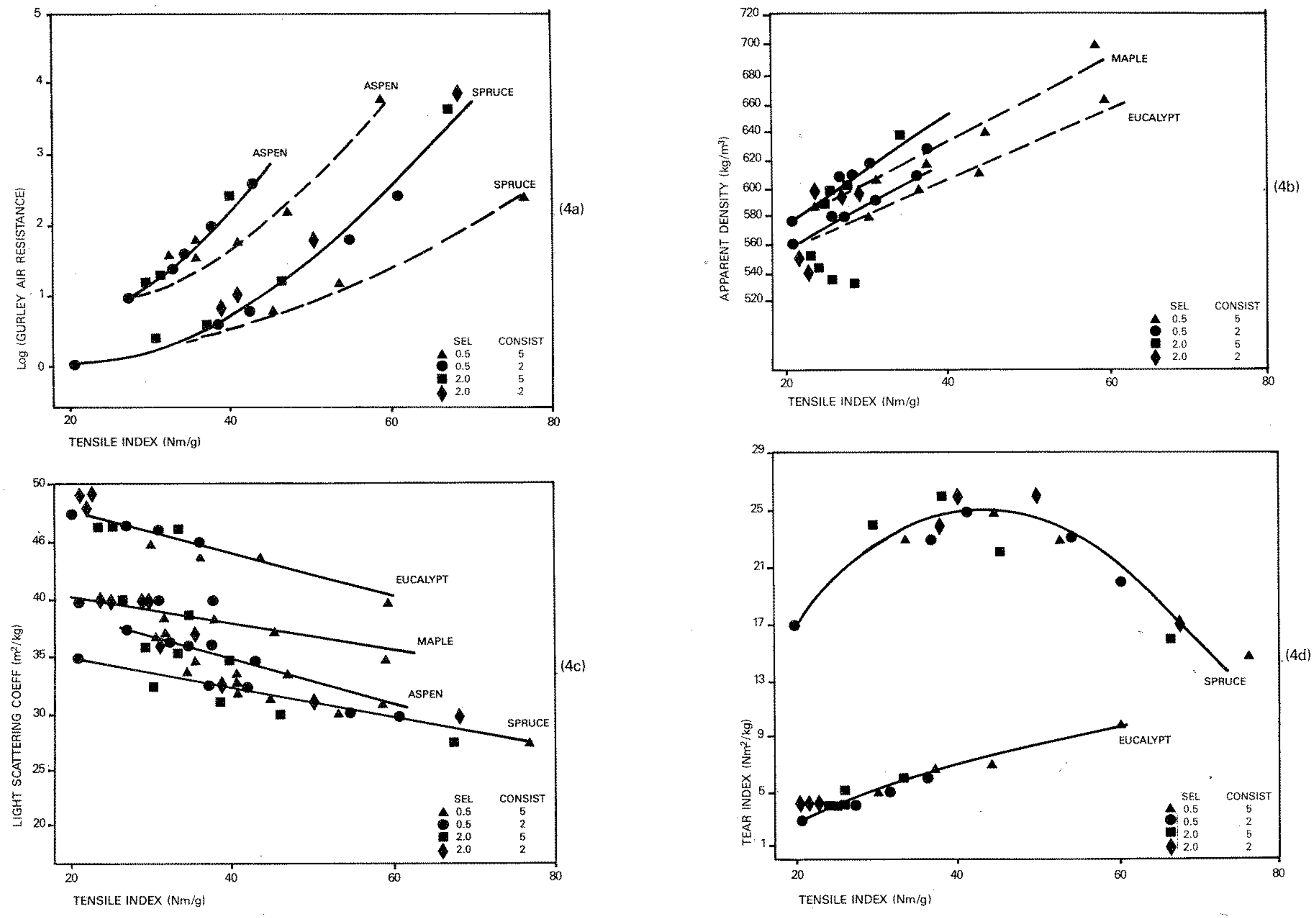


Figure 4 — Comparison of different paper properties against tensile index — pure pulps.

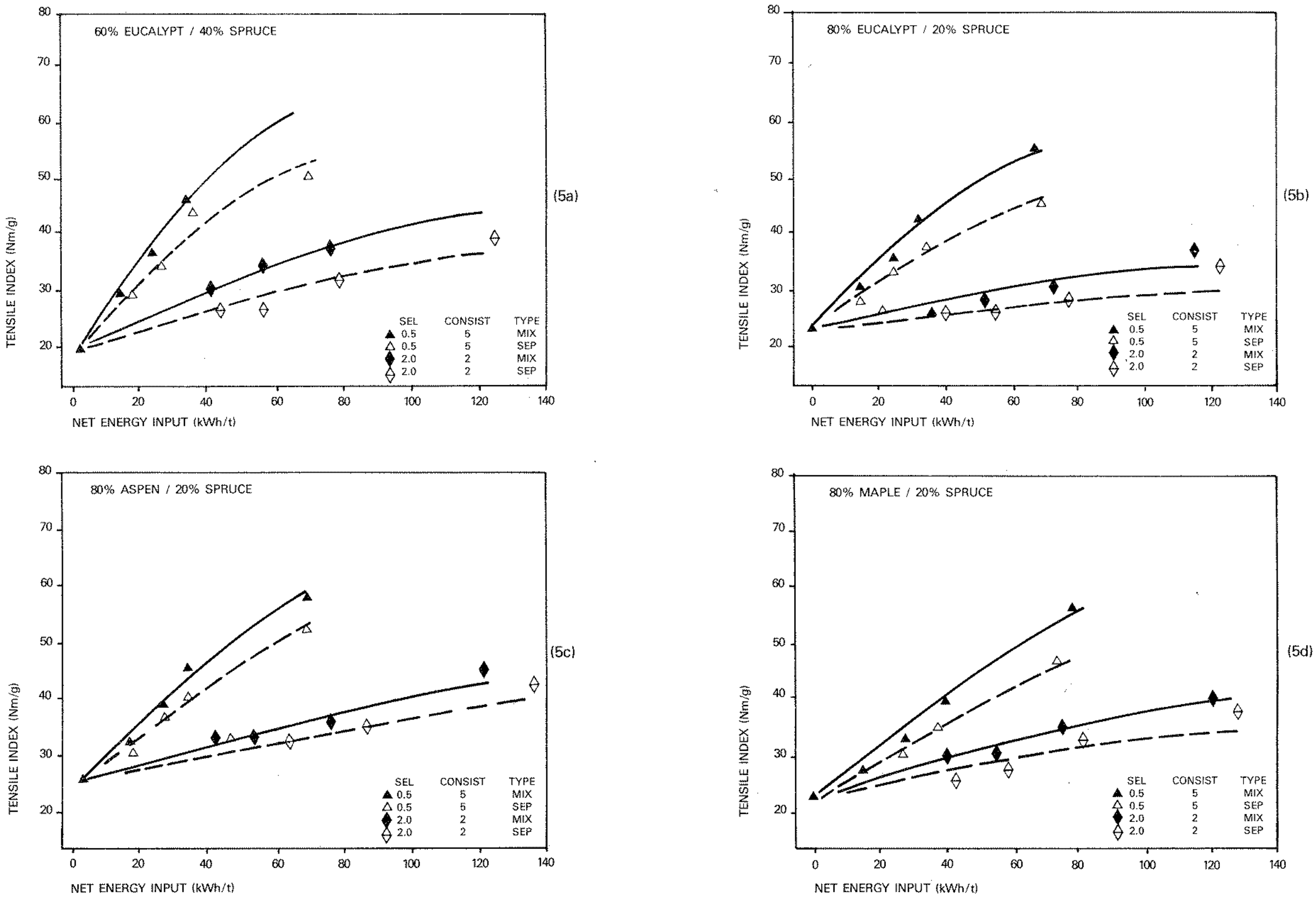


Figure 5 — Tensile index development of spruce-hardwood blends — mixed and separate refining, each with two combinations of refining conditions.

