Evaluation of various mechanical pulping processes for mature and juvenile loblolly pine in lightweight coated paper

ZHIRUN YUAN, CYRIL HEITNER, KEITH MILES, INGUNN OMHOLT, PETER MCGARRY, AND TOM BROWNE

ABSTRACT: Although loblolly pine (*Pinus taeda*) is less costly than northern softwoods, loblolly pine mechanical pulps tend to be of poor quality and are mainly used in low-value grades such as newsprint. We evaluated various mechanical pulping processes for mature and juvenile loblolly pine and their potential for use in value-added grades, especially in lightweight coated (LWC) paper. Results for black spruce were also included for comparison purposes.

Pilot plant results have shown that loblolly pine is inferior to spruce in terms of sheet density, brightness ceiling, and long fiber coarseness. To some extent, the quality disadvantages of pine pulps could be offset by proper chemical pre-treatment, high specific-energy application, or both, in the pulping process. With proper chemical pretreatment or refining, all the loblolly pine mechanical pulps should have adequate strength and light-scattering ability for LWC and supercalendered grades, compared with the general requirements reported in the literature. However, paper containing pine mechanical pulp is rougher on the surface, less dense, and has higher air permeability than the paper with spruce mechanical pulp. Therefore, proper papermaking strategies, such as precalendering, are essential to reduce sheet surface roughness and pore size before coating. This was confirmed by a LWC dynamic sheet former (DSF) sheet study that used three selected loblolly pine mechanical pulps.

Application: With proper strategies in chip pretreatment, refining, and the papermaking process, mechanical pulps from mature and juvenile loblolly pine can be used in value-added grades such as lightweight coated paper.

Loblolly pine (*Pinus taeda*) is one of the most common southern pine species used in pulp and paper manufacture. Its fast growth rates and suitability for plantation harvesting result in lower wood costs compared with northern softwoods such as black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*)[1]. However, **Table I** shows that mature loblolly pine has relatively larger fiber diameter, thicker fiber wall, and higher extractives content than spruce and balsam fir, which are the preferred softwood species for papermaking [1, 2]. Because of their characteristics, mature loblolly pine fibers are coarser and more rigid and require greater chemical or mechanical treatments to develop pulp properties and to collapse the pine tracheids and expose sufficient fiber wall surface for bonding. While spruce and balsam fir are normally used in high-value papers, loblolly pine is mainly used for low-value grades such as newsprint.

The fiber diameter and wall thickness of juvenile loblolly pine, however, are reported to be comparable to those of mature spruce [2]. Due to its short fibers, the low strength of juvenile thermomechanical pulp (TMP) may require more reinforcing pulp in certain paper grades [4]. The use of juvenile pine has increased during the past decade at most southern pine paper mills, and a higher sensitivity to refining was observed [5, 6].

Janknecht et al. [1] compared the properties of residential mixed paper (RMP), TMP, chemithermomechanical (CTMP),

	Black spruce	Balsam fir	Loblolly pine
Density, kg/m³	406	320	430
Fiber length, mm	3.5	3.5	3.6
Fiber diameter, µm	25–30	30–35	35–45
Fiber wall thickness, µm	2.2	2.5	3.5
EtOH-Benz extractives, %	2.2	2.5	3.2–5.4

I. Typical fiber characteristics and extractives content of some mature softwoods [1-3]. The densities are the measured data for the species used in this study.

and semi-chemithermomechanical (SCMP) pulps from loblolly pine. Compared with RMP, pre-steaming of wood chips in TMP produced a pulp with higher strength properties but at the expense of 10%–15% more refining energy. Using sulfite in the CTMP process further increased pulp strength, but again required 10%–15% more energy to reach a given freeness. CTMP had lower shives content, higher fiber flexibility, and a lower light-scattering coefficient than TMP. Due to higher temperatures in the refining process, the TMP and CTMP pulps are difficult to bleach to high brightness. The use of these pine pulps was studied for newsprint but not high-value grades.

