MILL DEMONSTRATION OF TMP PRODUCTION FROM FOREST THINNINGS: PULP QUALITY, REFINING ENERGY, AND HANDSHEET PROPERTIES

J. Y. Zhu,[a]* C. Tim Scott,[a] Roland Gleisner,[a] Doreen Mann,[a] D. P. Dykstra,[b] G. Holton Quinn,[c] and Louis L. Edwards[c]

High-value, large-volume utilization of forest thinning materials from U.S. National Forests is a potentially important contributor to sustainable forest health. This study demonstrated the utilization of wood chips produced from thinnings for the production of thermomechanical pulp (TMP). Both whole-log chips (primarily from small-diameter logs, tops, and reject logs) and sawmill "residue" chips from a Hewsaw[TM] system (Mäntyharju, Finland) were evaluated. The residue chips produced in this study were substituted for a TMP mill's standard residue chips up to about 50%. The whole-log chips were substituted for the mill's whole-log chips up to about 30%. The results show that substitution of chips produced from forest thinnings reduced refining energy in all trials. Pulp quality was maintained throughout all trials.

Keywords: Forest thinning, Small diameter trees, Suppressed growth trees, Thermomechanical pulp (TMP), Forest fire, Whole log, Saw mill residues, Pulp quality measurement, Sheet properties

Contact information: a: USDA Forest Service, Forest Products Laboratory, Madison, WI 53726; **Corresponding author:jyzhu@fs.fed.us, b:* USDA Forest Service, Pacific Northwest Research Station, Portland, OR 97208, c: Department of Chemical Engineering, University of Idaho, Moscow, ID 83843

INTRODUCTION

Decades of forest fire suppression practices in U.S. National Forests have created fuel overloading as a result of an overpopulation of small-diameter, suppressed-growth trees. To reduce the incidence and extent of catastrophic wildfires in these forests, various remediation strategies are being implemented. One such strategy is selective thinning, targeting the removal of small-diameter trees (Mason et al. 2006). This practice is desirable because it can restore the forest to a more natural state, providing an environment that is far less fire prone and more recreationally attractive. But selective thinning operations are very expensive. Finding high-value, large-volume uses for small-diameter timber is critical to leveraging the costs associated with selective removal strategies. The production of solid wood products such as dimension lumber, poles, or posts is a preferred use in terms of best value. But many of these small-diameter trees are too small to be converted in a conventional sawmill operation. Several sawmill operators in the Pacific Northwest region of the United States have recognized this opportunity and have installed equipment to process logs as small as 10 cm (4 in.) in diameter. Although these new installations can process ever-smaller logs, a substantial volume of unused material remains in our forests. Fortunately, quality wood chips are needed for paper production in this region. Integrating the production of lumber and paper using chips from small-diameter trees would be highly desirable and could add considerable value to the resource. However, chip quality and consistency is a paramount concern in paper production. Research must demonstrate that residues from these new equipment installations, chips produced from the smallest diameter trees, and other removals such as tree tops are suitable for paper production. Only then would thinned materials be considered a viable resource for paper production.

Our goal in this study was to investigate the suitability of sawmill residues and whole-log chips from selective removals for production of thermomechanical pulp (TMP). Our study demonstrated the viability of using forest thinnings in the integrated production of lumber and paper. By adding value to the resource, this strategy could also alleviate the high costs associated with selective thinning operations and enhance their implementation as important tools for sustainable forest management.

Forest thinning materials from the National Forests are very different from traditional small-diameter trees from commercial thinning in plantation forests. High juvenile wood content is the major characteristic of small-diameter trees produced from plantations. This is a concern for wood-fiber production by the pulp and paper industry because juvenile wood fibers have lower mechanical strength (Zobel and van Buijtenen 1989). Much research on evaluating the papermaking potential of commercial thinnings has been conducted. Of those studies that reported mechanical pulping of thinning materials, Hatton and Johal (1993, 1996) and Hatton (1997) indicated that more energy may be required to refine commercial thinnings. Also, they found that chips from commercial thinning produced different pulp properties than chips from final harvests. Conversely, forest thinning materials from the National Forests include many older trees that have small diameters as a result of several decades of growth suppression, primarily from overcrowding. For example, the tree diameter at breast height (DBH) of a 100-year-old tree can be as small as 12.5 cm (5 in.) or less. Juvenile wood content in such trees is low, but the industry perception has been that forest thinning materials are inferior for fiber production. As a result, this resource has not been well accepted nor fully utilized by the pulp and paper industry as a viable fiber source. Scientific evaluation through laboratory and pulp mill trials is required to elucidate the value of these materials and make the case for broad industry acceptance for incorporating forest thinnings in the commercial production of pulp and paper.

Several laboratory studies on the production of TMP from small-diameter trees have been conducted at the USDA Forest Service Forest Products Laboratory (FPL), Madison, Wisconsin (Meyers et al. 1999, Myers 2004). These studies indicated that mechanical properties (tensile, tear, burst) of handsheets made from thinning materials are consistently lower (10%–30%) than those of paper made from sawmill residues. However, the laboratory refining protocol employed in these studies involved multi-pass refining (up to 5 passes) to achieve a target freeness of 100 Canadian Standard Freeness CSF (Myers et al. 1999). This process can cause significant fiber damage, resulting in about half the weighted average fiber length of commercial pulp. Consequently, the quality of pulp produced under this protocol could not be compared to commercial production with high confidence.

