EFFECT OF PRECOMMERCIAL THINNING ON RESIDUAL SAWMILL CHIP KRAFT PULPING AND PULP QUALITY IN BALSAM FIR

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ABSTRACT

This study examined the effects of precommercial thinning (PCT) on kraft pulping and pulp properties of balsam fir [*Abies balsamea* (L.) Mill.]. Heavy precommercial thinning of balsam fir stands results in detrimental effects on the kraft pulping and pulp properties of the residual stems. It was found that at a stand density of 1,500 stems per hectare, sawmill residual chips obtained from the stems are more difficult to cook and exhibit a corresponding reduction in pulp yield with concomitant increased cooking chemical consumption. Shorter, finer fibers were observed, and the kappa 30 kraft pulps exhibited improved sheet tensile strength. These results indicate that balsam fir stems from heavily precommercially thinned stands contain a higher proportion of juvenile wood, although a contribution from compression wood cannot be completely ruled out.

Keywords: *Abies balsamea,* precommercial thinning, compression wood, kraft pulping, kraft pulp quality, juvenile wood.

INTRODUCTION

The Canadian industrial wood supply is under pressure. Multiple forest use demands are increasingly removing areas from industrial availability, and in addition, transportation distances (hence costs) for wood from mature stands are increasing. Silvicultural treatments, such as precommercial and commercial thinning, are receiving increasing interest as a means of accelerating residual tree growth and maximizing merchantable wood production from a stand. The opportunities to enhance residual tree growth, which reduces future harvesting and manufacturing costs, and to reduce stand rotation age are compelling.

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Balsam fir (*Abies balsamea* (L.) Mill.) is widely distributed across eastern and central Canada and is an important source of industrial wood. This relatively low density wood species is prone to windthrow and heart rot in older stands (Isenberg et al. 1980); therefore, improved stand management appears to be extremely attractive. In eastern Canada and the northeastern United States, young balsam fir [*Abies balsamea* (L.) Mill] stands are often overstocked, reaching almost 72,000 stems/ha in some cases (Ker 1981; Lavigne and Donnelly 1989; Karsh et al. 1994; McArthur 1965). Such overstocking usually results in a high mortality, slow growth, and small-size sawlog trees, which are associated with high harvesting and manufacturing costs and low lumber volume recovery. As sizable sawlogs are becoming scarce in eastern Canada and the forest industry in this region is moving toward intensive silviculture, precommercial thinning (PCT) of the young and dense balsam fir stands has become increasingly popular in recent years. For example, over 50,000 hectares of balsam fir stands were precommercially thinned in Québec in 1997 compared to less than 5,000 hectares in 1985 (Canadian Council of Forest Ministers 1996).

A number of studies (Ker 1981; Piene 1981; Mérette and Martel 1985; Ker 1987; Lavigne and Donnelly 1989; Karsh et al. 1994; Zarnovican and Laberge 1996) have reported that precommercial thinning applied to the young and dense balsam fir stands can reduce the mortality, accelerate the diameter growth of residual trees, and shorten the rotation age for sawlog production. On the other hand, it is well known that increased spacing generally leads to increased crown size, branch diameter, and juvenile wood, and to decreased stem straightness (Nicks 1991; Barbour et al. 1994). Therefore, the industry has shown increasing concern over the negative effects of this treatment on wood quality and end uses. A multidisciplinary project was initiated by Forintek to evaluate the impact of precommercial thinning on tree and wood characteristics, product quality, and value recovery in balsam fir (Zhang et al. 1998).

A number of studies have evaluated the kraft pulping potential of both green and decadent balsam fir (Hunt 1981; Hatton and Gee 1984; Matolcsy 1975; Johal et al. 1994; Macleod 1986). From these data, it is evident that balsam fir can be somewhat variable in quality. However, the effect of precommercial thinning on the quality of the kraft pulp prepared from the sawmill residual chips obtained from the residual stems has not yet been determined.