The alkaline peroxide mechanical pulps (APMP), developed in the early 1990s, have interesting pulp properties for many paper grades [7-10]. Alkaline peroxide treatment of wood chips softens the lignin and hemicellulose, resulting in easier fiber separation during refining. Also, the oxidation and hydrolysis of lignin and hemicellulose by alkaline peroxide result in increased carboxylate groups and consequently increased interfiber bonding. The peroxide in the refiner minimizes the thermal or alkaline darkening, making it possible to reach high brightness [11]. Therefore, there is potential to use the APMP process for loblolly pine, in order to better develop fiber properties, obtain high brightness, and possibly decrease refining energy. However, to date, there are no published data available on APMP of loblolly pine.

Refining intensity is defined as the specific energy delivered per bar impact; at a given consistency it is proportional to the square of the rotational speed. Fiber development depends upon the material's ability to absorb this energy at impact stresses below the point of fiber cutting. For spruce, when higher quality is needed, the application of the additional energy could be facilitated by reducing the refining intensity [12, 13]. For rigid and coarse loblolly pine, the structure of the fibers themselves or other factors may limit the amount of deformation needed to control refining stress at conventional levels of refining intensity. Therefore, there is potential to improve pine TMP quality by lowering the refining intensity in the post-primary refiners.

We undertook a project to evaluate various mechanical pulping processes for mature and juvenile loblolly pine and the potential of using these pine pulps in value-added grades, especially in LWC. We included results of black spruce included for comparison purposes. Our report summarizes the results and implications; detailed data are presented elsewhere [14-17].

EXPERIMENTAL

Wood

We obtained mature and juvenile loblolly pine chips from a mill in Louisiana, USA. Juvenile pines were obtained from thinning and black spruce chips were obtained from an eastern Canadian mill. The chips were screened at Paprican's pilot plant before processing.

Pulping processes for mature and juvenile loblolly pine

To evaluate various mechanical pulping processes for loblolly pine, we made mechanical pulps from the same batch of chips. Pilot trials were done at FPInnovations-Paprican.

Process	Mat. pine BTMP	Mat. pine L-BTMP	Juv. pine BTMP	Mat. Pine APMP	Juv. pine APMP	Mat. pine BCTMP	Juv. pine BCTMP	Spruce BTMP	General pulp requirements for LWC and SC Grades [24]	
									SGW	TMP
Impregnation	--	--	--	Two stages	Two stages	One stage	One stage	--	--	--
Refining	Pres.+ atm.	Pres. + atm	Pres.+ atm.	Two-stage atm.	Two-stage atm.	Pres. + atm.	Pres. + atm.	Pres. + atm.		Pres. + atm.
Bleaching:										
Peroxide, %	3.5	3.5	3.5	2.5	2.0	3.4	2.7	2.0		
Caustic, %	3.5	3.5	3.5	2.3	2.3	2.7	3.0	1.2		
ISO brightness, %	71.1	71.0	71.2	74.1	72.6	70.4	71.4	71.6		
Specific energy, kWh/t	4270	5519	3521	3010	3050	3700	3600	3784	--	--
Density, kg/m3	350	380	353	366	358	360	340	420	450-500	450-500
Tensile index, N·m/g	38.6	40.7	29.4	36.9	35.9	39.3	41.7	50.1	>40	>50
Tear Index, mN·m2/g	6.8	7.3	4.3	5.1	5.0	6.2	6.1	7.0	>3.5	>6.5
Scatt. Coeff., m2/kg	56.8	55.3	54.4	49.4	47.1	56.8	56.7	56.1	>70	>58
Gurley air resis., s/100mL	105	187	72	60	116	120	109	185		
Shives, %	0.13	0.87	0.18	0.01	0.01	0.16	0.12	0.12	<0.05	<0.05
Bauer McNett R14 coarse fibe fraction, %	7.2	17.8	1.1	0.9	0.2	4.2	3.1	7.5	<1.0	<3.0
Bauer McNett P14/R28 long fiber fraction, %	19.6	19.6	12.2	12.9	13.8	17.6	15.9	18	10-15	22-27
Bauer McNett P200 fines fraction, %	34.7	30.5	33.9	35.5	32.8	34.9	35.3	35	>36	>28
Kajaani fiber length Lw, mm	1.43	1.55	1.04	1.26	0.97	1.37	1.25	1.45		
FQA P14/R28 coarseness, mg/m	0.315	0.295	0.298	0.288	0.280	0.284	0.302	0.205		
FQA P28/R48 coarseness, mg/m	0.262	0.244	0.237	0.233	0.230	0.227	0.240	0.175		
Max. bright., ISO	76.6	--	--	80.1	81.1	80.1	80.3	80.0		