Recently, we studied the effect of growth rate on wood properties, including trees harvested from National Forests that have experienced severe growth suppression (Zhu et al. 2007). We found that suppressed growth resulted in less distinction between earlywood and latewood fibers in terms of wood density and tracheid geometry. Normally, this distinction is dramatic, particularly for the variation in tracheid wall thickness. This makes it very difficult to optimize TMP process conditions (Rudie et al. 1994). Either the earlywood fibers are severely damaged (shortened) when refining conditions are optimized for latewood, or the latewood is not well refined when refining is optimized for earlywood. Therefore, we hypothesize that small-diameter suppressed-growth trees with a more uniform tracheid wall thickness distribution should refine more easily (giving higher consistency and requiring less energy), which could improve pulp properties in the production of TMP.

To evaluate our hypothesis that thinnings should be suitable for TMP production, we decided to conduct pulping trials at an industry pilot-scale, refining facility (Andritz, Inc., Springfield, Ohio) (Klungness et al. 2006). The objectives of this pilot demonstration were to (1) dispel the notion through rigorous laboratory testing that thinning residues are inferior to conventional wood sources and (2) encourage collaboration between industry and the Forest Service by attempting a commercial demonstration. The control run used sawmill residue chips from "normal" growth trees supplied by a pulp mill, Ponderay Newsprint Company (PNC), Usk, Washington, containing about 50% lodgepole pine (*Pinus contorta*) and 50% mixed hemlock and grand fir (*Tsuga heterophylla* and *Abies grandis*). In the trial with materials from thinnings, about 25% of the chips were from small-diameter logs supplied by a nearby sawmill, Ponderay Valley Fiber, Inc. (PVF), Usk, Washington. These chips were 50% Douglas-fir (*Pseudotsuga menziesii*) residue chips and 50% lodgepole pine whole-log chips. Residue chips are from the outside of the log and do not normally include heartwood, whereas whole-log chips do, of course, include heartwood. Comparisons of the tear strengths of the handsheets made from refined pulp samples at various freeness levels for both the control and small-diameter mixed blends were equivalent. Furthermore, the small-diameter blends produced paper with slightly higher tensile energy absorption than from control chips (Klungness et al. 2006). These results confirmed our initial expectations about the viability of producing TMP from forest thinnings and warranted the full-scale TMP mill evaluation described below.

EXPERIMENTAL

Raw Materials

A 70-acre site in the Colville National Forest at East LeClerc Creek near Usk, Washington, was selectively harvested by PVF according to Forest Service specifications (FS 1999). The logs were collected, inspected, and sorted at a nearby landing site and were later hauled to PVF for processing. All logs with severe defects (heart rot, checks, and distortion) and minimum diameters less than 10.41 cm (4.1 in.) (small logs and tree tops) were segregated from the saw logs and chipped as "whole logs." Visual inspection suggested that of the whole logs chipped, about one-third on a volume basis were small-diameter logs, one-third were tree tops, and one-third were large logs with defects that made them unsuitable for lumber production. Figure 1 shows a load of whole logs on the infeed deck at PVF. Logs to be sawn were processed through an automated Hewsaw™ system (made by the Veisto Group, Mäntyharju, Finland; http://www.hewsaw.com/) to produce dimension lumber. The Hewsaw™ system was developed to maximize the recovery of lumber while converting sawing residues from the outside of the logs directly into chips. Both the LeClerc whole-log (LWL) chips and the LeClerc residue chips (LRC) were shipped to PNC for separate pulping trials.

Fig. 1. Whole-log samples being transported to debarking machine.

TMP Production

The TMP mill at PNC has two production lines. Both lines have primary and secondary refining stages, after which the pulp is diluted and screened. The pressure-screen accepts (about 40%) move forward to the paper machine stock tanks, and the rejects (about 60%) from both production lines are thickened through a reject refiner and screened again. Each refiner is rated at 25,000 hp. Two separate mill demonstration studies were conducted over a 3-week period. The first study was conducted over a two-day period in late February 2006. It involved substituting normal PNC whole-log (PWL) chips with LeClerc-thinning whole-log chips (LWL). The second study was conducted over a two-day period in early March 2006, and involved substituting PNC mill residue chips (PRC) with LeClerc-thinning residue chips (LRC). Only partial substitution was carried out in both studies. Two trial runs were conducted in each demonstration study with different chip substitution ratios.

In the whole-log chip study, 20% substitution of PWL and PRC chips with LWL chips was carried out in the first run, and this was increased to 30% in the second run (Fig. 2). The first run lasted 5 h but the second run lasted only 3.75 h when the LWL chips ran out. The ratio of LWL to PWL chips was approximately 2:1 in both runs for a total chip blend of 30% whole-log chips with 70% residue chips in the first trial (LWL:PWL:PRC = 20:10:70) and 44% whole-log chips with 56% residue chips in the second trial (LWL:PWL:PRC = 30:14:56). The pulp mill technical staff was uncomfortable with increasing the whole-log chip content to 44% (two thirds from thinnings of small diameter and tree tops) because they feared inferior chip quality. The mill was, however, willing to attempt this level for a short time. The whole-log chip study was of particular interest to the mill because a large quantity of this material is available; however, its quality for papermaking was unknown.