Cown (1973, 1974) investigated radiata pine that was thinned from 3000 stems down to 540 stems and later to 200 stems per hectare and observed a 28% increase in stem volume, and a 10% reduction in tracheid length. Compression wood formation accelerated immediately after each thinning. In complementary studies, extreme thinning and tree spacing have been shown to promote the formation of shorter tracheids in conifers such as coastal Douglas-fir (Fernandez and Watson 1999) and western hemlock (Watson et al. 1999). These effects are thought to be due to increased crown size and consequently increased auxin content in the stem, which delay the onset of mature wood. Cown (1973, 1974) also reported that thinning favored the growth of a larger crown, capable of producing auxin (a hormone known to promote radial growth and compression wood formation); hence thinning had altered the hormonal balance in the stem. He concluded that up to 20% of the lower portion of the tree could consist of compression wood caused by heavy thinning. It has been widely reported that more than any other practice, thinning is associated with the incidence of compression wood in the residual trees of a conifer stand (Timell 1986). For the first few years after thinning, the stand will be susceptible to wind, snow, and ice damage; but with increased stem diameter and taper, this brief period of risk is soon passed. The enhanced radial growth in opened stands is attributable not only to favorable growth conditions but also to increased wind sway.

In this study Paprican was invited to participate in this multidisciplinary project to evaluate the impact of precommercial thinning on chip and pulp properties in balsam fir. The oldest precommercial thinning trial provided materials for this study. The pulping and pulp quality data from this trial were expected to be of lower variability as the samples were all obtained from the same location and were a composite of a large number of trees.

EXPERIMENTAL

Raw materials

The oldest balsam fir precommercial thinning trial in Canada provided materials for this study. The trial was located in Amqui, Bas Saint-Laurent Region of Quebec. The area was classified by Rowe (1972) as Gaspé Section (B.2) of the Boreal Forest Region. Soils are mainly stony loams, and the site is dominated by balsam fir with some birch and white spruce trees. The trial was regenerated from clear-cutting in 1948. A 4-hectare balsam fir stand was thinned manually in the summer of 1960 when the stand was 12 years old. The stand was equally divided into 100 plots. Thinning intensity in the 100 plots (or stand density after the thinning) covered a wide range of stand densities from 500 to 7,250 trees/ha. In 1995 or 35 years after the precommercial thinning, 63 thinned and 5 control plots were measured. Based on this measurement, destructive samples were collected immediately in fall 1995 from plots of heavy thinning (1,500 trees/ha) and moderate thinning (3,000 trees/ha) as well as control plots (12,100 trees/ha). The thinned and control plots were next to one another, and thus had comparable site quality and growth conditions.

The following parameters were calculated for each plot based on the field measurement: 1) number of trees per hectare (total or merchantable); 2) average DBH for merchantable and total trees (cm); 3) basal area of merchantable and total trees (m^2/ha); 4) merchantable volume (m^3). Sample trees in this study were selected based on diameter class. From the plots of each thinning intensity, 6 trees per diameter class were taken from each merchantable diameter class found in the 2 plots at an interval of 2-cm (e.g., 10, 12, 14, 16, . . .). In total, from the control plots 42 merchantable trees were taken for 7 merchantable classes (viz. 10, 12, 14, 16, 18, 20, 22); from the moderately thinned plots 48 trees were taken for 8 merchantable diameter classes (viz. 10, 12, 14, 16, 18, 20, 22, 24); and from the heavily thinned plots 60 trees were taken for 10 merchantable diameter classes (viz. 10, 12, 14, 16, 18, 20, 22, 24, 26, 28). In total, 150 merchantable trees were selected for this study.