II. Comparison of various loblolly pine mechanical pulps at a freeness of 50 mL.

Most of the results were based on a single pilot trial. After refining, the TMP and CTMP pulps were bleached by alkaline peroxide to a target ISO brightness of 70%. For APMP pulps, the hydrogen peroxide charge was also controlled to reach a brightness target of 70% (see **Table II** for peroxide and caustic charges) so the comparison can be made for all the pulps at the same brightness level. Also, alkaline peroxide bleaching conditions were optimized to determine the brightness ceiling of these pulps.

To produce reference TMP pulps, chips were preheated at 400 kPa gauge pressure for 20 s before the primary refining, unless stated otherwise. A pressurized Andritz 22-1CP single-disc refiner was used as the primary refiner with a D17C002 plate at a rotational speed of 1800 rpm. Second-stage refining was done with a 36-in. atmospheric variable speed Sprout-Bauer 400 double-disc refiner operated with a disc rotational speed of 1200 rpm. The plate pattern in this case was NiHard 36104. For low-intensity second-stage refining, we decreased the refiner speed to 900 rpm.

Pine CTMP preparation was identical, except that the chips were pre-steamed at atmospheric pressure for 15 min followed by impregnation with sodium sulfite, 16 g/L, $MgSO_4$, 0.5 g/L and DTPA, 10 g/L at pH 6, using an Andritz-Bauer model 6-in MSD press-impregnator. The impregnated chips were cooked at 130°C for 3 min in a vap-phase digester before refining.

To produce APMP, wood chips were atmospherically steamed for 15 min in a chip bin and then impregnated in two stages: first stage with 0.7% DTPA and 0.05% $MgSO_4$; second stage with 0.2% DTPA, 1.2% $NaSiO_3$, and 0.05% $MgSO_4$, as well as various charges of NaOH and H_2O_2. Chips were then retained for 60 min at a temperature up to 70°C in a covered drum. After retention, treated chips were refined in the pilot plant using the Sprout-Bauer 400 double-disc refiner at conventional intensity (disc speed 1200 rpm) in two stages.

Bleaching

Bleaching of all TMP and CTMP pulps was preceded by chelation with 0.2% DTPA at 60°C for 1 h. Pulps were bleached to a target ISO brightness of 70% through use of designed experiments optimized for brightness with varying peroxide and caustic charge while temperature and time where held steady at 75°C and 3 h, respectively. Ancillary chemicals were kept constant at 3% $NaSiO_3$, 0.2% DTPA, and 0.05% $MgSO_4$.