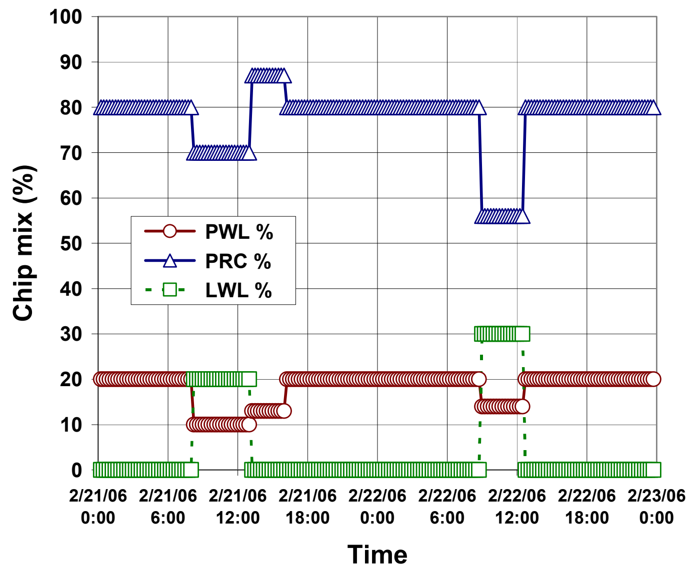

Fig. 2. Time series showing the chip-mix ratios during the whole-log chip study.

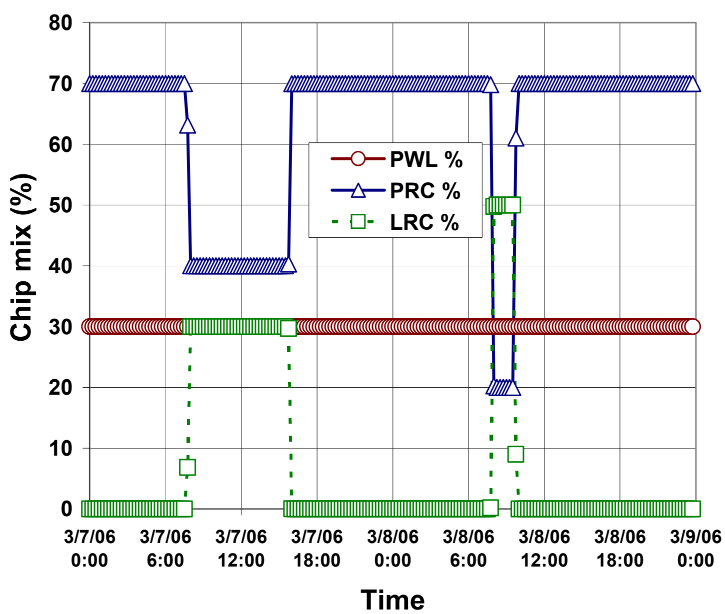

Fig. 3. Time series showing the chip-mix ratios during the residue chip study.

In the residue chip study, 30% of the PNC mill residue chips (PRC) were substituted with LeClerc thinning residue chips (LRC) in the first trial run (trial 3), and the substitution was increased to 50% in the second run (trial 4) (Fig. 3). The first run lasted 8 h, and the second run lasted 1.75 h, when the LRC ran out. No changes in pulp quality were expected from these trials.

Pulp Sampling and Control System Data Recording

Pulp sampling was conducted at several locations along the production line; i.e., primary and secondary refiner transfer lines (diluted), pressure screen accepts and rejects, and reject refiner discharge. Samples were taken hourly, starting 1 h before each trial run and continuing until up to 2 h after. The samples were then shipped to the Forest Products Laboratory in Madison, Wisconsin, to test for pulp freeness and fiber length after latency removal. Pulp freeness was measured according to TAPPI standard method T 227 (1996b), while fiber length was measured by the Fiber Quality Analyzer (FQA, OpTest Equipment Inc., Ontario, Canada). The pulp mill control system records production data such as refining power for each refiner every 5 min. It also records pulp quality data such as pulp freeness as measured by the Pulp Quality Measurement (PQM) system about every 30 min.

Handsheets Preparation and Testing

The pulp samples were tested for freeness and then made into handsheets for testing. To reduce the number of samples tested, two to three pulp samples collected in the same trial run with similar freeness levels were combined into one pulp sample. Handsheets were prepared using a semiautomatic handsheet mold (Messmer Instrument Limited, Model 255/SA, UK) according to TAPPI standard T205 (1996a). All handsheets were made using recycled white water that had passed through the sheet mold. The white water accumulated in a small holding tank during handsheet making. The tank would fill after making about three handsheets. Overflow of white water was not collected. The accumulated white water was recycled to retain fines that would normally pass through the handsheet screen. The effectiveness of fines retention was demonstrated by measuring changes in handsheet properties as fines accumulated in the white water tank. The properties of the handsheets stabilized as soon as system equilibrium was reached (about three sheets). Paper testing was carried out by the Paper Test Laboratory at the Forest Products Laboratory according to TAPPI standard methods. A set of 10 handsheets was used in paper physical property measurements.

RESULTS AND DISCUSSION

Wood Chip Analysis

Wood chip analysis was conducted by Integrated Paper Service, Inc. (Appleton, Wisconsin) according to TAPPI Standard 401 (1996c) (Table 1). Most notable is the low amount of Douglas-fir in the trial chips in spite of the fact that Douglas-fir makes up more than one-quarter of the volume of logs processed at the sawmill. The PNC specifically requested that whole-log Douglas-fir chips be excluded from the trials because of the dark coloration common in Douglas-fir heartwood, so the logs were segregated at the sawmill and processed separately. In spite of this, Table 1 shows that the PNC chips contained about 15% Douglas-fir; the exclusion was more effective for the chips from the LeClerc site. Table 2 shows the species composition of the chip blends that were used during the four trial runs based on the substitution levels shown in Figs. 2 and 3.