Levlin (18) has proposed that since the refining gap was much larger when refining pine than when treating birch, separate refining should allow better optimization of properties. In our view perhaps his results were influenced by three major factors: firstly the fibers from scandinavian pine are not as long and flexible as spruce's, while birch fibers are expected to be as long and flexible as those from the northern hardwoods used here; secondly, the consistency used in his studies may have not allowed significant differences to be observed (e.g. our results in figure 5, for 2% consistency); and thirdly, tue complex phenomenon of fiber interaction when forming a floc should not be overlooked, since this may be strongly affected both by the morphological and surface chemistry properties of fibers (in other words a pine/birch floc may have properties – in terms of size and strength – which are much different from those of flocs from individual pulp fibers).

The considerations above bring up a completely new approach into the evaluation of refining results of different pulps and their mixtures, by incorporating the discussion about the probable influence of the mechanical and physical properties of the actual entities being impacted within the refiner. The dynamic properties of flocs, under turbulence, compression and shear forces, as influenced by the surface chemistry and morphological properties of fibers, and also by the physical chemistry of the aqueous medium (hardness, conductivity, pH, etc.) may provide better means for the evaluation of refining action vs. effects, as well as for more fundamented predictions of the result from refining of various furnishes.

Although the evaluation of fundamental properties of flocs is beyound the scope of this study, a preliminary investigation was undertaken to compare the relative flocculation tendencies of the different pulps and mixtures used. The measurement of the terminal volume (31), after allowing a dilute pulp suspension to settle for 6 hours, was used for this estimate, which is reported in Table IV. The calculated values for Sedimentation concentracion are included. The results indicate how much bigger the flocs from softwood pulps may be in relation to hardwoods, and the relative sizes among short and long fibered pulps. It is also noticeable that the flocs from spruce-hardwood mixtures have relative sizes situated between those of the respective components.

Obviously these empirical determinations are far from being able to predict the floc behavior under dynamic conditions (33,34) but it is believed that, at this stage, they provide additional information, not available from other measurements on pure pulps. For instance, the values obtained for terminal volumes of sprucehardwood mixtures are closer to the values for pure hardwoods, although still bigger than those, indicating that spruce fibers are actually adding to fiber entanglement in the mixture, and hence improving mixed refining over separate refining (on the basis of refining action mechanisms discussed earlier). According to the results in figure 5, when comparing the relative behavior of the four mixtures, it can be postulated that mixed treatment will have advantages over separate refining, at least with respect to paper strength development, especially when:

- SEL is low and stock consistency is high;
- The terminal volume of the mixture is higher than that of the pure hardwood (better results the higher this value for the mixture, and the shorter and stiffer the hardwood fiber fibers are).

TABLE IV — Flocculation tendency of pure pulps and mixtures, as estimated by their sedimentation volumes.

	PURE PULPS						MIXTURES					
	EUCALYPT	ASPEN	MAPLE	SPRUCE	Sc. PINE	So. PINE	E60/S40	E80/S20	A80/S20	M80/S20	E80/Sc.20	E80/So.20
Terminal volume, ml	320	320	280	640	540	535	440	400	350	340	310	300
Sedimentation Concentration, %	0.63	0.65	0.71	0.31	0.37	0.37	0.45	0.50	0.57	0.59	0.65	0.67
Suspension pH	6.1	6.5	6.4	6.4	6.4	6.5	6.6	6.5	6.7	6.7	6.4	6.4
Conductivity, µS/cm	16.7	15.1	16.7	16.5	16.5	17.0	16.4	16.1	16.5	16.6	16.6	15.0

Under this assumption there should be little or no difference between mixed and separate refining of pine-eucalypt blends, as it will be later discussed. Accordingly, if refining is performed at low consistency, or high specific edge load (or even *varied* load, as sometimes observed), or in multiple passes (which would change floc behavior), and most importantly if the physicalchemistry of the system is significantly changed (by quality of the water and/or chemical additives) the conclusions above may be changed, and the applicability of the terminal volume determination remains to be verified.

Properties of Spruce-hardwood Blends

As for pure pulps, other measured properties displayed the same trends as observed for the development of tensile index, in figure 5. Comparisons at a given tensile strength are made in figures 5 through 12.

Firstly it was interesting to observe, in figure 6, that slowness development was faster, at a target strength, for pulp blends refined at high load/low consistency. Consequently, if slowness or freeness values are used as refining targets, the pulp may end up unnecessarily overbeaten, with respect to strength. Furthermore, as it can be observerd from figures 6a and 6b, one may arrive at misleading conclusions in terms of drainability when using slowness as a yardstick.

For the two proportions of eucalypt/spruce mixtures, there were different ^{o}SR vs. tensile index relationships for mixed vs. separate refining at SEL 0.5 w.sec/m – 5% consistency, and their relative positions were different in each case. On the other hand, as shown in figure 7, the dynamic drainage/ tensile index relationships were the same for all blends, with no distinction between mixed and separate refining, at constant strength and same set of refining conditions. Actually for the maple/spruce pulps there was not even a distinction between refining conditions, while for the other three blends the low intensity/high consistency combination produced pulps which drained faster at the same tensile strength of paper.

The air resistance of dry paper followed approximately the same behavior as the dynamic drainage time: when plotted against tensile index it is seen, in figure 8, that a more porous paper is obtained at the same strength, when the refining load is applied through a large number of low-intensity impacts, and higher stock consistency. Again, there was no observable distinction between mixed and separate refining, indicating that the combinations of effects which influenced strength development under either of the mixing conditions were approximately the same, although one has proceeded more efficiently than the other.

The above mentioned relationships between dynamic drainage time vs. tensile index and air resistance vs. tensile index were similar to those observed when comparing the influence of different sets of refining conditions on pure pulps. However, with regard to handsheet apparent density, the values obtained for each pulp blend were shown to follow the same curve when plotted against strength, as seen in figure 9. In other words, there was no improvement in bulk, at constant strength, for pulps treated at SEL 0.5 w.sec/m – 5% consistency, as observed with pure pulps. Probably the new types of flócs obtained by mixture of different fibers have enabled different mechanisms for the transformation of refining action into effects.

Except for the results obtained when refining in separate at high load/low consistency, which are probably due to excessive fiber cutting with formation of the type of fines ("chunky") that increase the number of refractive surfaces, the light scattering coefficient values showed variations in the direction expected from an increased degree of sheet consolidation and interfiber bonding (figure 10). The single-line relationships in figures 9 and 10 have shown that with all four different combinations of fiber types, each treated under four sets of refining variables, the variations in tensile strength were followed by equivalent modifications in paper strucuture, irrespective of what the refining effects were in each case. Such evidences configurate additional advantages for the use of properties such as handsheet density or tensile index to follow the beating result.

The procedure of analysing refining effects by plotting measured pulp and paper properties against another property such as tensile strength, which is strongly related to paper structure, may also allow the indentification of the relative extent of the various transformations occured on pulp constituents. In the discussion above it was described that for the different refining conditions the density and light scattering properties of paper were constant at the same tensile strength. On the other hand, the mixtures, prepared before or after refining, and treated at low SEL/ higher consistency showed to drain faster and to have higher porosity. These two properties are known to depend heavily on the total specific surface area of the pulp, which is influenced by the degree of external fibrillation and fines development. Therefore, having lower levels of surface area development, and to ensure equivalent degrees of interfiber bonding and bond strength, the pulp treated under low load/higher consistency must have been developed further, with respect to other primary refining effects, most probably the degree of internal fibrillation and fiber flexibilization.