Base sheet and coating

The pulps were screened on a Somerville screen (0.15-mm slots) before sheet making. The Dynamic Sheet Former (DSF, made by Noram, Pointe-Claire, Quebec, Canada), which has been described in detail elsewhere [18-22], was used to make the base sheets for coating. To simulate a 56-g/m² LWC paper, a 39-g/m² DSF base sheet was made from a mixture of 40% northern bleached softwood kraft and 60% of the various mechanical pulps produced as described above in Paprican's pilot plant. The bleached softwood kraft was obtained from a mill in the eastern United States. For comparison, a 50/50 aspen/spruce commercial BTMP from the same mill was used to make control sheets. Clay filler was also added to the base sheet (6% ash in paper). A pulp consistency of 0.3% and a DSF wire speed of 1000 m/min were used to simulate commercial LWC paper. After forming, the sheets were pressed in a laboratory two-roll press and then dried in a drum dryer, as described previously [19]. If necessary, the base sheet was pre-calendered before coating by a hard-nip calender to a Parker Print Surf (PPS, S10) roughness of about 5–6 µm. Since the wire side of the DSF sheets was much rougher than the top side, the surface properties we reported are from the top side of the DSF sheets.

Chemicals	Parts
70% delaminated and 30% No. 1 clay pigment	100
Ethylated starch	5
Styrene-butadiene-acrylate latex	10
Calcium stearate lubricant	0.4
Ammonium zirconium carbonate insolubilizer	0.1
Total solids content of 60%, pH around 8.5	

III. Main components of the coating formulation.

The base sheet was pigment-coated to a target coat weight of 8.5 g/m² per side using a cylindrical laboratory coater (CLC 6000) at 800 m/min. The coated paper was soft-nip calendered, conditioned, and then subjected to various tests. **Table III** lists the main components of the coating formulation used in this study.

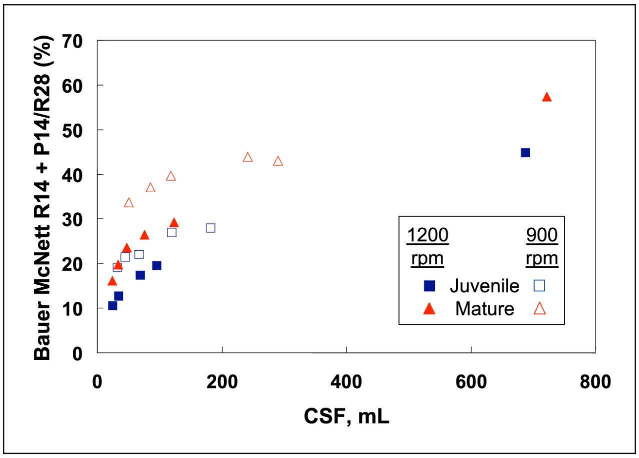
Tests and measurements

The pulps were screened on a Somerville screen (0.15-mm slots) before testing. The tests were done according to PAPTAC standard methods. Coating holdout and uniformity were measured by scanning electron microscopy (SEM) and image analysis on the cross-sections of coated papers, as described in detail by Allem [23].

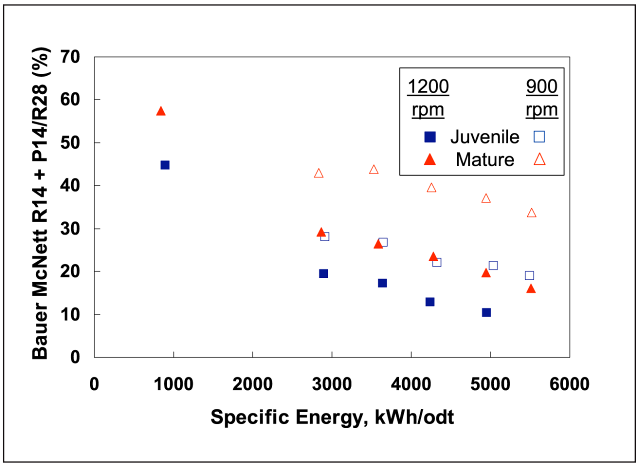
The ink demand test (PAPTAC Useful Method L.6U "Test printing of paper using a laboratory printability tester") was done on coated samples soft-nip calendered to a Parker Print Surf roughness (PPS-S10) of 1.3–1.5 µm, using a Prüfbau printability tester. The printing was performed at a pressure of 3.6 MPa and a speed of 3 m/s. The amount of ink transferred was calculated from the weight difference of the disk before and after printing. The prints were measured 12 h after printing for print density, print gloss, and print-through on the Elrepho Datacolor 2000.