Each sample tree was bucked into 8-foot-long logs. To facilitate the log conversion and identification of lumber origin, logs from the three samples (control, moderate, and heavy thinning intensity) were painted with distinct colors. The logs were converted at a typical sawmill in Quebec. Logs from the three samples were processed separately. Each log, after debarking and diameter class sorting , was sawn into lumber of different dimensions (e.g., 2 × 3, 2 × 4, and 2 × 6) and boards (e.g., 1 × 3, 1 × 4, and 1 × 6). When all the logs from one thinning intensity were converted, two bags of chip samples were collected randomly for the evaluation of chip quality and pulp properties. The same operation was repeated for logs from 2 other stand densities.

The chips were screened in Wennberg chip classifier to obtain the accept chips in the thickness range of 2–6 mm. Accept chips were well mixed before representative samples were taken for exploratory and larger scale cooks.

Kraft pulping

Three representative aliquots of accept chips from each of the 3 samples were kraft cooked in bombs (45 gram, oven-dried charge) within a B-K micro-digester assembly (Keays and Bagley 1970).

The cooking conditions were as follows:
Time to maximum temperature 135 min
Maximum cooking temperature 170°C
Effective alkali, % o.d. weight of wood 16%
% Sulphidity 26%
Liquid to wood ratio 5:1
H factor 1200–1800

All of the pulps produced were washed, oven-dried, and weighed to determine pulp yield. Pulp kappa number and black liquor residual effective alkali were determined by standard procedures. From these results, the optimum cooking conditions required to produce kraft pulps at 30 kappa numbers were estimated by fitting regression lines through each set of data ($r^2 \geq 0.95$). Large quantities of kraft pulp were subsequently produced in a 28-L Weverk laboratory digester. These pulps were disintegrated, washed, and screened through an 8-cut screen plate.

Physical testing of the pulps

Five-point beating curves were constructed using PFI mill runs of 0, 1000, 3000, 6000, and 9000 revolutions according to PAPTAC standard C7. Canadian standard freeness was determined for each point according to PAPTAC standard C1. Handsheets were formed and tested for physical and optical properties using PAPTAC standard methods.

RESULTS AND DISCUSSION

Kraft pulping

The H-factor versus kappa number data are presented in Fig. 1. It is evident that the heavily thinned stand produced wood chips that were more difficult to cook to a given kappa number, (i.e. required an additional 200 H-factor at kappa 30) than the control and moderately thinned samples. Consequently, the pulp yield from the heavily thinned stand is significantly lower, (>3%), at a given kappa number, as shown in Fig. 2. The small difference observed between the control and moderately thinned pulp yield data, (1%), is likely not significant as the alkali consumed by these experiments is similar for the control and moderately thinned samples but much higher for the heavily thinned sample. It is interesting to note that the pulp yields observed in this study are 0.5%–2.5% higher for the control and moderately thinned sample and 1.0%–1.5% lower for the heavily thinned sample than previously reported (Hunt 1981; Hatton and Gee 1984; Johal et al. 1994), (also presented in Fig. 2), which confirms that the yield reduction observed is real.

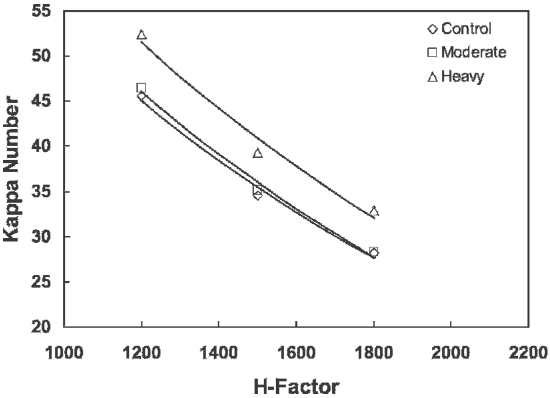

FIG. 1. Kappa number vs. H-factor data shows that the heavily thinned sample is more difficult to kraft pulp.

Pulp yields estimated at 30-kappa number together with the corresponding H-factor and effective alkali consumed are shown in Table 1. From these results, it is evident that precommercial thinning of balsam fir to a residual stand stem density of 1,500 stems per hectare, will negatively affect kraft pulping. This results in a higher H-factor, a lower pulp yield, and increased chemical consumption, which will provide additional organic load on kraft chemical recovery processes.