Usually this effect can be estimated by the water Retention Value of pulps. It was, therefore, expected from this reasoning, that at constant tensile strength the mixtures which drained faster and were more porous, while having the same paper density and light scattering ability, would show higher WRV values. However, this behavior was not observed in the plots of figure 11. The results of three out of four combinations of refining conditions fell on the same WRV vs. tensile index straigth line, for all pulp blends. And for the mixed refining at low SEL/higher consistency, the WRV values were lower at constant strength. One possible explanation for this result was found through microscopic observation of the refined samples, which indicated a significantly larger degree of fiber curl for the mixtures with lower WRV.

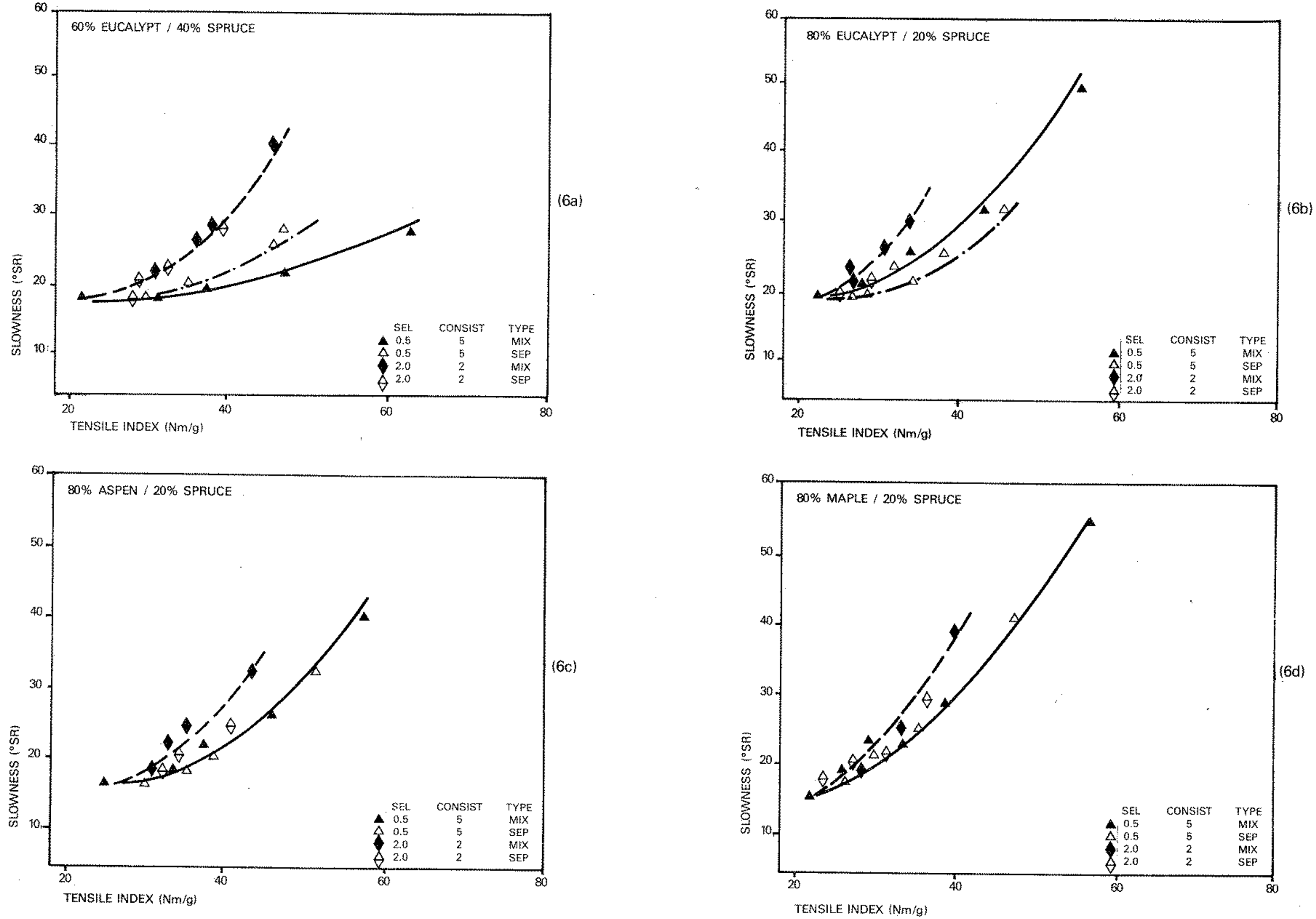


Figure 6 — Slowness vs. tensile index relationships for spruce-hardwood blands.

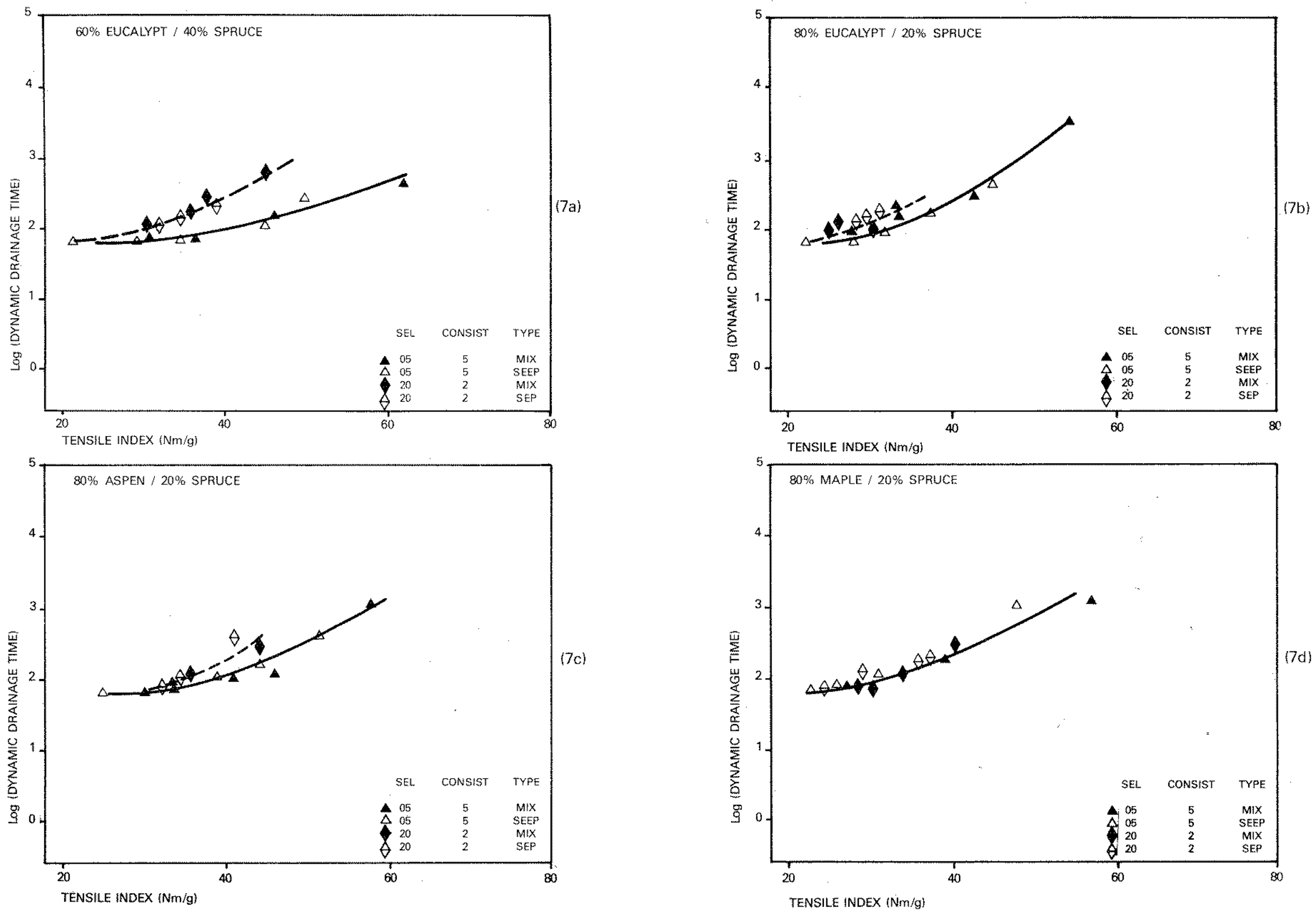


Figure 7 – Relationship between logarithm of dynamic drainage time and tensile index of different spruce-hardwood blends.