The surface profile of the sheets was obtained from a non-contact optical profilometer (ALTISURF 500). Five lines 0.5 cm apart from each other were scanned per sample. The frequency analysis results were presented by plotting the roughness against wavelengths, which correspond to the scale of fiber width, micro-formation, and flocs.

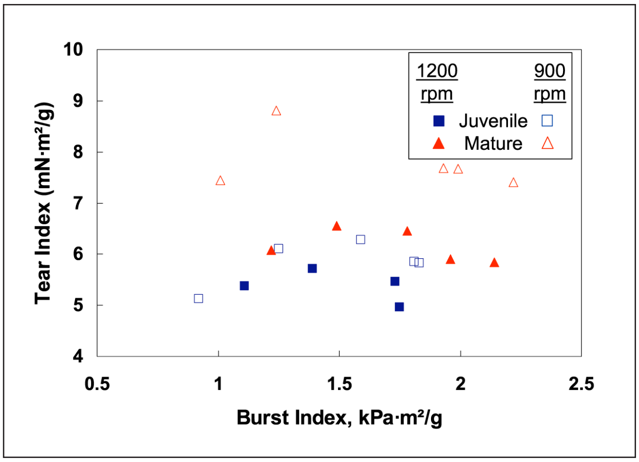
We measured pore size distribution and pore diameter of



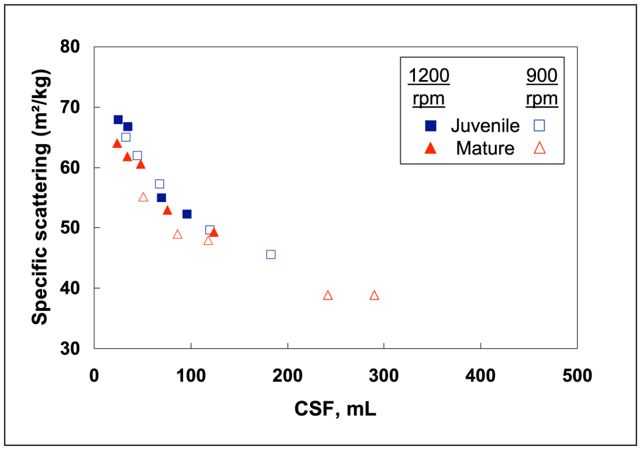
1. Low-intensity refining gave a higher long fiber content at a given freeness. The first stage sample is the point at the highest freeness level.



2. The long fiber content was higher after low-intensity refining compared at a given specific energy. The effect was larger for the mature than for the juvenile wood. The juvenile wood was refined at 250 kPa in the primary stage, which gave a better result than 400 kPa for this wood type. The first stage sample is shown as the point at the lowest energy level.



3. Low-intensity refining gave a higher tear index at a given burst index.



4. The light scattering coefficient at a given freeness was similar after low and conventional refining.

the base sheet by the mercury intrusion method using a Pore Sizer 9320 (Micromeritics).

