LOW ENERGY SHIVE SEPARATION
EVALUATION OF A NEW METHOD OF FIBRE PROCESSING

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ABSTRACT

The potential of a new mechanical pulping strategy to enable the separate development of earlywood and latewood fibres has been evaluated in a pilot plant study. In this study, wood chips were treated with a low energy application to produce a primary-stage pulp containing a high proportion of shives. Conventional “fractionation technologies” were then used to separate the shives from the liberated fibres so that these two streams could be given separate refining treatments.

The key observations from this study were;

- Fractionating a low energy feed pulp containing 57% shives is difficult as this type of pulp dewaters and thickens very quickly resulting in blocked pipes and valves. However, processing the pulp at 0.5% consistency produces an accept pulp containing 5 % shives and rejects with 73 % shives.
- Pressure screens are more “efficient” in removing shives from the single stage pulp than hydrocyclones.
- The fibre dimension data obtained from the screening stage provided support for this processing concept where earlywood and latewood fibres are separated as the shives (rejected by the screening system). The shives contained fibres with an average lumen perimeter of 88 µm, and the liberated fibres (accepted by the screens) had an average lumen perimeter of 80 µm.
- The differences in fibre length and fibre lumen perimeter observed after fractionation were maintained when the liberated fibre (accepts) and shives (rejects) were given additional refining treatment. The fibres from the refined shives consolidated to the same sheet density, but had higher tensile strength than the fibres from the refined liberated fibre. This indicates that the earlywood fibre in the refined shives may be more fibrillated or have greater surface development than the latewood fibre in the refined liberated fibre stream.

These findings indicate that this new process strategy can enable more effective treatment of fibre types based on their dimensions, and increase the ability to direct a given fibre type to the most appropriate end use.

BACKGROUND

In conventional refining, the refiner bars apply the same constant amplitude cyclic load to both the earlywood and latewood fibres. Consequently, neither fibre type is likely to be subjected to the optimum compressive and shear stresses to minimise the energy needed to develop its papermaking properties. It is possible that the refining energy demand for a given fibre quality could be reduced if the amplitude and frequency of the compressive stress could be varied depending on whether earlywood or latewood fibres were being treated. In practice, this is impossible to achieve unless an economic method of separating the earlywood and latewood fibres during the initial stages of processing can be found.

Research performed by Murton et al. (1) has indicated that, “the larger diameter and thinner-walled earlywood type fibres appear to remain within the shive fraction when low refiner energy inputs are applied to wood chips”, and that “these larger diameter and thinner-walled earlywood fibres require more energy for refining to a given freeness than the thicker-walled latewood fibres”. The implication of these findings is that the more compliant (elastic) larger perimeter, thin-walled fibre component of the wood absorbs more energy and thus remains within the shive fraction. Hence, the defibration characteristics of primary-stage thermomechanical (TMP) pulp were studied to test this hypothesis, (2). In that study it was shown that latewood type fibres are liberated preferentially for low refiner energy inputs (~500kWh/odt), and was independent of the wood type, Figure 1. Based on these findings a new mechanical pulping strategy that could potentially allow earlywood and latewood fibres to be treated separately was proposed, (2) which may lead to a substantial increase in the conversion efficiency of the conventional TMP process.

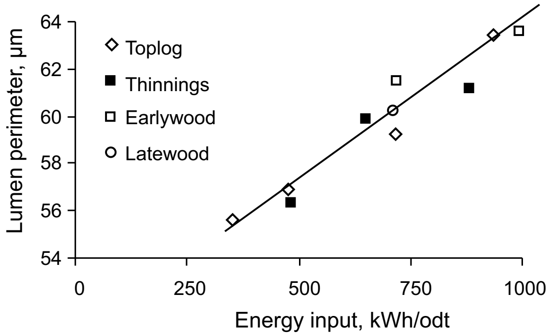

Figure 1 Effect of refiner energy input on accept lumen perimeter for four different radiata pine wood types, from (1-2).

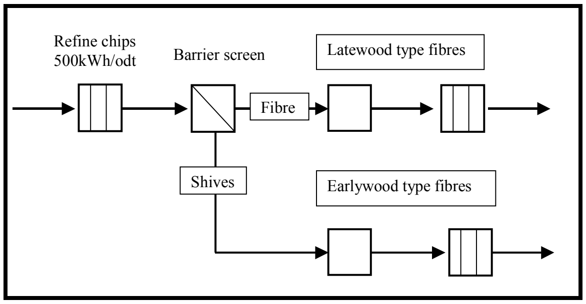

Figure 2 Process strategy, (2).

The basic concept is that at low refiner energy inputs latewood type fibres are liberated preferentially. When barrier screened, these fibres will report to the screen accepts and the earlywood type material contained within the shives will report to the rejects see Figure 2. Both of these streams may need further treatment prior to the second refining stage, with the process conditions chosen for the refining (chemistry, temperature and intensity) likely to be determined according to the cross-sectional compliance of the fibres used.

EXPERIMENTAL

Design

The experimental work discussed in this paper is divided into two key parts:

- Evaluate a new method of fibre processing, (LESS), i.e is the concept detailed above achievable using conventional, semi-commercial scale equipment. This involved the production of a low energy primary-stage pulp (approximately 400 kWh/odt) followed by a sequence of screening stages to separate shives from the liberated fibres. These two streams were then refined further to produce pulps in the freeness range of 500 to 100 CSF, (note: no attempt was made to optimise these refining treatments). "Control" pulps in the freeness range 400 to 100 CSF were also produced by conventional two-stage TMP refining.
- Evaluate the shive removal efficiency of hydrocyclones, to determine whether hydrocyclones would be more effective at fractionating shives than pressure screens.

"Proof of Concept" Evaluation of the Low Energy Shive (LESS) Process

Wood resource

Approximately 7.5 wet tonnes of radiata pine logs were extracted from Kaingaroa forest, New Zealand and were debarked and chipped on a commercial chipping line. The chip properties for this wood sample are given in Table 1.

Table 1
Chip properties

Oven-dry content, %	43.5
Basic density, kg/m³.	392
Mean length-weighted fibre length**, mm	2.68
Fibre coarseness**, mg/m	0.197

**Kraft fibre properties.

Production of TMP pulps

Two refining runs were performed: 1) a single-stage TMP refining run to produce approximately 600 od kg of pulp (specific energy ~350 kWh/odt) for an evaluation of the "LESS" process, and 2) a "control" two-stage TMP refining run for comparative purposes. All refining was performed using the Jylha SD52/36 refiner using Jylhavaara plate pattern 205-216, a nominal consistency of 35% and the same primary stage chip pre-treatment conditions, Appendix 1. In this process, the chips were steamed in an atmospheric bin for 5 minutes at 80°C prior to pressurised preheating at 110°C for three minutes and refined at 1 bar steam pressure. The pulp was discharged from the refiner through an atmospheric cyclone and either; 1) conveyed to the pulper for latency removal, or 2) collected in a pulp storage bin for a second refining stage.