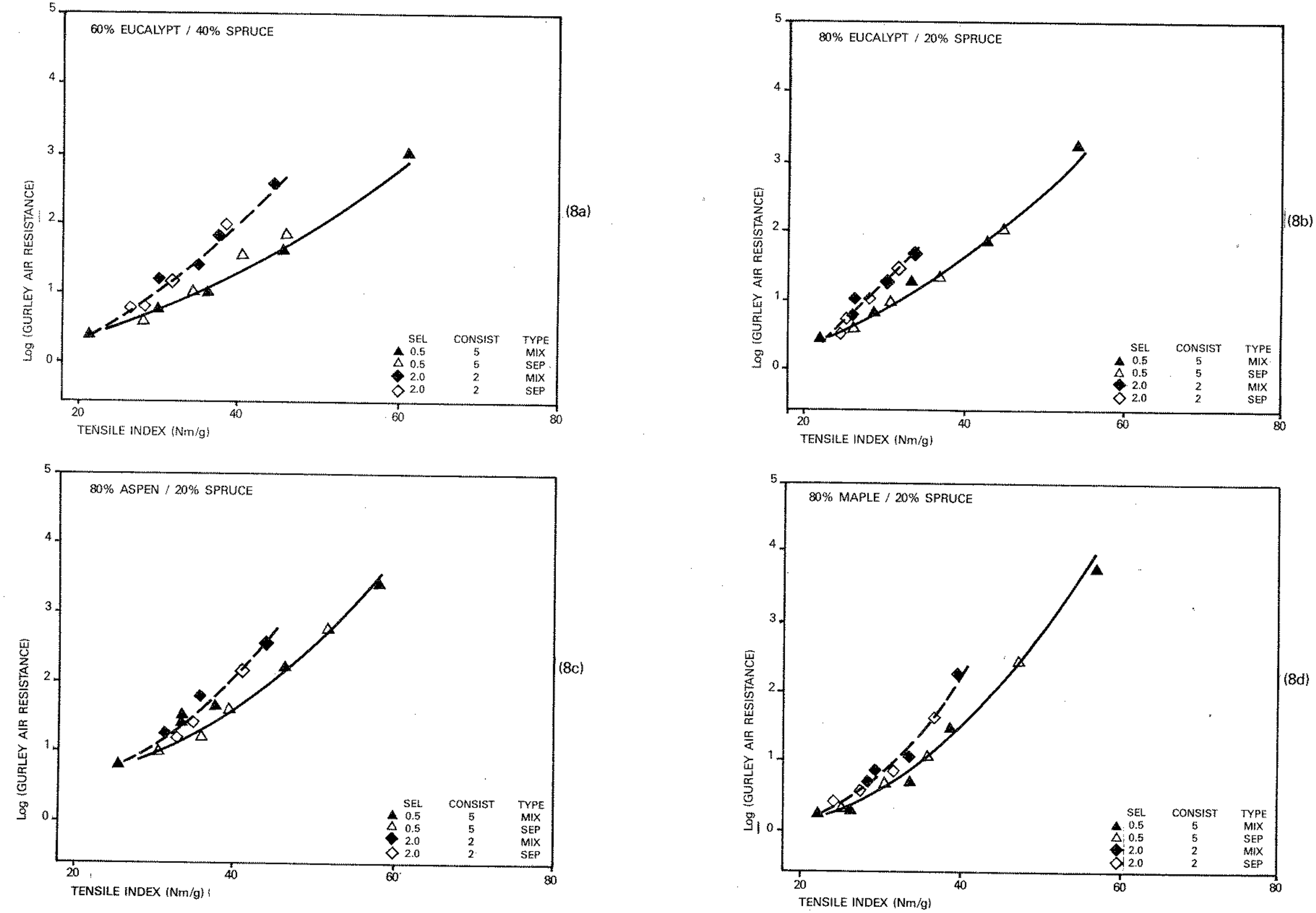


Figure 8 — Relationship between Gurley air resistance and tensile index of paper from different spruce-hardwood blends.

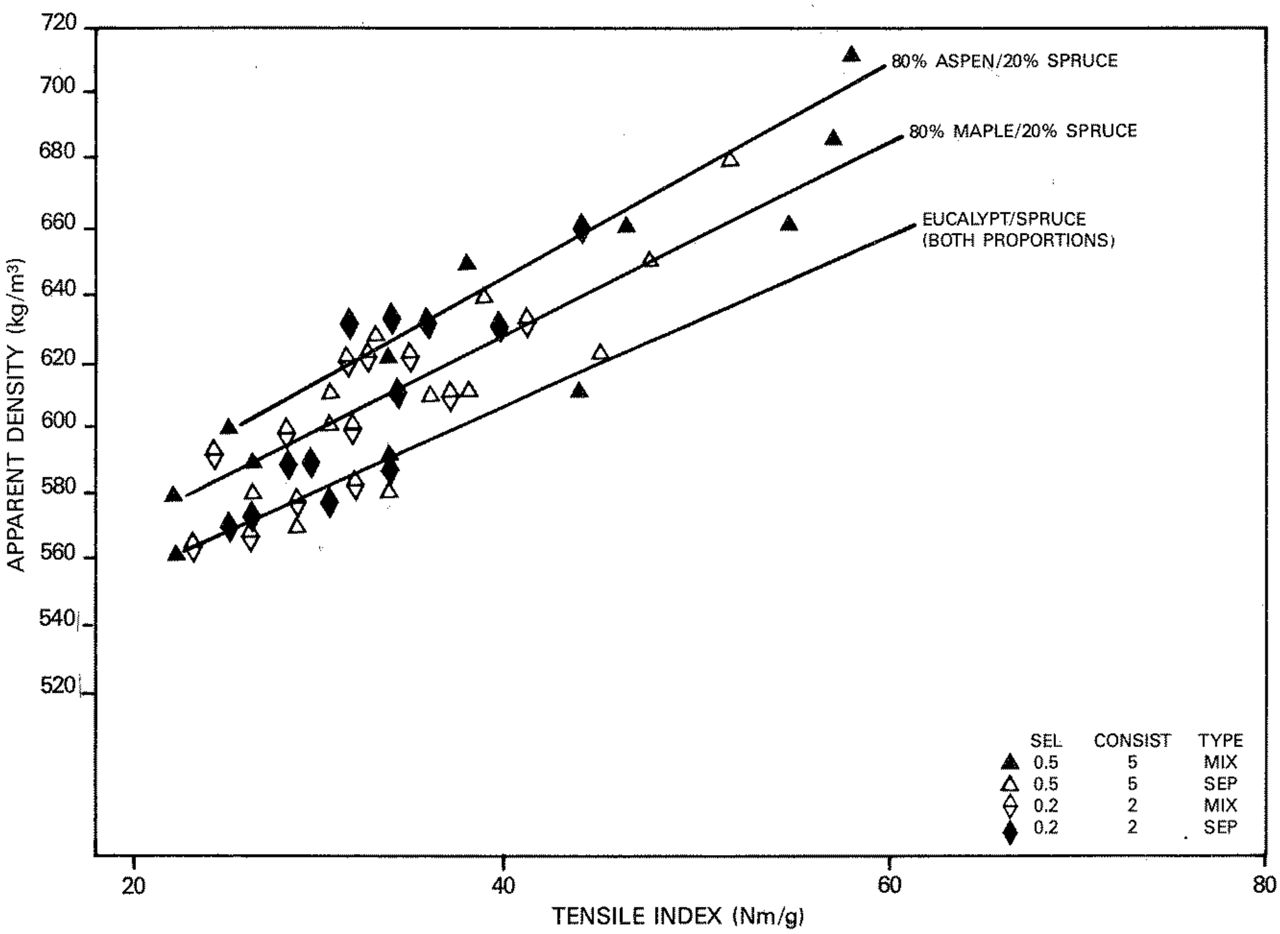


Figure 9 — Apparent density vs. tensile index of papers from spruce-hardwood blends.