Table 1. Chip Species Analysis (columns add to 100%)

Species	LWL[a]	LRC[b]	PWL[c]	PRC[d]
Douglas-fir	3.6	0.8	14.1	15.5
Grand fir	38.0	18.3	33.8	18.3
Hemlock	2.5	8.2	17.5	0.0
Hard pine	28.1	57.5	23.0	53.2
White pine	26.8	1.4	1.4	0.0
Spruce	0.9	13.8	10.1	13.1

[a] LeClerc-thinning whole-log chips.
[b] LeClerc thinning residue chips.
[c] Ponderay Newsprint Company whole-log chips.
[d] Ponderay Newsprint Company mill residue chips.

For the whole-log trials, the main difference in species composition between the control chips and trial chips was that the trial chips contained a little less Douglas-fir, hard pine (lodgepole), and spruce and a little more white pine and grand fir. For the residue chip trials, both trial blends contained substantially less Douglas-fir and slightly more hemlock than the control chips. We also observed that the residue chips (PRC and LRC) produced by the Hewsaw™ system were smaller than the whole-log chips (PWL and LWL).

Table 2. Species Composition of Chips Used in the Mill Demonstration Runs (columns add to 100%)

Species	Whole-log trial 1		Whole-log trial 2		Residue chip trial 3		Residue chip trial 4	
	Control	Trial	Control	Trial	Control	Trial	Control	Trial
Douglas-fir	15.2	13.0	15.2	11.7	15.1	10.7	15.1	7.7
Grand fir	21.4	23.8	21.4	26.4	23.0	23.0	23.0	23.0
Hemlock	3.5	2.3	3.5	3.2	5.3	7.7	5.3	9.4
Hard pine	47.2	45.2	47.2	41.4	44.1	45.4	44.1	46.3
White pine	0.3	5.5	0.3	8.2	0.4	0.8	0.4	1.1
Spruce	12.5	10.4	12.5	9.0	12.2	12.4	12.2	12.6

To further examine the differences among the different wood chips, we measured the fiber lengths and widths of the Kraft pulps derived from these wood chips. The final pulp kappa number was around 25. The measured fiber length and width of a Kraft pulp are a reliable measure of the natural wood fiber dimension. As shown in Table 3, the differences in length-weighted mean fiber lengths and arithmetic mean widths were very small between LeClerc-thinning chips and PNC mill chips when comparing whole-log with whole-log chips and residue with residue chips. The differences in fiber dimension between the control and trial 2 chips used in the whole log trial were also insignificant.

Table 3. Comparison of Fiber Length of Kraft Pulps from Wood Chips Used in the Mill Demonstration

Wood Chips	Length Weighted Pulp Mean Fiber Length (mm)	Arithmetic fiber width (μm)	Pulp Kappa Number
LWL	2.59	37.2	25.5
PWL	2.59	34.1	28.7
LRC	2.49	34.5	25.4
PRC	2.52	35.5	23.3
Whole-log Trial Chips			
Control	2.69	34.7	25.2
Trial 2	2.54	33.8	25.2

Pulp Quality

The data collected from the mill's PQM system and laboratory testing of the pulp samples were used to assess pulp quality. For the whole-log study, no significant differences in pulp freeness (Fig. 4) and weighted-average fiber length (WAFL) (Fig. 5) were observed for pulps produced from control chips or pulps produced from trial chips. The PQM data were not available for the freeness of pulps obtained from pressure screen accepts. However, these freeness values were later determined from laboratory tests at FPL. For all pulps tested, the FPL lab data showed slightly higher freeness and WAFL than the corresponding PQM data did. However, the lab data showed the same trends as the PQM data, indicating that the PQM data were quite reliable. To determine the extent of refining in the whole-log trials, the pulp long-fraction data from PQM were plotted against pulp freeness (Fig. 6) and the pulp shive content was plotted against WAFL (Fig. 7). No substantial differences were observed in either of these relations between the pulp from the control and trial runs.

A simple statistical analysis was conducted to confirm conclusions from the visual comparisons. The limited amount of chips available for the trails restricted the trail runs to only a few hours and thus produced much less data than were available for the control runs. Therefore, the data do not conform to strict statistical standards and a full analysis of variance could not be justified. For pulp from transfer line A, a *t* test ($\alpha = 0.05$) of the mean freeness between the control run and the combined trial 1 and 2 runs suggests a significant difference in the means of about 10 mL. It is expected that different blends of wood chips would produce different results. In practice, a difference of 10 mL in pulp freeness at a mean of about 200 mL can be ignored even if it is statistically significant. This is because the measurement error in Canadian Standard Freeness at a freeness level of about 200 mL can easily be 10 mL. The measured standard deviation of pulp freeness for the control run was 11 mL. For pulps from the reject refiner, a *t* test found no significant difference in mean freeness between the control and trial runs. Table 4 summarizes the results from the statistical analysis and shows that few of the tests found statistically significant differences. In the cases where statistically significant differences were indicated, the magnitudes of the differences fell within normal measurement error. Overall, we therefore conclude that the quality of pulp produced from the chip blends incorporating whole-log chips from forest thinnings was essentially equivalent to the quality of pulp produced from standard mill chips. This same result was obtained for the residue chip trials.

Refining Energy

Analysis of total specific refining energy (primary + secondary + reject) was an integral part of this study. As the trials proceeded, we observed a drop in total specific refining energy (Fig. 8) and a substantial drop in refining energy for both chip substitution levels for the whole-log trial. The data presented in Fig. 8 were calculated by multiplying the PQM-specific refining energy and the corresponding PQM production tonnage of each production line A and B (sum of the primary and secondary) and the reject refiner (the rejects from both A and B were fed into one reject refiner; the rejection ratios were about 50% to 65%).