LESS screening conditions

A conventional P1/S1, P2 screen configuration was used to separate the shives from the liberated fibre, Figure 3. A 2.4 mm smooth hole screen basket and a bump rotor were fitted to the P1 and S1 screens, whereas two different basket types were evaluated in the P2 position (0.15 and 0.1 mm wedgewire). The 0.1 mm wedgewire basket and LR rotor combination was chosen for this screening stage as it gave the lowest accept shive content. Details of the screen basket and rotor combinations used for each screening stage are given in Table 2.

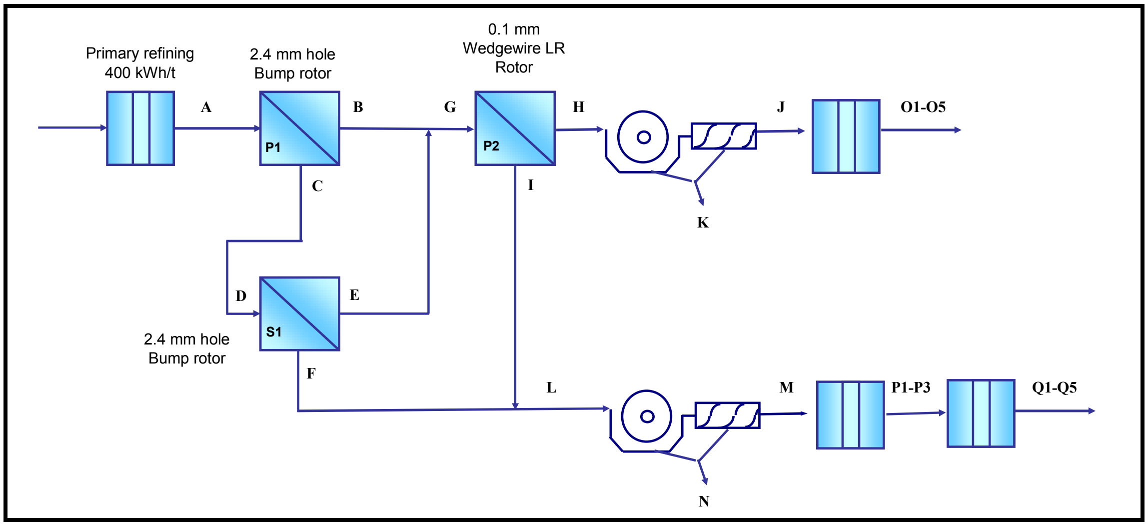

Figure 3 Fibre processing for shive separation.

Screening this pulp at 1.5 % consistency (as initially proposed) caused several operational difficulties. In particular, reject thickening and the subsequent dewatering of reject pulp resulted in numerous blockages within the pipelines. To alleviate this problem, the feed consistency was lowered to 0.5 %.

The pulp screening was performed as follows:

1) Approximately 300 od kg of primary-stage pulp had latency removed and was fed into the stock chest and diluted to a consistency of 0.5 %, sample A.
2) Initially the P1 screen was operated in recycle mode to enable the minimum reject rate to be determined. The screen was then operated with rejects and accepts being split and sent to separate tanks, samples B & C. 300 litres of sample B was also collected to provide the feed pulp for the “Shive removal using hydrocyclones” experimental work detailed below.
3) The P1 rejects were diluted to 0.5 % consistency and the S1 screening stage performed producing samples D, E & F.
4) Several different screen baskets were evaluated for the P2 screen position with the 0.1 mm wedgewire/LR rotor combination chosen as the best option. The aim of the P2 screen was to minimise the shive content and maximise the long fibre content in the accept stream. The rejects and accepts were split to separate tanks to produce samples G, H & I.
5) The overall accepts were dewatered to produce sample J (after dewatering) and refined in a single stage, using five different energy input levels in the range of 800 to 1800 kWh/odt to produce samples O1 – O5 (process conditions in Table 11, Appendix 1).
6) The overall rejects were then dewatered producing sample M (after dewatering) and refined in one stage (P1-P3) or two-stages producing samples Q1 – Q5. (process conditions in Table 11).

Table 2
Basic screen parameters

Screen position	P1	S1	P2
Basket	2.4 SM hole	2.4 SM hole	0.15 C WW
Rotor	Bump	Bump	LR
Aperture velocity, m/s	1.0	1.0	1.0
Rotor speed, rpm	1425	1425	1188
Reject rate	Minimum	Minimum	
Feed consistency, %	0.5	0.5	0.5

Shive removal efficiency definitions

Two methods of the determining the shive removal efficiency are used. They are shive fractionation efficiency, (Q index) and the shive removal efficiency, (R_{eff})

$$Q_{shive} = 1 - \frac{Shive_{accept}}{Shive_{reject}}$$

$$R_{eff} = \frac{Shive_{reject}}{Shive_{feed}} * R_m$$

Where R_m is the mass reject rate, (%).

Testing

All pulp samples were evaluated for, Freeness, consistency, Pulmac shive content (0.10 mm slot screen) and Bauer McNett fibre fractionation. The refined accept and reject pulps were also analysed for fibre length distribution and standard handsheet properties. The pulp and fibre test procedures used, are given in Appendix 2.

Samples, J and M were fractionated using the Pulmac shive analyser and the free-fibre (accept) and shive cross-sectional dimensions were measured. In addition, the fibre dimensions of selected refined accept (O1-O5) and refined reject (P1, Q1-Q5) samples were measured.

Experimental work carried out to investigate the shive removal efficiency of single hydrocyclone units

A series of trials were performed to investigate the shive removal efficiency of hydrocyclones for a feedstock containing a high shive content (~ 20%). This was performed using three different hydrocyclone units in a forward configuration:

- Cellico Tripac90 smooth-cone
- Cellico Tripac90 step-cone
- Cellico C700

The pulp sample used for the hydrocyclone study was obtained by screening a primary stage TMP pulp produced using an energy input of 350 kWh/odt. This pulp was then screened using a 2.4 mm smooth-hole screen basket to remove any very large shive particles that could block the inlet or outlet ports of the hydrocyclones. This sample had a consistency of approximately 0.2 % and a Pulmac shive content of approximately 20 %.

The hydrocyclones were tested by pumping stock through a single hydrocyclone unit in recycle mode as shown in Figure 4. The feed and reject flows were measured using magnetic flowmeters with the accept flow determined by difference. Once the process conditions had stabilised at the target operating conditions (Table 3), feed, accepts and rejects samples were collected.

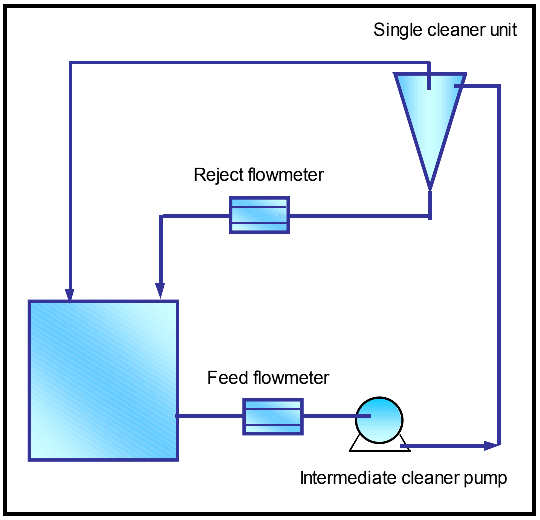

Figure 4 Hydrocyclone experimental rig.