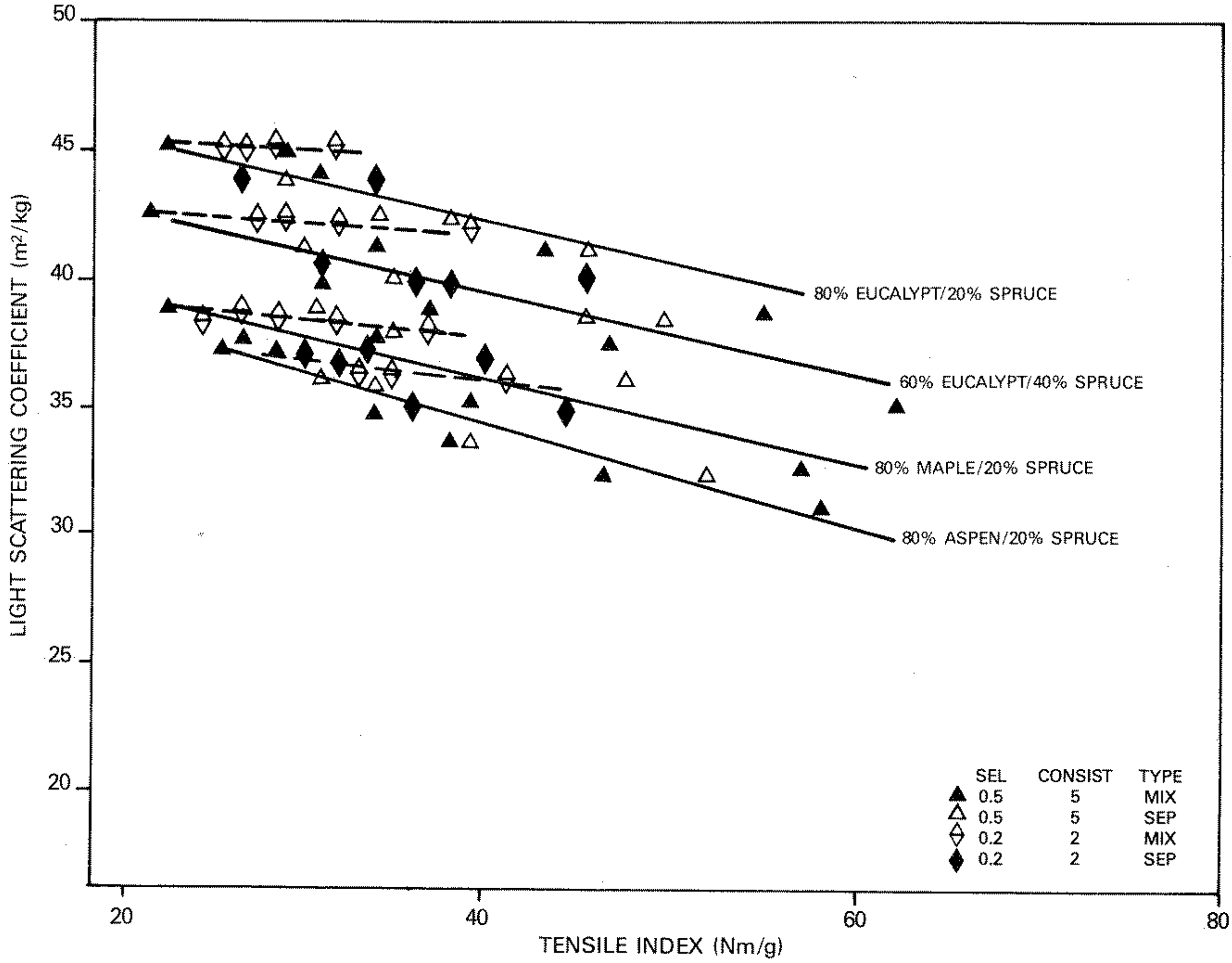


Figure 10 — Light Scattering Coefficient vs. tensile index of papers from spruce-hardwood blends.

This refining effect is more common to occur extensively when pulps are refined at consistencies higher than 10%, but apparently for mixed refining under low intensity impacts and 5% consistency it was already noticeable in significant proportions. Curled fibers may explain the lower tendency for the pulp mat to retain water, by providing bigger voids among pulp constituents, which diminish the capillarity effect. Those voids may also have increased the number of refractive interfaces in the structure of paper, thereby helping to keep the scattering coefficient of papers made from those more flexible fibers at the same level as of those made from pulps containg more fines and lower degree of fiber flexibility.

The tear vs. tensile plots revealed new phenomena not recognized in the discussions above. In contrast to the single line relationships obtained for pure pulps, each mixture studied was shown to have its particular behavior with respect to tear strength, when refined under different combinations of conditions (figure 12). For instance, the E80/S20 and A80/S20 mixtures showed similar behaviors, with higher tear strength at low load/ higher consistency, irrespective of how the mixtures were prepared.

On the other hand, the mixture containing 60% eucalypt/40% spruce and the maple/spruce mixtures have displayed particular results in each case. For the E60/S40 a low intensity/higher consistency treatment produced similar tear values, whether from mixed or separate refining, while at high intensity/low consistency the results were much better for mixed than for separate treatment. The latter indicate that actually fiber cutting was extensive under this treatment, as already observed in figure 10. The same behavior appears to be true for the maple/spruce mixtures, which in addition also showed a differentiated behavior between mixed and separate refining at low load/higher consistency. In this case the results may have beem influenced by the lower fiber viscosity of maple pulp, especially when treated at 2.0 w.sec/m and 2% stock consistency.

It can, therefore, be concluded that the main observations from treating pure pulps can be applied to different spruce – hardwood pulps, i.e. the low refining intensity/higher consistency combination allows significant savings in net applied energy to reach a target tensile strength, and that under those refining conditions a more porous paper is produced, which drains faster and probably is also more easily wet-pressed (lower WRV). Additional savings can be obtained by mixed vs. separate refining of those pulp blends, with regard to target tensile and tear strength indexes.

Properties of pine-eucalypt Blends

The behavior and properties of flocs, as estimated from terminal volume measurements have helped to interpret the results from refining of spruce-hardwood pulps. It was expected that the same principles would be aplicable to the Scandinavian pine-eucalypt (E80/ Sc.20) and Southern pine-eucalypt (E80/So.20) mixtures, both treated at SEL 0.5 w.sec/m – 5% consistency, under mixed and separate refining conditions.

The values obtained for terminal volumes of E80/Sc.20 and E80/So.20 pulp blends were, on the contrary to what was observed for eucalypt/spruce blends, slightly smaller than for pure eucalypt pulp, probably due to the chemical interaction between the different types of fibers. Consequently, the presence of longer fibers, in these cases, have not added to an increased flocculation ability of the blends in relation to pure pulps, and the result should be little, if any, difference between the outputs of mixed and separate refining. Indeed, the results in figure 13a have shown that there was no difference in the relative rates of tensile index developments of both pulp blends, for either mixed or separate treatment.
Actually in figure 13a. there is only one curve to describe the tensile index development of both eucalypt/pine blends, while the other plots in figures 13a and 14 merely reflect the differences between the properties of scandinavian and southern pine fibers, with respect to the attainment of other paper properties at constant tensile index: the stiffer southern pine fibers produce papers with slightly higher porosity and bulk (for separate refining), and lower opacity when mixed with eucalypt, than equivalent mixtures of scandinavian pine.