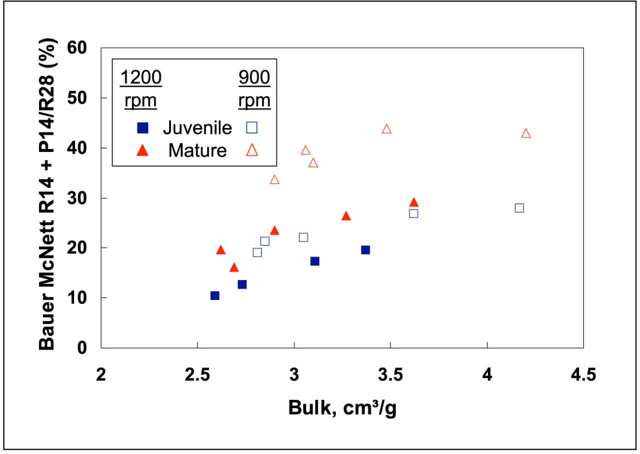
RESULTS AND DISCUSSIONS

High-value SC and LWC papers made from loblolly pine TMP and CTMP must compete with the same paper grades made from spruce/fir TMP or GWD. Table II lists the properties of pine mechanical pulps compared with spruce TMP at a similar brightness of 70% ISO. The values listed are interpolated or extrapolated to a common freeness of 50 mL. The table also lists general quality requirements for LWC and SC grades that were originally tabulated by Mokvist et al. [24].

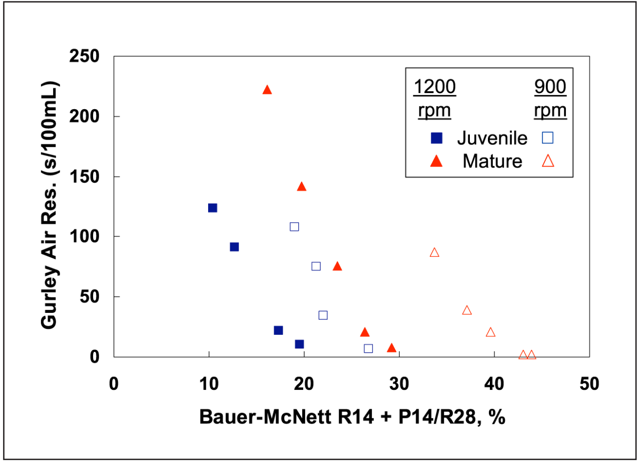
Pine TMP vs. spruce TMP

Compared with the spruce BTMP, mature pine BTMP required 10% more specific energy to reach the target freeness of 50 mL. Both pulps had similar Bauer-McNett fiber fractions and fiber length, but mature pine BTMP had much coarser long fibers than the spruce BTMP, as indicated by the FQA data on coarseness of P14/R28 and P28/R48 long fiber fractions. Due to its coarse fibers, mature pine BTMP had a lower density, tensile index, and air resistance than the spruce BTMP. It required more bleaching chemicals than spruce TMP to reach the target ISO brightness of 70%, and had an ISO brightness ceiling of 76.6% vs. 80% for spruce TMP. However, both pulps had similar tear, light-scattering coefficient, and shives contents.

For spruce, when higher quality is needed, the application of additional energy could be facilitated by reducing the refining intensity [12, 13]. For pine TMP, reducing the refining intensity in the secondary refiner by lowering the refiner speed from 1200 rpm to 900 rpm led to a better preservation of fiber length at a given freeness (**Fig. 1**) or specific energy (**Fig. 2**). As a result, the tear index was maintained at higher levels of burst index (**Fig. 3**). Light scattering was similar compared at the same freeness (**Fig. 4**). The same values of bulk and air resistance were reached at a higher long fiber



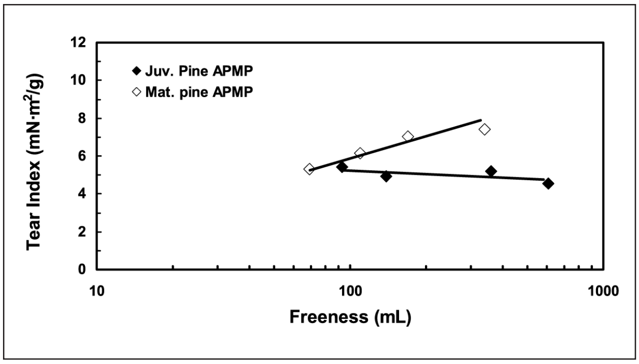
5. The bulk was reached at higher long-fiber content after low-intensity refining.