Table 3
Target hydrocyclone operating parameters

Hydrocyclone	Reject rate, R_v %	Feed flow l/min	Reject flow l/min	Pressure Feed kPa	Pressure Drop kPa
C700	15	650	97.5	235	100
C700	35	650	227.5	235	100
TR90 SM/13	15	343	51.4	300	150
TR90 SM/13	35	343	119.9	300	150
TR90 ST/13	15	350	52.5	300	150
TR90 ST/13	35	350	122.5	300	150

Testing

All pulp samples were evaluated for, Freeness, consistency, Pulmac shive content (0.10 mm slot screen) and Bauer McNett fibre fractionation.

RESULTS AND DISCUSSION

The low energy, 350 kWh/odt, 756 CSF primary-stage feed pulp had a Pulmac shive content of 57 %. Although this pulp was screened at 0.5 % consistency to prevent the pulp dewatering and blocking pipelines, the mass balance errors around each screening stage were large. It is assumed that the "shivy" nature of the pulp made it difficult to obtain a representative pulp sample for the consistency measurements. An example of this was demonstrated by sampling the feed to the P2 screen (operated in recycle mode) at five different times. The consistency ranged from 0.17 to 0.40 % for the five samples and the shive content varied in the range of 26 to 36 %. The pulp sample variability around the P1 screen would be expected to be even greater as the feed pulp had a considerably higher shive content of 57 %.

Comparison of the shive removal efficiency of single hydrocyclone and screen units

The Tripac90 hydrocyclone fractionation efficiencies were low (Q indices between 0 and 0.18) indicating that the shive levels in the accepts and rejects streams were similar for the configurations and reject rates studied, Table 4. In contrast, the C700 hydrocyclone had substantially greater shive fractionation efficiency, (Q index of 0.74). However, this fractionation efficiency was still lower than that achieved using a single pressure screen fitted with a 0.1 mm wedgewire basket, (Q index of 0.86). The rejects thickened substantially for both the C700 hydrocyclones (factor of 3) and the 0.1 mm wedgewire screen (factor of 5.4).

Table 4
Hydrocyclone and screen shive removal efficiency

	Reject rate, %		Reject thickening	Fractionation efficiency Q_{shive}	Shive removal efficiency, % R_{eff}
	Volumetric, R_v	Mass, R_m			
Hydrocyclone					
TR90 SM/13*	12.7	35.3	2.78	-0.054	35.0
TR90 SM/13*	7.3	22.4	2.43	0.184	25.4
TR90 ST/13**	32.6	57.4	1.76	0.109	63.5
TR90 ST/13**	14.7	21.1	1.44	0.143	25.0
C700*	18.2	46.5	2.54	0.743	73.9
C700*	12.1	36.4	2.99	0.738	61.9
Screen					
0.1mm ww/20**	10.1	46.3	5.40	0.86	nd.

*Trials performed at 0.13 % consistency, **Trials performed at 0.23 % consistency, nd.-Not determined due to mass balance errors.

Fractionation using multistage screening

The low energy primary-stage pulp containing 57 % shives was fractionated using multi-stage pressure screening to produce accept and reject pulps with average shive contents of 5 % and 73 %, respectively, Figure 5. The screening system was effective in separating the shives from the liberated fibre with approximately 90 % of the shives in the feed pulp being diverted to the rejects.

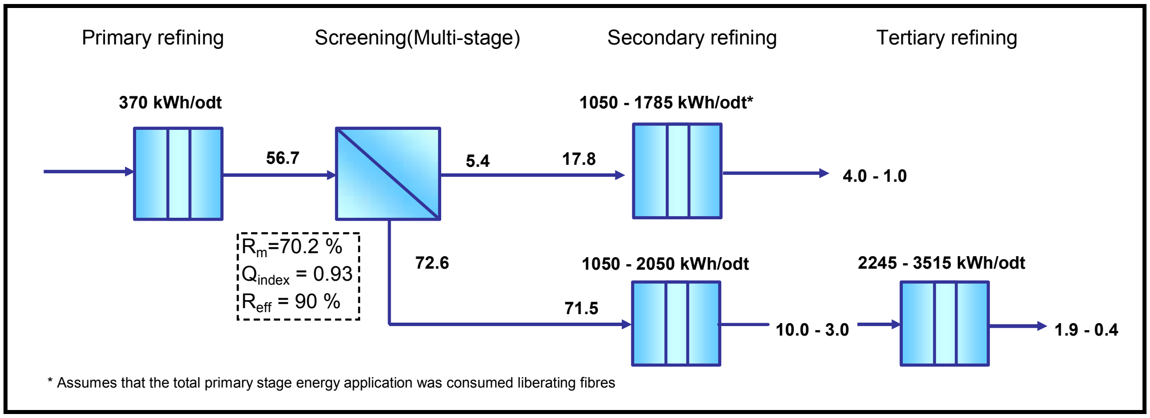

Figure 5 Pulmac shive contents (average values from the two runs) for the overall screening and refining stages.

Both the accepts and the rejects were dewatered using a drum thickener and Thune press combination. The fines-rich accept pulp shive content increased significantly across the dewatering stage (5.4 to 17.8 %) as a considerable amount of fines were lost. For this pulp, the overall yield for the dewatering operation was only 67 %. In contrast, the reject pulp had an overall yield of 96 % and was less affected by the dewatering operation due to its relatively low fines content.

Fibre length

The shives present in the feed, accept and reject pulps obtained from the multi-stage screening system meant that the fibre length distributions for these pulps could not be measured directly using conventional fibre length analysers. The Bauer McNett mass fraction data is shown in Table 5. However, this data must be treated with caution as most of the material retained on the +10 and +14 screens would have been shives rather than liberated fibre. The initial feed and overall rejects produced in this study had average shive contents of 57 and 73%, respectively.

Table 5
Bauer McNett and shive data for the overall feed, accept and reject pulps, before and after dewatering

		Prior to dewatering		After dewatering	
	Feed	Accept	Reject	Accept	Reject
Pulp ID.	A	H	L	J	M
Consistency, %	44.2	0.140	1.01	35.9	36.1
Bauer McNett fines, -200 %	12.0	33.3	10.9	10.6	2.7
Bauer McNett long fibre, R30 %	75.7	40.1	80.8	59.7	88.6
Pulmac shive content, %	56.7	7.3	75.7	19.5	70.5

To enable the liberated fibre length to be compared with that present in the chips, a series of pulps were screened using the Pulmac shive analyser with the fibres that passed through the 0.10mm screen plate being collected and evaluated using the FiberLab^{TM} fibre length analyser. In this comparison, fibres with length shorter than 0.5 mm were excluded from the analysis to minimise the influence of fines on the mean values and distributions. This was because Terylene cloth was used to collect the fibres from the Pulmac analyser and thus would have resulted in fines loss from these pulps. Also, in the case of the accept pulp, it has already been established that a substantial proportion of the fines were lost during the dewatering operation.