For the tear vs. tensile relationships there were, again, different behaviors for the blends studied. The eucalypt/escandinavian pine mixture showed no difference between mixed and separate refining, while the results were significantly better for separate treatment of the eucalypt/southern pine blend.

In other words, the results from pulp and paper testing indicate that both eucalypt-pine blends behave quite differently from spruce-hardwood blends with respect to mixed refining as compared to separate treatment. These differences are well in line with recent suggestions (25), that the type of pulps could lead to results in opposite directions. The present investigation has focused on floc characteristics of the different blends as the main responsible features influencing the link between refining action and effects. It is expected that future refining studies will concentrate on aspects that may help to elucidate these points of fundamental importance to the industry.

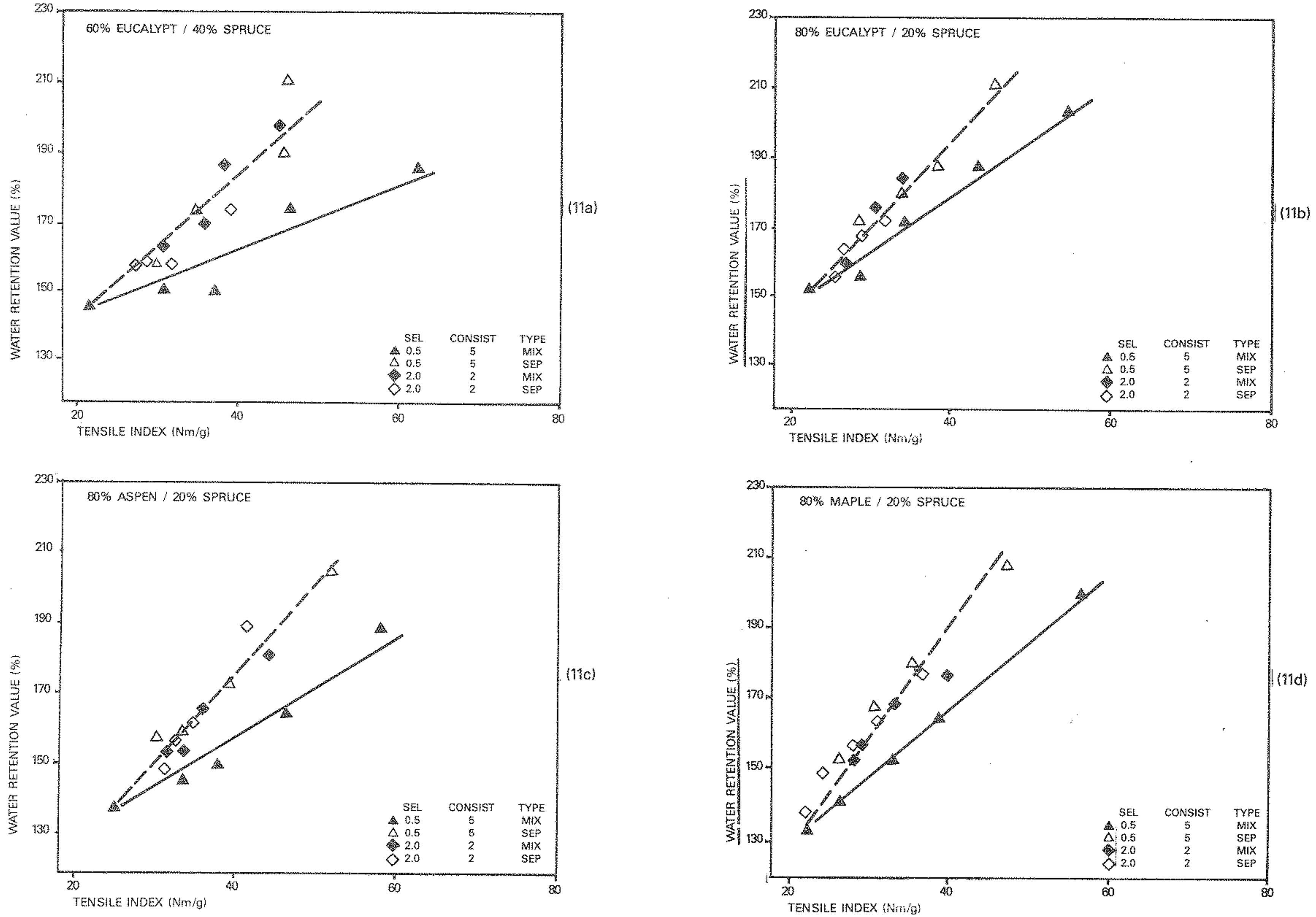


Figure 11 — Relationships between water retention value of pulps and paper tensile index — sprûce-hardwood blends.

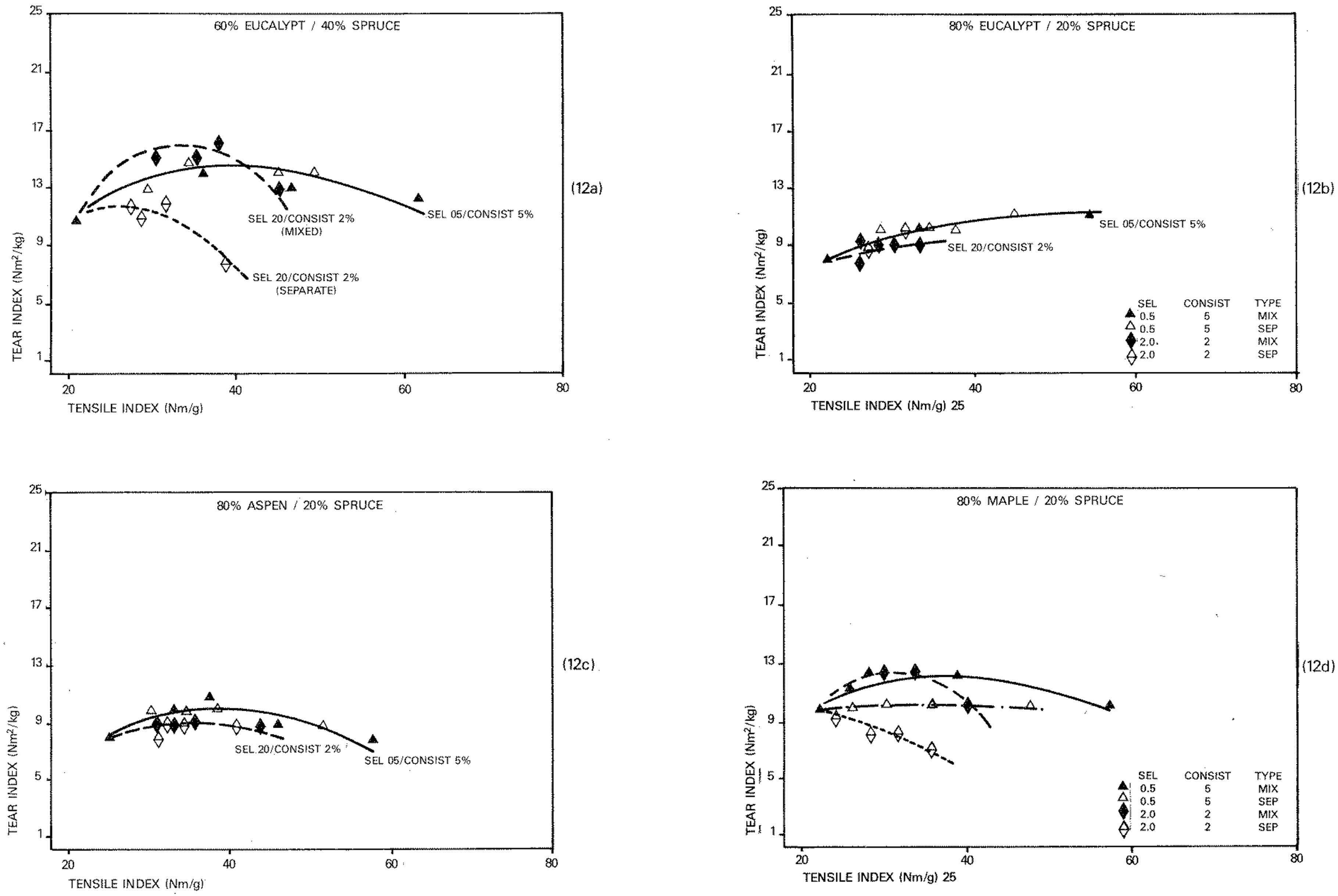


Figure 12 — Tear index vs. tensile index of papers made from spruce-hardwood mixtures.