Thinning has been reported to intensify the occurrence of compression wood, and increase

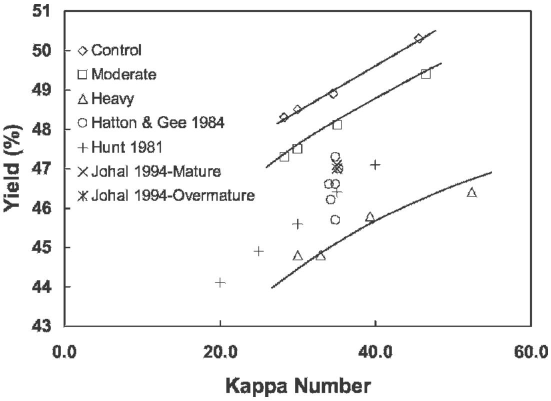

FIG. 2. Kraft pulp yield vs. kappa number with literature data included indicates that although the stand is perhaps superior to data previously reported, the detrimental effect of heavy precommercial thinning is significant as this harder to cook heavily thinned sample exhibits the lowest yield at a given residual lignin content.

TABLE 1. *Calculated balsam fir kraft pulp yield, H-factor and EA consumed, to achieve 30 kappa, and measured fiber properties.*

Thinning Intensity	Stems per hectare	H-Factor	% Yield (Unscreened)	% EA Consumed	Length Weighted Fiber Length (mm)	Coarseness (mg/m)
Control	10,000	1701	48.5	10.7	2.45	0.166
Moderate	3,000	1713	47.5	10.6	2.52	0.153
Heavy	1,500	1918	44.8	11.2	2.28	0.141

the knot size through a rise in branch size (Megraw 1985). Increased branch size was indeed observed in these thinned stands (Zhang et al. 1998). In addition, Isenberg has reported that balsam fir is susceptible to windthrow. Lack of "wind-firmness" might suggest that once released from the protection afforded by a high stocking density, balsam fir trees will generate more compression wood in order to cope with environmental factors such as wind. In order to confirm this, we have undertaken chemical analysis of the chips. The results are presented in Table 2 and confirm that the heavily thinned sample contains more lignin and elevated levels of mannan and galactan, which is consistent with the presence of compression wood in these samples.

Unbleached kraft pulp physical properties

All pulp quality data are presented in Table 3. A comparison of previously reported data for balsam fir indicates that this species produces kraft pulps with wide variability in properties (Hunt 1981; Hatton and Gee 1984; Matolcsy 1975; Johal et al. 1994; Macleod 1986) confirming the necessity for carefully controlled sampling.

TABLE 2. *Chemical composition of balsam fir chips different precommercial thinning intensities.*

	Control (10,000 stems/ha)	Moderate (3,000 stems/ha)	Heavy (1,500 stems/ha)
Total Lignin * (%)	29.4	28.7	31.0
Arabinan (%)	1.7	0.5	0.0
Xylan (%)	4.0	3.9	2.8
Mannan (%)	13.6	13.2	14.1
Galactan (%)	2.3	4.2	7.2
Glucan (%)	47.4	48.2	44.1
Extractives (%) (Acetone)	1.6	1.3	0.7

* Klason + Acid Soluble

Overall sheet properties

The effect of beating on pulp freeness is presented in Fig. 3. The control and the moderately thinned samples exhibit a slightly higher freeness than the heavily thinned sample at low levels of beating. This result is consistent with the shorter average fiber length and lower coarseness of this pulp.

The effect on sheet density is presented in Fig. 4. The control sample displays a lower sheet density than the precommercially thinned samples, which is consistent with the higher coarseness of this pulp. The thinned chip samples produce denser and better bonded sheets, which also exhibited higher air resistance and were smoother than the control sample. Thus it can be concluded that precommercial thinning results in trees with shorter finer outer wood fibers which exhibit juvenile wood-like characteristics and produce better bonded pulps.