6. The air resistance was reached at higher long-fiber content after low-intensity refining.

content (**Figs. 5** and **6**, respectively), indicating that the fibers were well developed, flexible, and conformable. These observations were made for unbleached pine TMP. For bleached mature pine TMP at 70% ISO brightness, Table II confirmed that, despite its higher long fiber and lower fines contents, low-intensity BTMP (L-BTMP) had higher density, improved strength properties, and better air resistance than the control BTMP. A similar light-scattering coefficient was obtained. L-BTMP also had a higher fiber length and marginally lower long-fiber coarseness than control BTMP at the same freeness. The disadvantage of L-BTMP is that it required about 30% more energy to reach a freeness of 50 mL.

Juvenile pine TMP responds similarly to the decrease in refining speed as mature pine TMP, but the difference in properties between the two refining speeds is somewhat smaller than that of mature pine TMP (Figs. 2–6). Also, as shown in Table II, juvenile pine TMP required less energy to reach a given freeness compared with mature pine TMP. Juvenile pine BTMP had similar density, light scattering, and shives content, but significantly lower tensile, tear, air resistance, and fewer long fibers than mature pine BTMP. The coarseness of the ju-



7. Tear of juvenile pine APMP remains almost constant with increased refining energy or decreased freeness. At freeness lower than 100mL, the tear index of juvenile pine APMP was approaching that of mature pine APMP.

venile pine used in this study was between that of spruce and mature pine, but closer to the latter.

Pine APMP vs. pine and spruce TMP

Compared with the corresponding TMP process, mature and juvenile pine, when processed as APMP, required less (about 30% for mature and 14% for juvenile pines, respectively) specific energy to reach a given freeness, used fewer bleaching chemicals to obtain the target ISO brightness of 70%, and produced a pulp with much lower shives content (Table II). For mature loblolly pine, 80%+ brightness was obtained with APMP while the BTMP had a brightness ceiling of 76.6% ISO. The average fiber length of the APMP pulps and the coarseness of their long fibers were slightly lower than those of the corresponding BTMP pulps.

Compared with the TMP process, the APMP process had a larger impact on juvenile pine than on mature wood for pulp properties. It significantly increased tear and tensile index, but at the expense of light scattering, compared with the corresponding TMP process. It improved the strength properties of juvenile pine pulp to a level close to mature pine APMP. Therefore, the APMP process is more beneficial for juvenile loblolly pine in order to increase strength and reduce shives content, compared with the TMP process. Note the tear of juvenile pine APMP remains almost constant with increasing refining energy (**Fig. 7**); therefore, juvenile pine APMP could be refined to a low freeness to maximize the other strength properties and improve surface properties.

Pine CTMP vs. pine TMP

Table II shows that for mature loblolly pine, a light sulfonation treatment reduced specific energy (13% less than BTMP) to reach the target freeness of 50 mL; this is in contrast to the findings of Janknecht et al. [1]. The discrepancy in energy consumption could be explained by the effect of pH in impregnation. In this study, we controlled the impregnation pH at 6 using metabisulfite instead of sodium sulfite used in Janknecht's work which would have a pH of about 9 or higher, although the same sulfonate content, about 0.5%, was obtained in both

	CM-BTMP	L-BTMP	BCTMP	Juv.-BTMP
Canadian standard freeness, mL	28	47	47	25
Density, kg/m³	400	380	360	391
Specific scattering., m²/kg	78.3	55.3	56.8	59.0
Tensile index, N·m/g	39.3	40.6	39.3	37.4
Tear index, mN·m²/g	4.7	7.26	6.2	4.1
Burst index, kPa·m²/g	1.9	2.4	2.1	1.7
Gurley air resistance, s/100 mL	181	187	120	181

IV. Physical properties of the pulps used in this study.

cases. Therefore, impregnating pine chips at pH 6 reduced refining energy while impregnation at pH 9 increased energy consumption compared with TMP at a given freeness. This is consistent with the observed pH effect on black spruce CTMP reported by Argyropoulos and Heitner [25]. For both spruce and mature pine at a given freeness, compared with the corresponding TMP, sulfonation at pH 6 led to higher tensile and lower energy consumption; sulfonation at pH 9 also increased tensile but resulted in higher energy consumption.