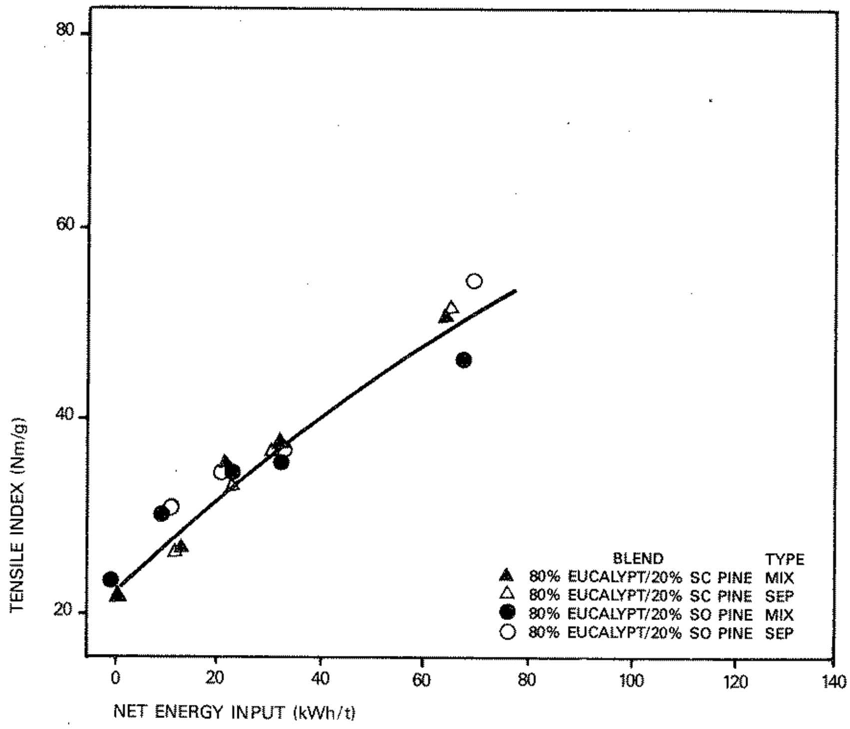


Figure 13a — Tensile index development of eucalypt — pine blends

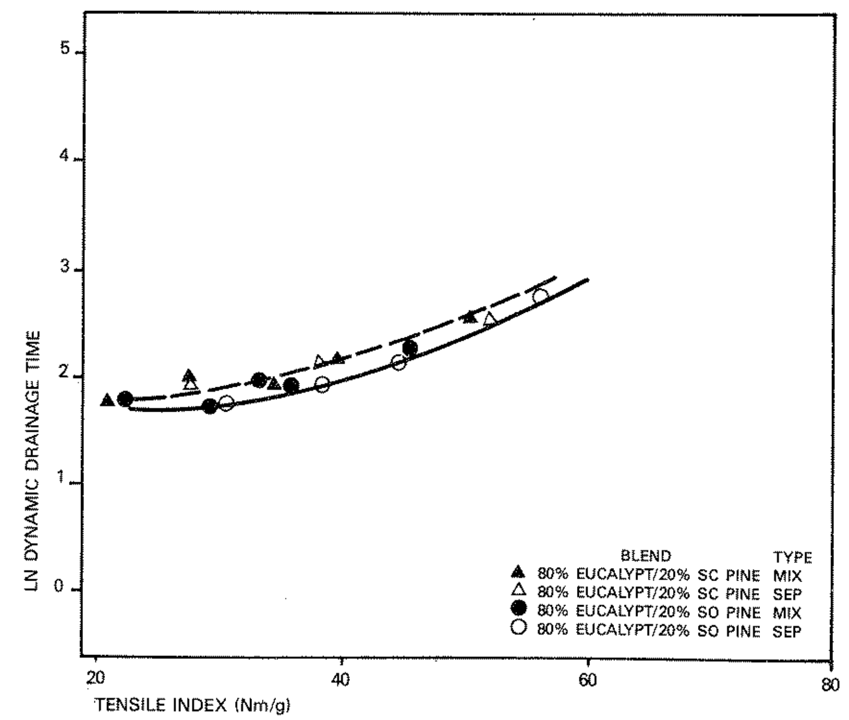


Figure 13b — Relative dynamic drainabilities of eucalypt — pine mixtures at constant tensile index.