The liberated fibre in the overall screen accepts had a similar mean fibre length and fibre distribution to the feed pulp, Figure 6. For both pulp streams approximately 60% of the fibres were less than 2.0 mm in length. As expected, the liberated fibre rejected by the screening system had a lower proportion of short fibre with only 50% of the fibres less than 2.0 mm in length. However, the mean fibre length of the overall rejects (2.2 mm) was still substantially shorter than that of the kraft pulp (2.8 mm) indicating that there is still a considerable amount of fibre breakage even when a very low energy application is used in the primary refining stage.

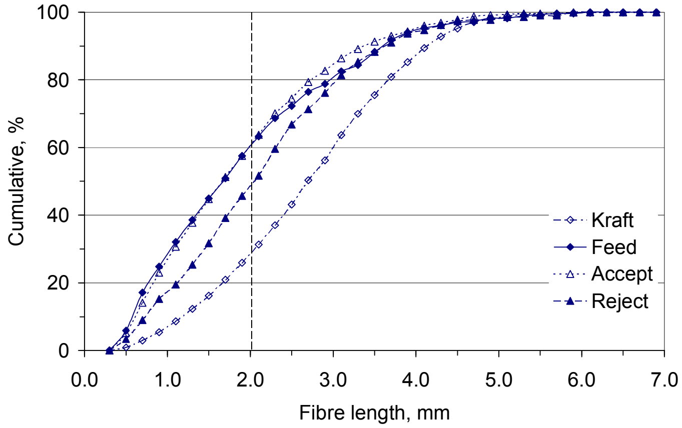

Figure 6 Length-weighted fibre length distributions of the overall feed, accept and reject pulp and the kraft pulp produced from the chips.

Fibre cross-sectional dimensions prior to refining

The shives in the rejects had a lumen perimeter of 87.5 µm, which was substantially higher than 79.5 µm lumen perimeter of the liberated fibre in the screen accepts. Even when the shives remaining in the screen accepts and the liberated fibre remaining in the screen rejects are taken into account, there was still a large difference between the lumen perimeters of the reject and accept streams (87.5 versus 80.2 µm), Table 6.

Table 6

Lumen perimeter of shives and free fibres in the overall feed, accept and reject pulps for the first screening batch

	Pulp ID.	Shive content, %	Lumen perimeter, µm		
			Shive	Free fibre	Mass based average
Accepts	J	7.3	89.2	79.5	80.2
Rejects	M	75.7	87.7	86.7	87.5

The liberated fibres were fractionated by the screening system with the accept pulp containing fibres with smaller lumen perimeter and thinner fibre walls than those in the rejects, Figure 7 and Table 7. Within a radiata pine tree, latewood tracheids have a greater wall thickness and a smaller perimeter than earlywood tracheids. However, it is also known that fibre wall thickness and fibre perimeter increase as the tracheid length increases from pith to bark (3). Consequently, the thinner wall thickness and smaller lumen perimeter of the accepts is most likely related to the screens fractionating the liberated fibres on the basis of length, rather than an earlywood-latewood separation.

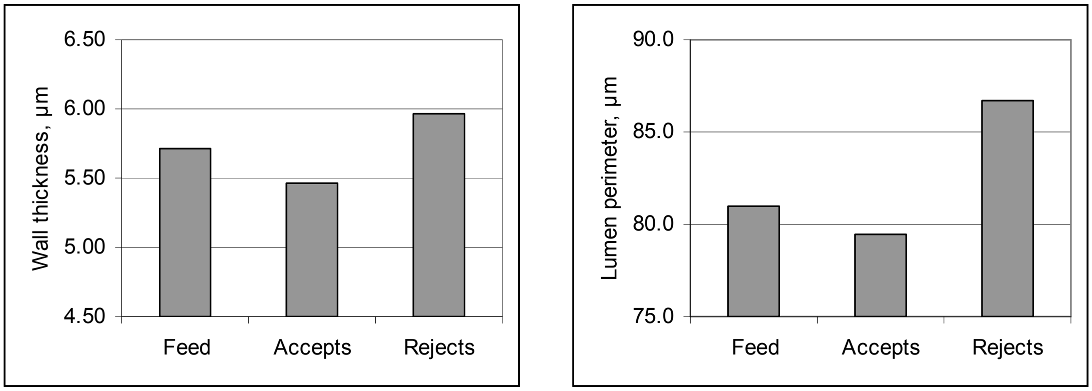

Figure 7 Liberated fibre average wall thickness and lumen perimeter for the overall feed, accept and reject pulps.

Table 7

Liberated fibre dimensions for the overall feed, accept and reject pulps

Pulp ID	Feed A	Accepts J	Rejects M
Mean length-weighted fibre length, mm	2.00	1.95	2.23
Wall area, µm²	530	496	590
Wall thickness, µm	5.71	5.46	5.97
Lumen area, µm²	365	366	412
Lumen perimeter, µm	81.0	79.5	86.7
Collapse (width/thickness)	1.62	1.59	1.65
Collapse resistance index (CRI)	4.55	4.16	4.11
Relative modulus of inertia (RMOI)	5.10	4.46	6.28

Refining of dewatered accept and reject fibre streams

Both pulp fractions were refined at several different energy input levels in a secondary refining stage. A sub-sample of the rejects was refined further in a tertiary refining stage, Figure 5.

Refiner energy input

Determining the total refiner energy input applied to each pulp fraction is complicated by the fact that the primary-stage refiner energy input split around the screens is unknown. For this study it is assumed that all the primary-stage energy input went in to fibre separation and thus the primary-stage energy input was added to the energy applied to the accept pulp in the secondary refining stage (corrected accept energy data). This approach was considered reasonable given that:

- The energy required to refine the rejects to a given freeness in the secondary and tertiary refining stages was similar to that required by the chips in the two-stage control pulp, Figure 8;
- The rejects were predominantly shives, which like the chips used in the control pulp, consisted of fibres constrained within a wood matrix.

However, it is possible that some energy was absorbed by the shives and that their energy demand is slightly higher than that of chips. Given that the screen mass reject rate was 70.2%, the assumption means that the primary-stage energy input of 350 kWh/odt equates to 1180 kWh/odt being applied to the accepts. The uncorrected and corrected freeness – energy input data are plotted in Figure 8. After the accept pulp data had been corrected to include the primary-stage energy input, this pulp required slightly more energy to a given freeness than the reject pulp (shives).