Table 4. Statistical Analysis of Key Parameters for Pulp Produced during the Control and Trial Runs (null hypothesis = same, $\alpha = 0.05$; STD = standard deviation)

	Pulp Freeness (mL)		**Long Fraction (%)**		**Length Weighted Mean Fiber Length (mm)**	
Transfer Line A	**Control**	**Trial 1+2**	**Control**	**Trial 1+2**	**Control**	**Trial 1+2**
Mean	213	204	31.6	31.2	1.24	1.23
STD	11.3	15.3	1.17	1.36	0.037	0.043
t test (Mean)	Different		Same		Same	
Levene's test (Variance)	Different		Same		Same	
Reject Refiner	**Control**	**Trial 1+2**	**Control**	**Trial 1+2**	**Control**	**Trial 1+2**
Mean	172	170	38.5	37.9	1.47	1.45
STD	5.7	6.0	0.73	0.68	0.023	0.023
t test (Mean)	Same		Different		Different	
Levene's test (Variance)	Same		Same		Same	

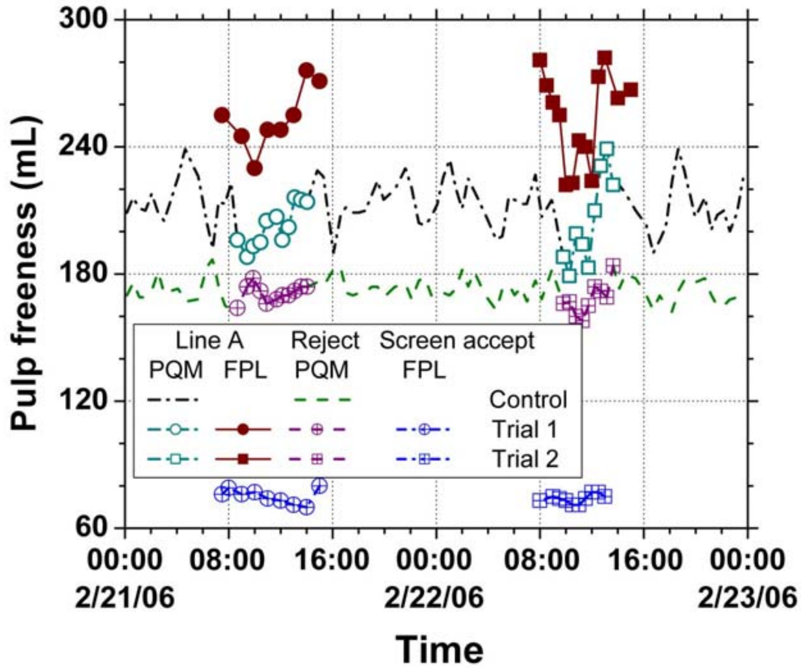

Fig. 4. Time series of pulp freeness measured by Pulp Quality Measurement (PQM) and Lab (FPL) analysis during the whole-log chip study (see Fig. 2).

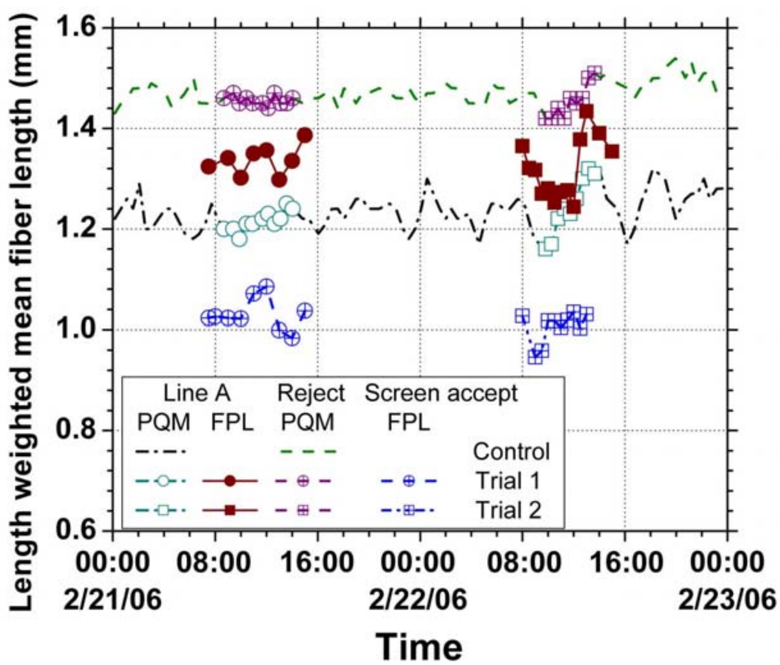

Fig. 5. Time-dependent pulp length weighted mean fiber length measured by Pulp Quality Measurement (PQM) and Lab analysis during whole-log chip study (see Fig. 2).