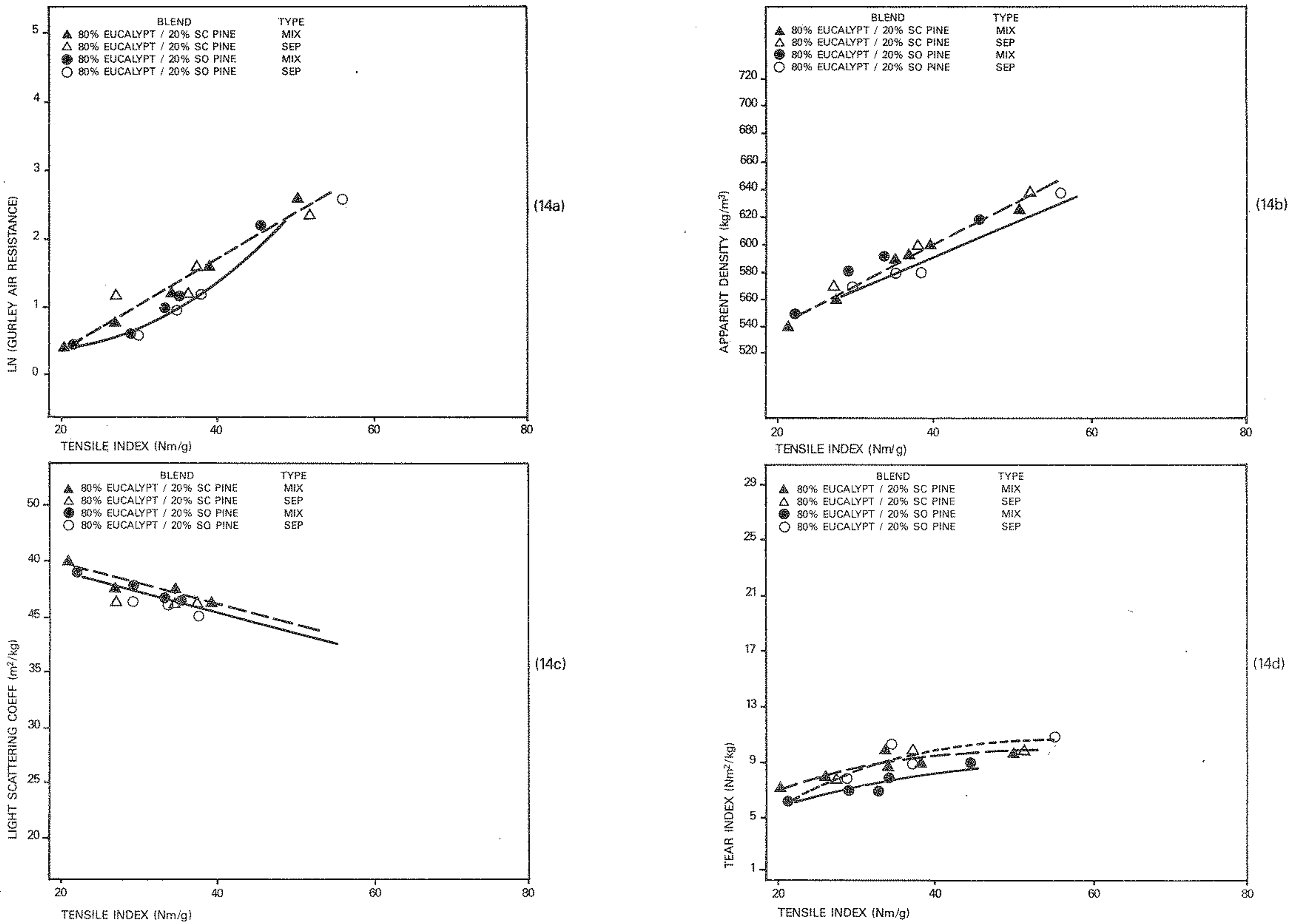


Figure 14 — Relationships between paper properties and tensile index of eucalypt — pine blends.

SUMMARY AND CONCLUSIONS

This investigation has focused on the different responses of six types of bleached kraft market pulps and their mixtures to various combinations of refining conditions. Three hardwood pulps – aspen, maple and eucalypt, and one Canadian spruce pulp were studied under four sets of specific edge load and consistency combinations. At a later stage, mixtures of eucalypt with two types of pine pulps were also analysed. The pulps were treated separately and also as mixtures, thus allowing the analysis of the relative results from mixed versus separate refining.

The experiments were performed in a refining pilot plant designed to allow operation in single-pass, which enabled the trials to be as representative as possible of actual refining conditions. It was shown that all pulps benefit from a large number of gentle impacts (0.5 w.sec/m vs. 2.0 w.sec/m), with respect to strength development. The influence of stock consistency was also significant, particularly to the hardwoods, which responded much better to treatment under 5% consistency, as compared to 2% consistency. The combination of low specific edge load/high consistency allowed the best results in terms of energy savings towards a target tensile strength, and also higher porosity and faster drainage at constant strength, due to lower fines development.

The results from mixed refining of pulp blends showed the same trends in terms of responses to specific edge load levels and stock consistency, and additionally demonstrated that mixed refining of the spruce-hardwood mixtures was preferable when compared to blending after separate mechanical treatment. On the other hand, for the eucalypt-pine blends there where no observable differences between the outputs from mixed and separate refining.

It is believed that the discussion of results in terms of flocculation tendency of the different pulps may provide a more fundamental approach towards the understanding of refining action versus effects. Since fiber networks are the actual entities receiving mechanical impacts inside the refiner, increased pulp consistency should enable the formation of thicker fiber mats between the refiner surfaces, thus improving the impact frequency and intensity distribution. Gentler refining impacts, under lower loads, should add to this effect.

The properties of flocs, as also influenced by the fiber components in the pulp blends, their morphological and chemical characteristics, have helped to evaluate the different relative responses to the same set of operating conditions. A simple method was proposed to indicate the relative size of fiber flocs, and based on such observations it was postulated that a mixed treatment will be advantageous, at least with respect to strength development, when the presence of softwood fibers can add to the flocculation tendency of the hardwood component in the blend.

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LITERATURE CITED

1 – Banks, W.A. – Paper Technology 8(4): 363 (1967)
2 – Fox, T.S.; Brodkey, R.S. and Nissan, A.H. – TAPPI 62(3): 55 (1979)
3 – Nordman, L.; Levlin, J.E.; Nakkonen, T. and Jokisalo, H. – "Conditions in an LC-Refiner As Observed By Physical Measurements" – in International Symposium on Fundamental Concepts of Refining" – IPC – Appleton (1980)
4 – Kurdin, J.A. – Pulp and Paper 59(3):97 (1985)
5 – Wultsch, F. and Flucher, W. – Das Papier (12(13/14): 334 (1958)
6 – Brecht, W. – TAPPI 50(8): 40A (1967)
7 – Danforth, D. H. – Southern Pulp and Paper Manufacturer 32(7): 52 (1969)
8 – Leider, P.J. and Nissan, A.M. – Tappi 60(10): 85 (1977)
9 – Helle, T. – "Technical Refining of Chemical Pulps" – IPC – Appleton (1983)
10 – "Refining in the Pulp, Paper and Board Industry" – Beloit Corp. (1975)
11 – Pycraft, C. – Paper Southern Africa: 6, January/February (1986)
12 – Levlin, J. E. – "Characterization of the Beating Result" – in International Symposium of Fundamental Concept of Refining – IPC – Appleton (1980)
13 – Claudio-da-Silva, Jr., E. – "Chemical Pulp Beating Related to Fiber Structure" – Ph.D. Thesis – SUNY College of Environmental Science and Forestry – Syracuse (1981)
14 – Hartman, R.R. – "Mechanical Treatment of Pulp Fibers For Paper Property Development" – in "Papermaking Raw Materials" – Eigth Fundamental Research Symposium – Oxford (1985)
15 – Evans, B.E. and Baker, C.F., "Experience with a Pilot Refiner" – Wiggins Teape R & D (1979)
16 – Steenberg, B. – "A Model of Refining as a Special Case of Milling" – in International Symposium on Fundamental Concepts of Refining" – IPC – Appleton (1980)
17 – Arjas, A. – "Influence of Residence Time Distribution on Pulp Properties" – in International Symposium on Fundamental Concepts of Refining" – IPC – Appleton (1980)
18 – Levlin, J. E. – "Some Differences in The Beating Behavior of Softwood and Hardwood Kraft Pulp" – in International Symposium on Fundamental Concepts of Refining" – IPC – Appleton (1980)
19 – Basile, F.C. – Pulp and Paper 59(3): 68 (1985)
20 – Saltarell, M.O. – Tappi 57(7): 83 (1974)
21 – Reinoso, E. – Inv. Y Tecnica del Papel 20(75): 218 (1983)
22 – Ferreiro Ribeiro, R. and Frazão, A. – "Eucalyptus from Portugal for Pulp and Paper" – in "New Pulps for the Paper Industry" – L. Haas (Ed.). Miller Freeman, Brussels (1979)
23 – Sallada, O. – "Eucalyptus for Specialty Papers" – in "New Pulps for the Paper Industry" – L. Haas (Ed.) Miller Freeman, Brussels (1979)
24 – Arjas, A. – "The Effect of Homogeneous and Non-Homogeneous Beating on Pulp Evaluation" – May (1981)
25 – Gess, J.M. – "The "Refinability Index" of a Pulp" – in Preprints of TAPPI 1985 Papermakers Conference : 279 (1985)
26 – Clark, J. d'A. – "Pulp Technology and Treatment for Paper" – Miller Freeman Publ. – San Francisco (1971)
27 – Amero, B.A. – Tappi 65(2): 57 (1982)
28 – Forgacs, O.L.; Robertson, A.A. and Mason, S.G. – "The Hydrodynamic Behavior of Papermaking Fibers" – in "Fundamentals of Papermaking Fibers" – (F, Bolam Ed.) – B.P.B.M.A. Kenley (1958)
29 – Warner, E. – Private Communication – E. Kodak Co. (1980)
30 – Rudie, G.F. and Justice, L.H. – Mead Central Research, Report No. 15,984 – Chillicothe, OH (1985)
31 – Marton, R. and Robin, J.D. – Tappi 52 (12): 2400 (1969)
32 – Helle, T. – Private Communication – Trondheim (1977)
33 – Norman, S. and Wahren, D. – Svensk Papperstidning 75(20):807 (1972)
34 – Ebeling, K. and Jokinen, O. – Paperi Ja Puu 67(5):317 (1985)