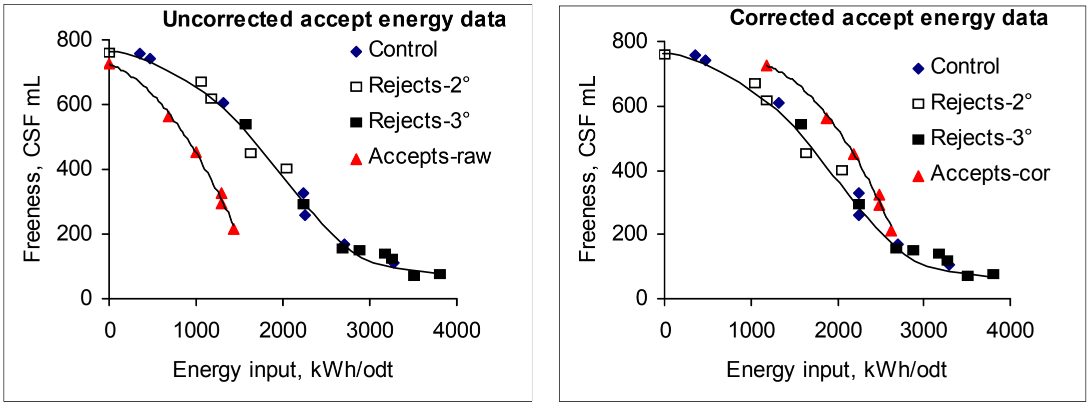

Figure 8 Freeness as a function of energy input for the two-stage control pulp, accepts and rejects (shives). The uncorrected accept energy data only includes the energy applied in the secondary refining stage. The corrected accept energy data assumes that all the primary-stage energy application of 350kWh/odt was applied to the accepts. The primary-stage energy input is not included in the reject data, only the secondary (2°) and tertiary (3°) energy inputs.

The freeness-energy input data is further complicated by the fines loss during the dewatering stage, particularly for the accept pulp which had a relatively high fines loss. To determine the impact of the fines loss on the freeness of the refined pulps, white-water from the respective dewatering operation was added back to three accept and three reject pulps in the correct proportion to compensate for the fines loss.

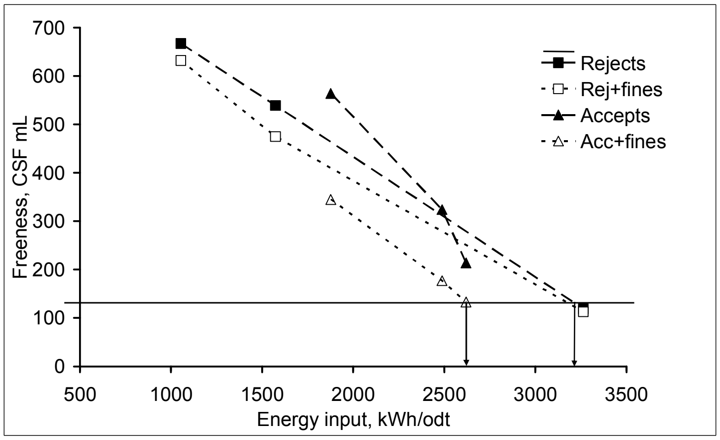

Figure 9 Freeness as a function of energy input for the two-stage control pulp, accepts and rejects (shives) with and without the fines from the respective dewatering operations being added back to the refined pulps. The accept energy data assumes that all the primary-stage energy application of 350kWh/odt was applied to the accepts. The primary-stage energy input is not included in the reject data.

As expected, the addition of white-water resulted in a much greater decrease in the accept pulp freeness at a given energy input compared to that observed for the reject pulp, Figure 9. When compared at 130 CSF after white-water addition, the energy demand of the accept pulp was 2620 kWh/odt compared to 3200 kWh/odt for the reject pulp (a difference of 580 kWh/odt). This difference in energy demand indicates that if the refined accepts and refined rejects were recombined based on the screen mass reject rate, the energy consumption to produce a 130 CSF pulp would be 3025 kWh/odt, which is similar to that of the control pulp.

Influence of refining on fibre dimensions

The fibre dimensions of the liberated fibres are shown in Table 8. It should be noted that the energy input data quoted in Table 8 and Figures 9 to 13 were calculated based on the assumption that all the primary-stage energy was applied to the accept pulp. It should also be noted that the freeness values have not been corrected to compensate for the fines lost during dewatering.

Table 8

Liberated fibre dimensions of the refined accepts and refined rejects

Sample	Shive content %	Fibre length *lwl* mm	Wall area µm²	Wall thickness µm	Lumen perimeter µm	CRI	RMOI	Collapse W/T	Energy input kWh/odt	Freeness CSF
Control										
A, Feed*	56.7		530	5.71	81.0	4.55	5.10	1.62	353	756
185	4.24	1.68	504	5.27	84.4	3.67	4.90	1.85	1313	607
187	1.10	1.74	512	5.33	83.7	3.96	5.47	2.04	2242	326
Accepts										
J*	16.0		496	5.46	79.5	4.16	4.46	1.59	1186	727
O1	4.00	1.42	542	5.82	80.8	4.91	5.29	1.80	1877	564
O2	2.76	1.5	500	5.45	82.1	3.83	4.53	1.76	2188	452
O3	1.56	1.44	466	5.34	77.9	4.89	3.99	1.84	2488	324
O4	1.04	1.35	464	4.97	81.9	3.67	4.74	2.06	2619	214
Rejects										
M*	72.4		590	5.97	86.7	4.11	6.28	1.65	0	758
P1	9.66		519	5.26	87.6	3.16	5.45	1.83	1054	667
P2	3.98		480	5.12	84.3	3.38	4.81	1.93	1175	614
Q1	5.16	1.77	524	5.23	87.7	3.68	5.75	1.83	1574	539
Q2	1.9	1.7	511	5.14	89.4	3.22	5.41	2.13	2243	289
Q3	0.92	1.63	492	4.79	91.5	2.82	6.31	2.23	2684	152
Q4	0.7	1.59	491	4.85	92.9	2.72	5.84	2.16	3263	119
Q5	0.36	1.54	463	4.92	87.7	3.12	5.21	2.04	3514	68

* These fibre samples contain a considerable quantity of shives. Given this, the dimensions of the fibres contained within the shives (see Table 6) must also be considered alongside those of the liberated fibres reported in this table.

The difference in fibre length between the accepts and rejects observed after the screening operation (Table 7) was maintained during secondary and tertiary refining of these pulps. The refined rejects have a considerably greater fibre length than the refined accepts when compared at either a common energy or freeness, Figure 10.

In the case of the accept pulp, the fibre length increased from 1.4 to 1.5 mm during the initial stages of secondary refining before decreasing, possibly at a faster rate than observed for the rejects. Although the initial increase may be simply experimental error, it is more likely that it can be attributed to long fibres being released from the shives (which made up 18% of the dewatered screen accept pulp).

The lumen perimeter of the liberated fibre in the refined rejects is approximately 6 µm greater than that of the liberated fibre in the refined accepts, Figure 11. This is consistent with the difference in lumen perimeter observed for the screen rejects and screen accepts prior to refining, Table 6. The control, rejects and accepts all show an increase in lumen perimeter with increasing energy application which is consistent with large perimeter fibres being retained in the shives after the initial primary refining stage and then being released in the subsequent secondary and tertiary refining operations. The accept pulp appeared to show the smallest increase in lumen perimeter for a given energy application. Although this is consistent with the lower shive content of the accept pulp, there is some scatter in the accept lumen perimeter data for the energy applications above 2000 kWh/odt.