Pulp strength properties

The tensile index as a function of PFI mill revolutions is presented in Fig. 5. These data are consistent with the fiber properties in Table 1 and show that, like juvenile and mature wood kraft pulps (Hatton 1997), the finer fibered pulps from the thinned sites exhibit an improved tensile strength over the control sample.

We have included data from other sources in the tear-tensile relationship presented in Fig. 6. The variability in balsam fir is clear and the quality of the samples tested in this study is evident as these data fall at the upper point of the

TABLE 3. *Kraft pulp physical and optical data for the precommercially thinned balsam fir.*

PFI Mill revs., (× 10^3)	Csf (mL)	Apparent Sheet Density (kg/m^3)	Surface Roughness (Sheffield units)	Air resistance (s/100mL)	Tensile Index (N.m/g)	Stretch (%)	Breaking Length (km)	Zero-span Breaking Length (km)	Burst Index (kPa.m^2/g)	Tear Index (1 ply) (mN.m^2/g)	Tear Index (4 ply) (mN.m^2/g)	Scattering coefficient,[a] (cm^2/g)	Opacity (%)
Control													
0	702	498	244	3.0	87.7	1.92	8.90	17.5	6.5	16.8	19.1	262	96.7
1	694	577	221	5.0	95.8	2.69	9.80	16.2	7.1	17.8	18.1	226	95.8
3	658	625	205	8.0	109.2	2.98	11.10	15.5	8.4	16.7	15.9	187	94.1
6	525	661	143	25.7	118.3	3.34	12.10	16.5	9.6	16.0	13.7	164	92.9
9	372	679	78	132.7	133.3	3.40	13.60	16.1	10.0	14.6	12.8	153	92.8
Moderately Thinned													
0	688	577	158	11.1	104.6	2.08	10.7	16.0	8.2	15.4	14.9	282	97.3
1	684	633	150	16.6	105.8	2.72	10.8	16.3	8.7	16.9	14.9	229	95.7
3	640	673	137	24.7	110.7	2.98	11.3	15.8	9.3	15.4	13.1	199	94.8
6	535	701	93	80.7	133.7	3.56	13.6	16.0	10.5	13.7	11.2	167	93.2
9	406	716	60	216.2	135.5	3.56	13.8	16.4	11.6	12.3	11.0	156	92.6
Heavily Thinned													
0	667	553	163	10.7	115.9	1.86	11.8	16.8	8.1	14.0	14.4	269	98.0
1	650	622	143	16.3	116.1	2.71	11.8	16.9	8.8	14.9	13.6	235	97.6
3	600	666	125	27.8	128.0	3.49	13.1	16.1	9.8	14.4	12.0	199	96.4
6	491	692	81	87.4	131.6	3.45	13.4	14.4	11.4	13.6	10.8	173	95.5
9	373	715	47	252.1	143.3	3.61	14.6	14.9	11.6	12.1	10.8	161	95.1

[a] Measured at 557nm

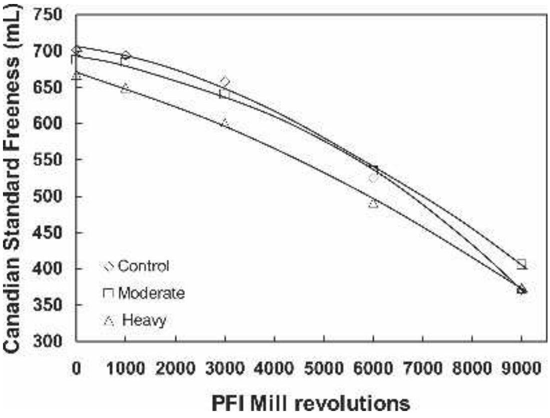

FIG. 3. Canadian standard freeness as a function of PFI mill revolutions indicates that the shorter fibered heavily thinned sample exhibits slower drainage characteristics.