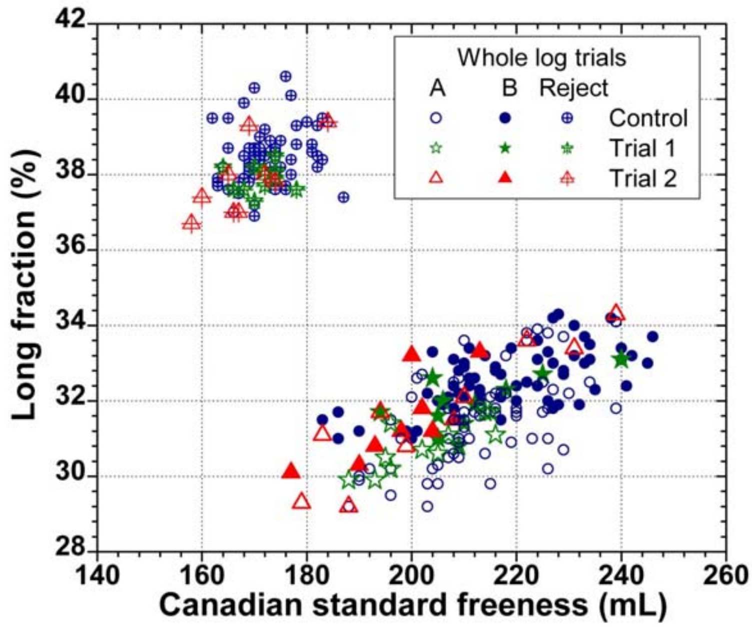

Fig. 6. Long fraction plotted against freeness for pulp produced during the whole-log chip study.

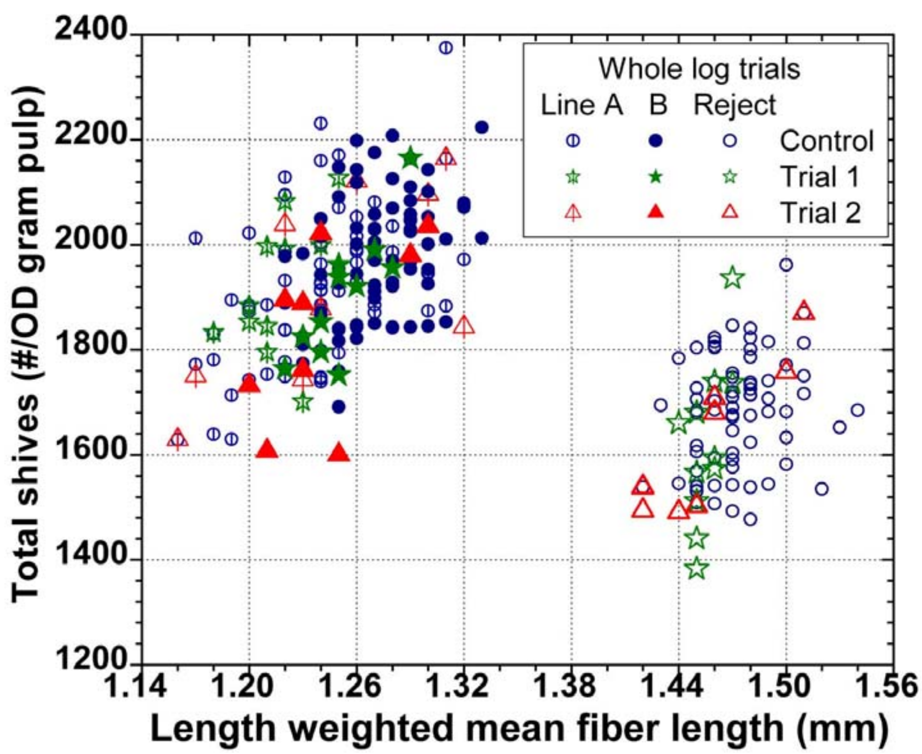

Fig. 7. Shive content plotted against length-weighted mean fiber length for pulp produced during the whole-log chip study.

Further analysis revealed that the energy reduction occurred in the secondary and reject refiners, not in the primary refiner (Fig. 9). We observed a similar trend for production line B (not shown). No abnormal adjustments to refiner CD or flat-plate gaps were observed during either the whole-log or residue chip trial runs. Nor were any abnormal changes in pulp freeness observed during the trial runs. These observations suggest that a reduction in refining energy could be obtained under normal operating conditions without sacrificing pulp quality, a conclusion that supports our hypothesis that TMP production from suppressed-growth trees with a narrower distribution of tracheid wall thicknesses (Zhu et al. 2007) may require less refining energy (Klungness et al. 2006). The observed reduction in energy required to refine mixed wood chips from forest thinnings in a U.S. National Forest is opposite to that reported in the literature using commercial thinnings (Hatton and Johal 1996, Hatton 1997). In the cited publications, more refining energy was required to produce pulp of a given freeness from commercial thinnings than from the wood of mature trees.