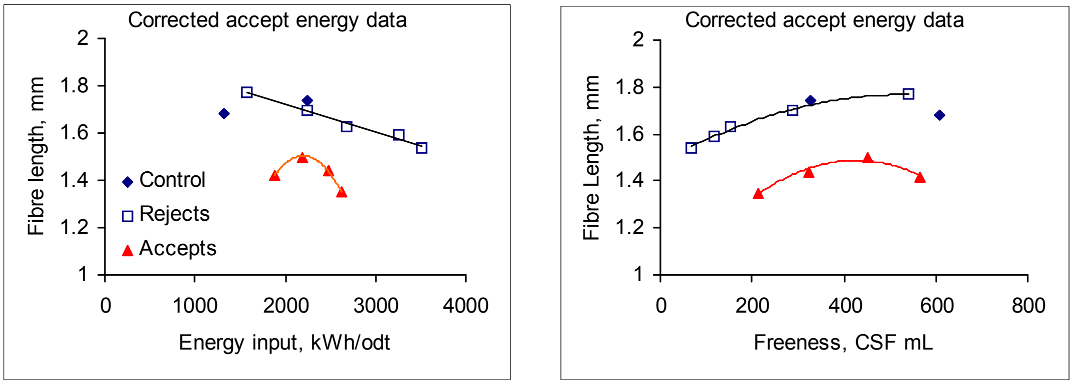

Figure 10 Length-weighted fibre length of the control, refined accept and refined reject pulps as a function of energy input and freeness.

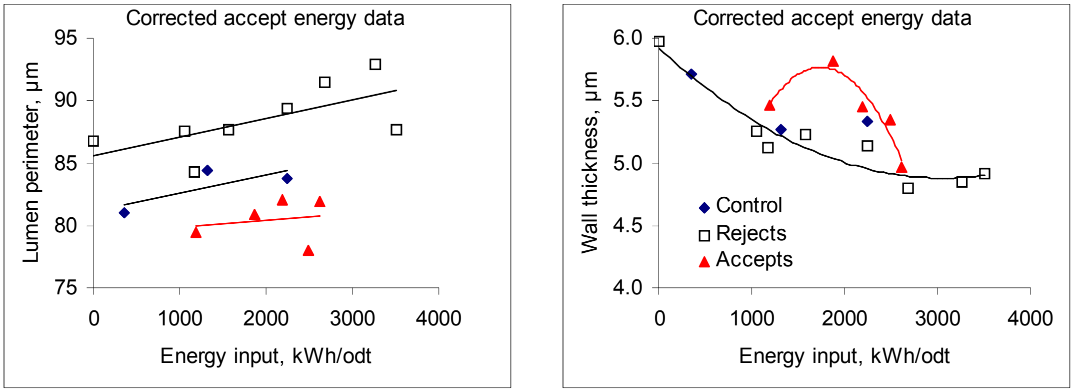

Figure 11 Lumen perimeter and wall thickness of refined accepts and rejects pulps.

The wall thickness of the liberated fibre in the control and reject pulps decreased with increasing refining energy, Figure 11. This decrease is expected and can be attributed to a combination of large perimeter, thinner-walled fibres being released from the shives and material being removed from the outer walls of the liberated fibres during refining. In contrast, the accepts pulp shows an increase in wall thickness during the initial stages of secondary refining (from 1200 to 1800 kWh/odt) followed by a rapid decrease in wall thickness as additional energy was applied. This initial increase in wall thickness is likely to be related to the release of long fibres from the shives (which made up 18% of the dewatered accepts). When the accept pulp was refined, relatively long fibres would have been released from the shives which have greater lumen perimeter and possibly greater wall thickness than the liberated fibres already in the accepts. After the initial increase, the wall thickness of the accept fibres decreased rapidly compared to the rejects. There are two possible explanations for this rapid decrease:

- It is possible that the longer (and hence thicker-walled) fibres released from the shives are preferentially broken when additional refining energy is applied in the refining system. This explanation is supported by the possible rapid decrease in fibre length observed in Figure 10.
- Alternatively, it may be that smaller perimeter accept fibres are less likely to collapse and rebound when impacted by a refiner bar than the larger perimeter reject fibres, Figure 12. Consequently, the accept fibres may not have been able to absorb the energy applied by the refiner bar and more material may have been removed from the fibre wall than for the reject fibre.

The collapse resistance index (CRI) and relative modulus of inertia (RMOI) data were calculated for the liberated fibres in the control, reject and accept pulps based on their cross-sectional dimensions (see Appendix 2). Although there is some scatter associated with the accept pulp data, these calculated values suggest that the accept fibres are less compliant in cross-section (higher CRI values), but more flexible in the longitudinal direction (lower RMOI values) than the control and reject fibres, Figure 12. The fibre collapse (as expressed as a ratio of the fibre width/fibre thickness) increased with increased energy input for the liberated fibre in both rejects and accepts, Table 8. When compared at a given energy input or freeness, the reject fibres have a greater collapse potential than the accept fibres.

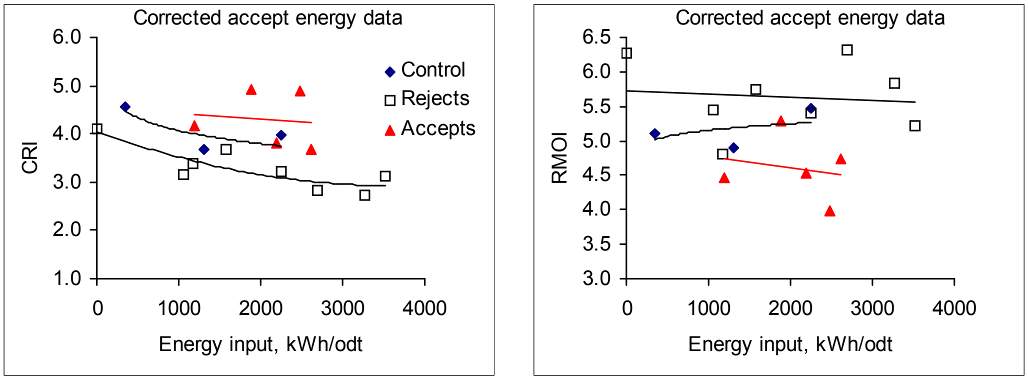

Figure 12 Collapse resistance index (CRI) and relative modulus of inertia (RMOI) of the control, accept and reject liberated fibre as a function of energy input.

Fibre fraction properties - Campbell sheets

Campbell sheets were produced to determine the properties of the long fibre and middle fractions of the refined screen accept and refined reject (shive) samples. The degree of consolidation (collapse behaviour) of the calendered handsheets produced from these samples was of particular interest. The energy input, freeness and fibre property data of the accept and reject pulps that provided the Bauer McNett R14-30 and R50-100 fractions for the Campbell sheet analysis are given in Table 9. Graphs of sheet density and tensile strength as a function of energy input for the Campbell sheets produced with 25% fines additions are given in Figure 13. These graphs show the same trends as those obtained for the Campbell sheets produced with 15% and 35% fines addition.