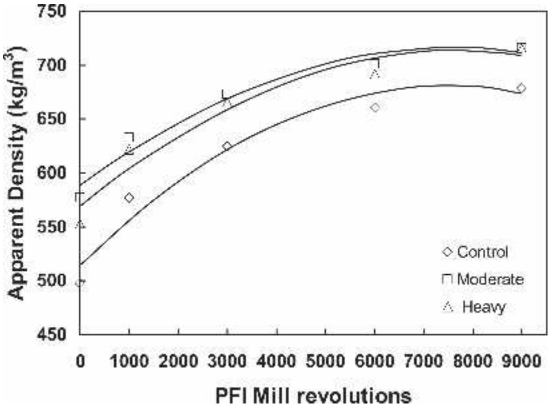

FIG. 4. The apparent sheet density of the precommercially thinned samples is higher than that of the control.

curve. The thinned samples correspond well with many of the samples previously analyzed (Hunt 1981; Hatton and Gee 1984; Matolcsy 1975; Johal et al. 1994; Macleod 1986). It is important to note that, although differences in pulp properties were observed between the samples tested in this study, they are perhaps minimal by comparison with the overall variability present in this species.

CONCLUSIONS

Silvicultural modification of balsam fir stands is clearly necessary to increase the size of the residual stems and to improve the overall wood volume production from a stand. However, very severe treatments, such as thinning to a residual stem count of only 1,500 per hectare, result in the production of increased levels of difficult to cook, and consequently poorer yielding, juvenile wood as shorter, finer fibers were observed. This may be due to an increase in the age of the juvenile:mature wood transition in the faster grown stems. Such shorter finer juvenile-like fibers exhibit improved sheet tensile strength and

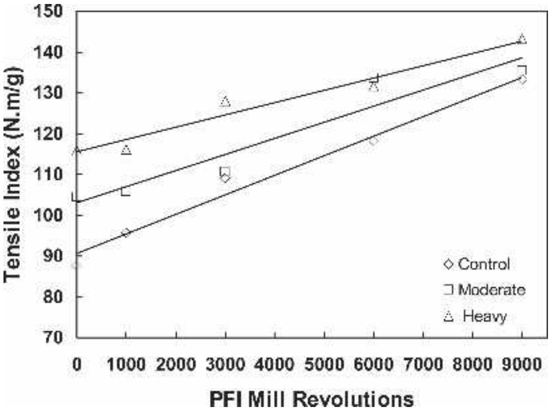

FIG. 5. Tensile index vs. PFI mill revolutions shows that the longer fibered control sample produces the strongest sheet and the shorter fibered, heavily precommercially thinned sample produces the weakest sheet.

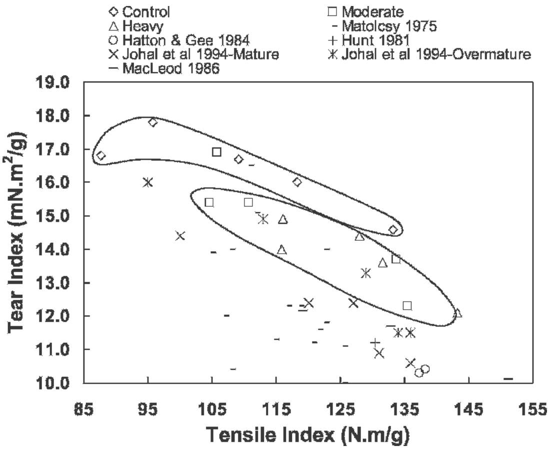

FIG. 6. The tear index vs. tensile index data are compared with literature data and indicate that balsam fir is extremely variable in these properties and that the samples evaluated in this study are perhaps exceptional for this species.

optical properties. The presence of compression wood in these stems may also be a contributing factor. From these data, final stocking levels of 1,500 stems per hectare or less are not recommended; hence an increase in the final crop age may mitigate any negative effects observed in the sawmill residual chip samples obtained from these 35-year-old stems.

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