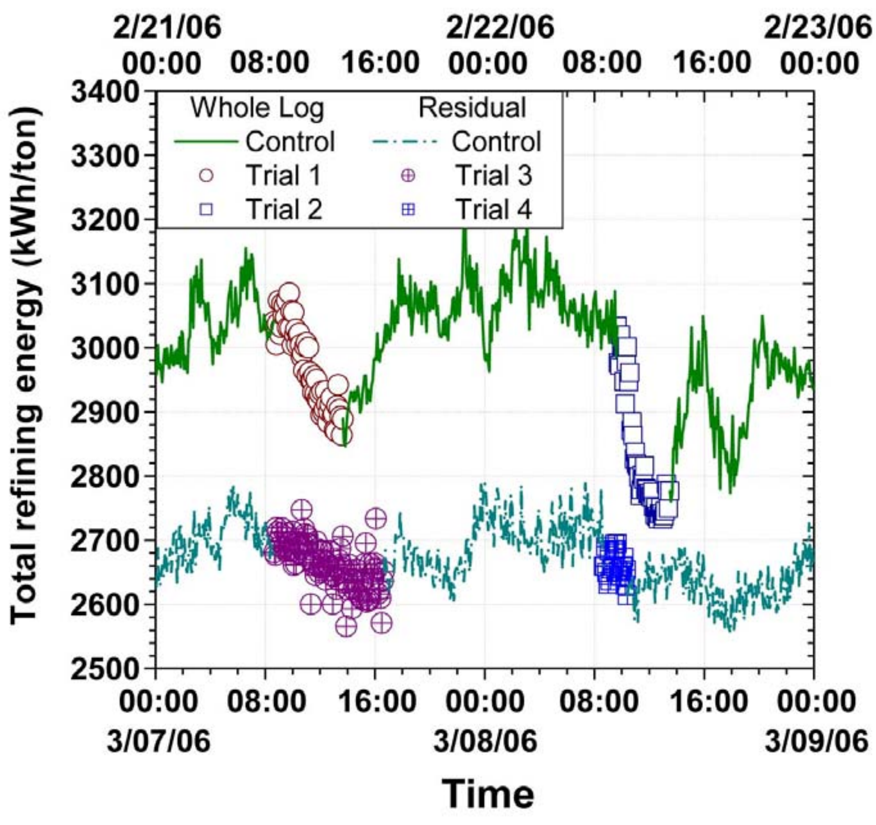

Fig. 8. Time series of specific energy consumption during refining for the whole log and residue chips studies.

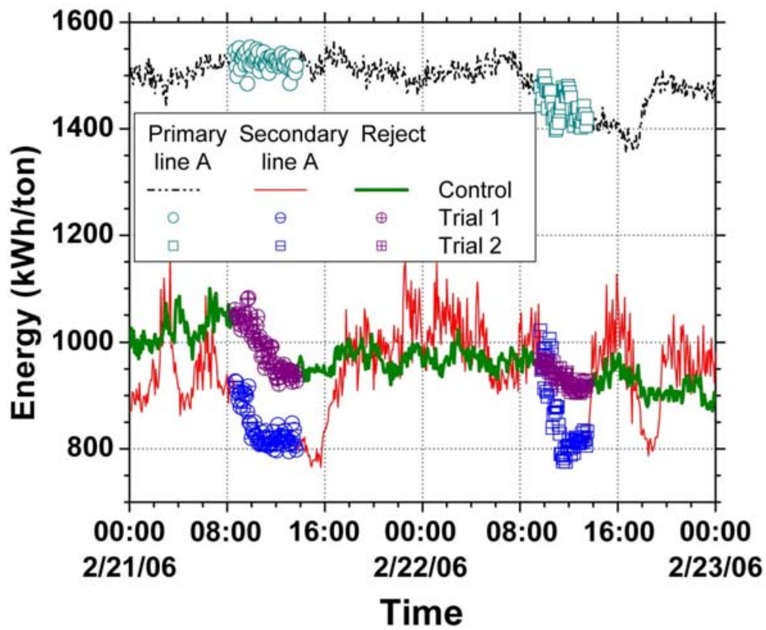

Fig. 9. Time series of specific energy consumption for the primary and secondary refiners for production line A plus the reject refiner during the whole-log chips study.

Handsheet Properties

The properties of handsheets made of pulp samples collected during mill trials reinforced our hypothesis that pulp quality would not be diminished by the addition of whole-log or residue chips from forest thinnings. For each control run, only two pulp samples were collected, one before the trial run and one after the trial run. Therefore, only two sets of handsheets were made for each control run. Many pulp samples were collected during each trial run. The trial pulp samples were combined based on the freeness level (see Experimental section) to reduce the number of sets of handsheets for testing. Figure 10 shows the relationship between handsheet tensile energy absorption and apparent density for all pulp samples collected in trial 2 (44% whole-log chips with 30% whole-log substitution) and trial 3 (30% residue chips substitution). From this figure, no obvious difference can be attributed to either chip blend used (mill or trial). Figure 10 also shows that the quality of pulp from the reject refiner was generally better than the quality of pulp from the pressure screen accepts. The two outliers around a density of 390 kg/m^3 and a TEA of 21 J/m^2 were due to the low stretch measured from those two sets of handsheets. The measured average stretches of those two handsheets were about 12% below the expected value of sheets with similar density. However, the standard deviations in stretch measurements of all the handsheet sets were between 5% and 13%. Apparently, the measured stretches of these two sets of sheets were at the low end of measurement accuracy, which caused the outliers in TEA data. The tensile and burst indices of all handsheets (for control and trial blends) were also indistinguishable (Fig. 11). Comparing the tear and tensile indices reveals that pulps from the reject refiner produced stronger handsheets (Fig. 12). Again, no obvious difference can be attributed to either chip blend used (mill or trial).