Generally, the refined accept and refined reject pulp fractions (R14-30 & R50-100) had similar sheet densities when compared at a common energy input, Figure 13. These results are unexpected as the collapse resistance index and collapse potential data suggest that the accept fibres are less collapsible than the reject fibres, Figure 12. Consequently, the accept fibres would have been expected to have a lower sheet density at a given fines content and energy input. The fact that the Campbell sheets do not show a substantial difference in sheet density for the two fibre types may be due to the greater cross-sectional collapse of the reject fibres being masked by their greater longitudinal stiffness (higher RMOI, Figure 12). Alternatively, it may be that with 1877 kWh/odt of energy being applied to the accept fibres, other factors such as fibre wall damage or delamination have a greater effect on sheet consolidation than the fibre perimeter and wall thickness.

Table 9

Property data for refined accepts and rejects pulps that provided the fibre fractions for the Campbell sheet analysis

	Accepts	Rejects		
Pulp ID	O1	P1	Q1	Q3
Energy, kWh/odt	1877	1054	1574	2684
Freeness, CSF mL	564	667	539	152
Fibre property data				
Lumen perimeter, µm	80.8	87.6	87.7	91.5
Wall thickness, µm	5.82	5.26	5.23	4.79
CRI	4.91	3.16	3.68	2.82
RMOI	5.29	5.45	5.75	6.31
Collapse, (width/thickness)	1.80	1.83	1.83	2.23

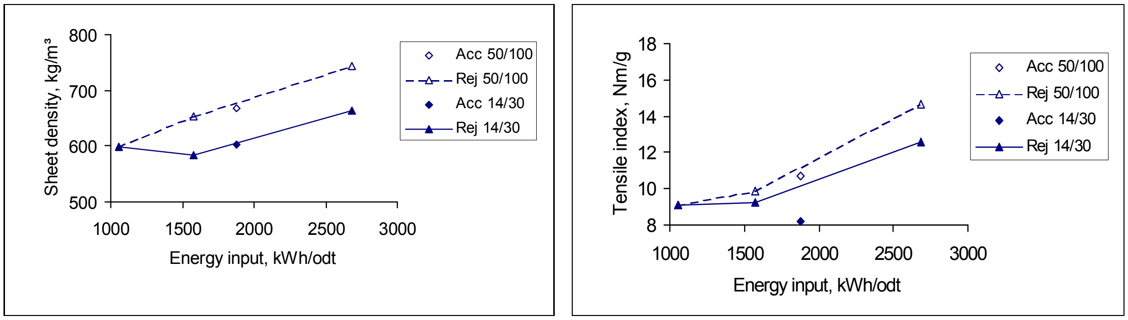

Figure 13 Sheet density and tensile index as a function of energy input for calendered Campbell sheets produced with 25% fines addition.

The calendered reject handsheets produced using the R14-30 and R50-100 fractions had greater tensile strength than the corresponding accept handsheets when compared at a given energy input. The fact that the reject fibres produced Campbell sheets with higher tensile strength even though they had a similar sheet density to those produced with the accept fibres, indicates that the reject fibre may have been more fibrillated or had greater surface development.

Handsheet properties

The sheet density and tensile strength of handsheets produced from the control, refined rejects and refined accepts are presented in Figure 14 and Figure 15, respectively. The handsheets for the accept and reject pulps were produced after white water from the respective dewatering operations had been added back to these pulps in the correct proportions to compensate for the fines loss.

The accepts pulps had a similar sheet density to the control and reject pulp when compared at a given energy input, Figure 14. However, the accepts also had a substantially lower fibre length and higher fines content, Figure 10. Consequently, when these pulps are compared at a given freeness, the accepts have a noticeably lower sheet density than both the control pulp and the rejects. This result is likely a combination of: 1) the poorer packing ability of the material recombined from the accepts dewatering stage; and 2) the greater collapse resistance of the accept fibres compared to those than reject fibres, Table 9.

A similar trend was observed for tensile index of the control pulp, refined rejects and refined accepts, Figure 15. However, in this case the accept pulp had lower tensile strength than the control and reject pulps when compared at both a given energy input and a given freeness. It appears that the shorter fibred accept pulps have particularly poor bonding and confirms the Campbell sheet data where the accept long and middle fibre-fractions also had lower bonding strength than the rejects. However, these tensile differences are greater for the standard sheets compared to the Campbell sheets, indicating that the accept fines may also be of poor bonding quality (middle lamella from primary stage).

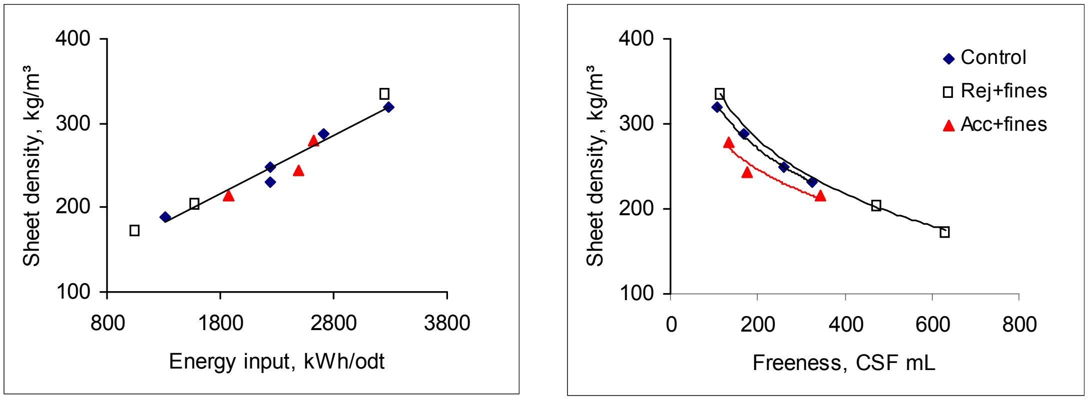

Figure 14 Sheet density as a function of energy input and freeness for the control, refined rejects and refined accepts for standard handsheets.

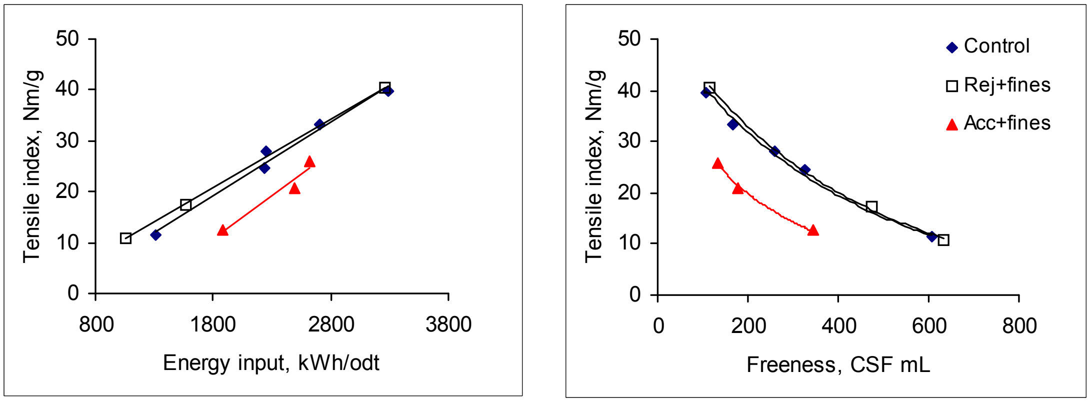

Figure 15 Tensile index as a function of energy input and freeness for the control, refined rejects and refined accepts for standard handsheets.