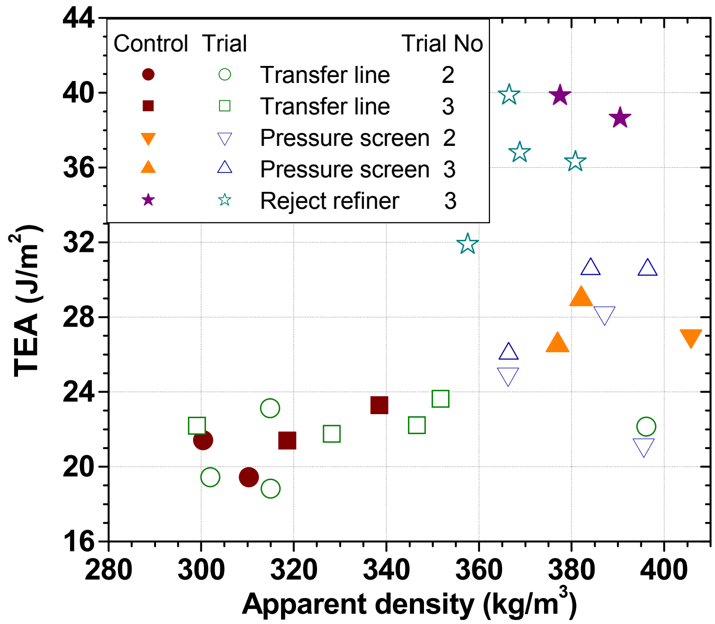

Fig. 10. Tensile energy absorption (TEA) comparisons of handsheets made of pulps produced from control chips and trial chips.

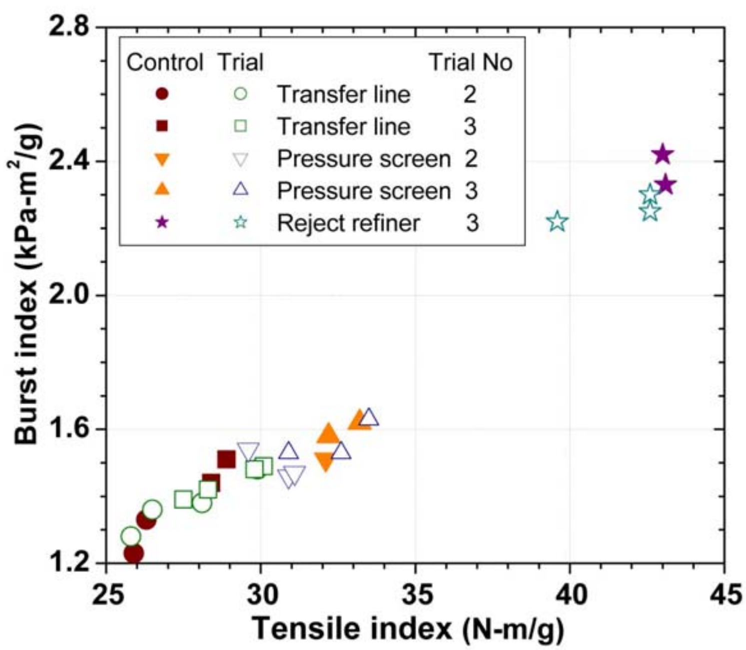

Fig. 11. A comparison of handsheet tensile–burst correlation between control and trial runs.

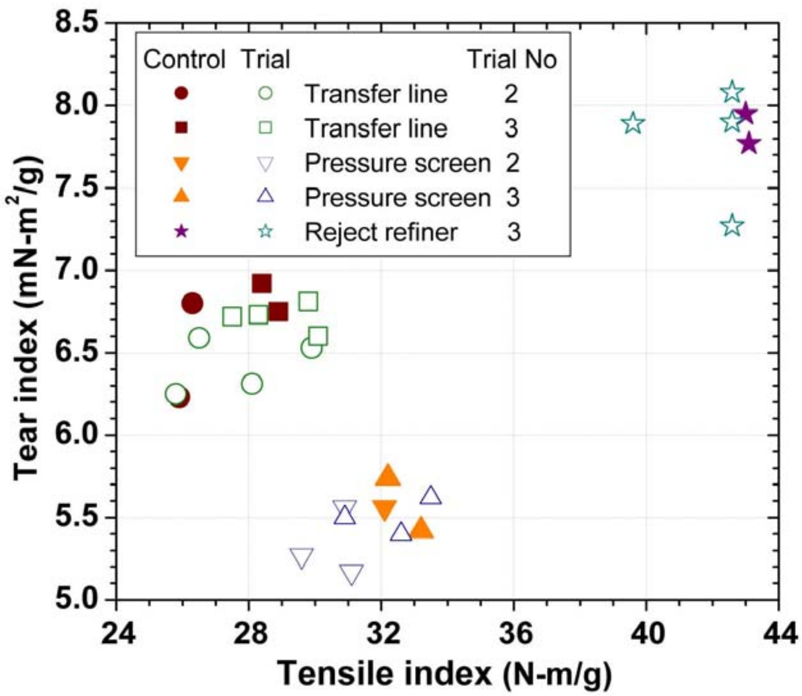

Fig. 12. Comparisons of handsheet tear and tensile relation between control and trial runs.

CONCLUSIONS

Finding high-value, large-volume uses for small-diameter trees removed in thinnings is of critical importance if the strategy to reduce forest fuels is to be achieved in the U.S. National Forests. The integrated production of lumber and paper from small-diameter trees is an important utilization strategy that could add significant value to a resource that is currently considered inferior. We have demonstrated that forest-thinning materials from older, small-diameter trees can serve as a viable wood fiber source for paper production in a full-scale TMP production facility. Our results suggest that less refining energy is consumed when wood chips are mixed with chips from forest thinnings, including those from whole logs as well as those from sawmill residues. In this study, pulp quality obtained from trial runs using chips from forest thinnings was equivalent to that obtained from control runs using normal mill chip blends. Quality was measured in terms of pulp freeness, WAFL, shive content, and handsheet properties. Of particular interest is the fact that whole-log chips could be substituted up to about 44% without an obvious decrease in pulp quality. It would be of great interest to conduct longer trials (days not hours) with various species blends to more fully assess the value of chips obtained from thinning materials for the production of paper.

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