CONCLUSIONS

The low energy primary-stage feed pulp containing 57 % shives was fractionated with a multi-stage screening system to produce accepts pulps containing 5 % shives and rejects with 73 % shives. However, processing pulp streams with high shive contents (>50 %) is difficult as this type of pulp dewaters and thickens very quickly resulting in blocked valves and pipelines. To overcome this problem, a screen feed consistency of approximately 0.5 % was used. To achieve the shive separation detailed above, the overall screening system mass reject rate was 70 %, the shive fractionation efficiency (Q-index) was 0.93, and the shive removal efficiency was 90 %.

The key observations were:

- Pressure screens are more "efficient" at removing shives than hydrocyclones from the single-stage low energy TMP pulp.
- The fibre dimension data obtained from the screening stage provided support for this processing concept where earlywood and latewood fibres are separated as the shives (rejected by the screening system) which contained fibres with an average lumen perimeter of 88 μm, and the liberated fibres (accepted by the screens) which had an average lumen perimeter of 80 μm.
- The differences in fibre length and fibre lumen perimeter observed after fractionation were maintained when the liberated fibre (accepts) and shives (rejects) were given additional refining treatment. However, the fibres from the refined shives consolidated to the same sheet density, but had higher tensile strength than the fibres from the refined liberated fibre. This indicates that the earlywood fibre in the refined shives may be more fibrillated or have greater surface development than the latewood fibre in the refined liberated fibre stream.
- The cross-sectional dimensions of the accept and reject fibres indicates that the accept fibres are less compliant in cross-section, but more flexible in the longitudinal direction than the reject fibres. However, in contrast the sheet density data obtained from Campbell sheets produced using accept and reject fibres did not provide supporting evidence for the accept fibres having a lower collapse potential than the reject fibre.

These findings indicate that this new process strategy can enable more effective treatment of fibre types based on their dimensions, and increase the ability to direct a given fibre type to the most appropriate end use. However, further work is required to develop specific processing strategies for treating the separate fibre streams.

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APPENDIX 1 – Refiner process conditions

Table 10
Control pulp TMP process conditions.

Pre-steaming temperature	80°C	
Pre-steaming time	5 min	
Preheating pressure	0.5 bar	
Preheating temperature	110°C	
Preheating residence time	3.0 min	
	Primary refining	Secondary refining
Inlet pressure	1.0 bar	1.0 bar
Outlet pressure	1.2 bar	1.5 bar
Consistency	35-38%	35-38%
Feedrate	10 od kg/min	10 od kg/min
Motor load	750 kW	550 – 1100 kW
Specific energy	~ 1,250 kWh/odt.	900 – 1800 kWh/odt.
Freeness	~600 CSF	~400 – 100 CSF

Table 11
Reject refining process conditions

Inlet pressure	1.0 bar
Outlet pressure	1.5 bar
Consistency	35-38%
Feedrate	10 kg.od/min
Motor load	~500 – 1100 kW
Specific energy	~ 800 – 1,800 kWh/odt.
Freeness	150 to 500 CSF

APPENDIX 2 - TMP Pulp Testing Methods

Latency was removed from the pulps in accordance with AS/NZ 1301.215S 1997. Freeness and fibre classification were based on AS/NZS 1301.206s-1988 and Tappi standard T233os-75, respectively. Shive content was determined on a Pulmac shive analyser fitted with a 0.10 mm screen plate.

Accept fibre dimensions

Dried and re-wetted accept fibre samples were dehydrated through an acetone series prior to impregnation with Spurr's resin according to the method of Kibblewhite (4). Resin capsules were microtomed into sections of 2 to 3 µm in thickness using glass knives and a Leica Ultracut. These sections were stained using a 50:50 solution of Azur 2 and methylene blue, and were mounted in EUKITT.

For each sample, a total of 200 fibres were measured for their cross-sectional dimensions of width, thickness, centreline perimeter, and wall area, from one section of each of the four replicate capsules. Thus, the mean estimates of each fibre dimension were based on the measurement of 200 fibres. From these measurements, the population distributions for fibre width, fibre thickness, fibre wall area, fibre wall thickness and, width-to-thickness ratio were also determined.

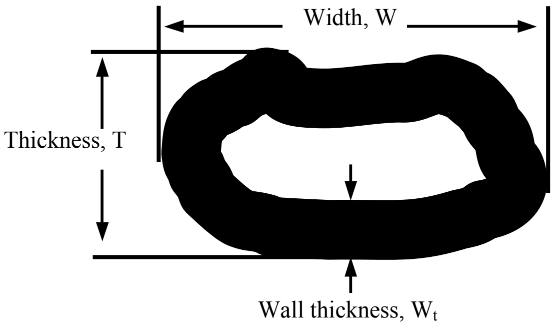

Figure 16 Fibre cross-section dimensions.

The fibre wall area and perimeter were used to calculate collapse resistance index, CRI and relative moment of inertia, RMOI as defined by Wakelin *et al.* (5):

$$CRI = 1000 * \left[\frac{1}{1 + \dfrac{p^2}{\pi . A_w}} \right]^3 \qquad RMOI = \frac{\pi}{2 * 33113} \left[\left(\frac{p}{2\pi} + \frac{A_w}{2p} \right)^4 - \left(\frac{p}{2\pi} - \frac{A_w}{2p} \right)^4 \right]$$

Where:
p = fibre centreline perimeter
A_w = fibre wall area

Shive dimensions

The cross-sectional dimensions of shives were measured using the following procedure. The shive samples were obtained by fractionating the pulp sample in a Pulmac shive analyser fitted with a 0.1mm screen plate. The shives obtained were dehydrated using an ethanol series, embedded in a resin block (LR white resin), sanded smooth and stained with acridine orange. Images of the shive cross-sections were captured on a Leica TCS NT confocal microscope. Optimas 6.5 image processing software was used to determine the shive area, wall area, lumen area and lumen perimeter, for a minimum of 100 shives from each pulp sample. The mean values of these parameters were also determined for each shive.

Campbell sheet analysis

To determine if fibre quality of the accepts differed from that of the rejects, Campbell sheets were produced with the fibre fractions from selected refined reject and refined accept pulps using the square sheet machine operated without fines recirculation.

A Bauer McNett was used to fractionate the selected samples using the 10/14/30/50/100 mesh screens. The +10 fraction was discarded, the +14 and +30 fractions were combined and the +50 and +100 fractions were combined. Several Bauer McNett screening runs were needed for each pulp sample to obtain sufficient fibre for sheet making. “Standard” TMP fines were obtained by screening a combination of conventional low freeness TMP pulps. Screening was performed using a 100 µm DSM bow screen. Three fibre/fines ratios of 85/15, 75/25 and 65/35 by weight were evaluated for each pulp sample. Both calendered and uncalendered handsheets were produced.