Sulfonation also lifted the ISO brightness ceiling to more than 80%, which may be attributed to sulfonation as well as better removal of pitch and extractives during impregnation with sulfite before refining.

Similar to the APMP process, the CTMP process had a larger impact on juvenile pine than on mature pine by significantly increasing fiber length, tear, tensile, and air resistance. Compared with the corresponding TMP process, sulfonation also increased the light scattering coefficient of juvenile BCTMP. This is different from the APMP process, which decreased the light scattering when alkaline peroxide was applied on chips.

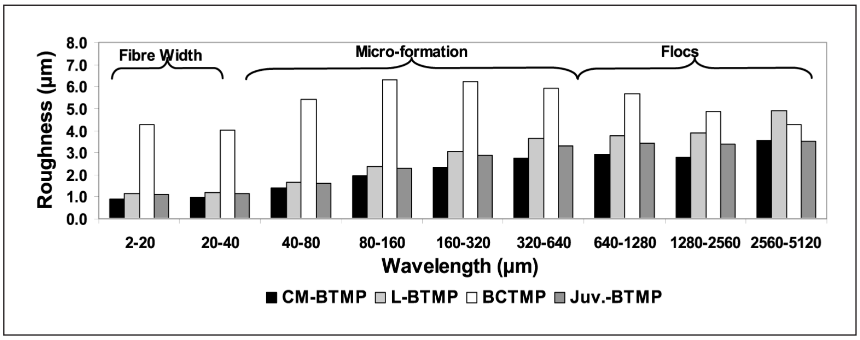
Comparison of pine pulp properties with typical values for LWC and SC

Table II compares the general quality requirements for LWC and SC grades that were originally tabulated by Mokvist et al. [24]. The density of all pine pulps are below 400 kg/m³, most likely due to their coarse and stiff fibers. In general, the coarseness of long fibers from pine pulps is higher than that of spruce BTMP. Reduction in refining intensity in the secondary refiner increased sheet density from 350 to 380 kg/m³, but its value was still below 400 kg/m³.

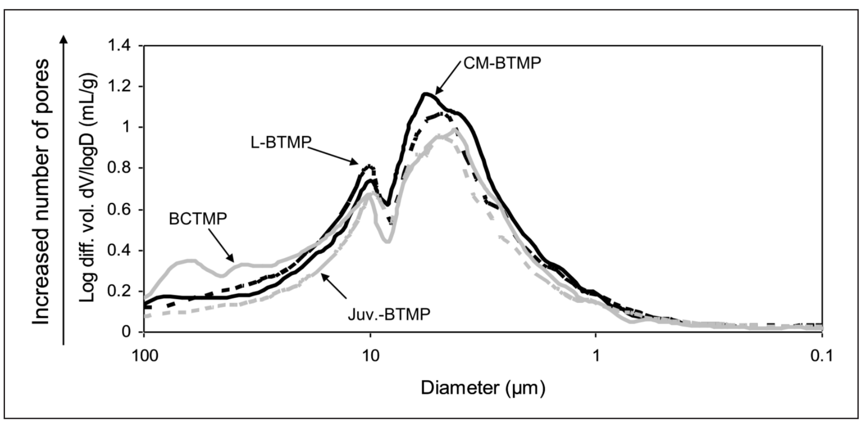
All pine pulps except juvenile pine BTMP have a tensile index close to that of spruce SGW but lower than spruce TMP. Mature pine BTMP and L-BTMP have a tear index higher or close to spruce BTMP while the tear index of other pine pulps sits between the typical value of SGW and TMP for LWC paper. The pine pulps except for APMP have a similar light-scattering coefficient as the spruce BTMP and should have adequate light scattering coefficient for making LWC and supercalendered (SC) papers.

The pine APMP have very low shives content, while the other pine pulps have shives content higher than 0.05%.

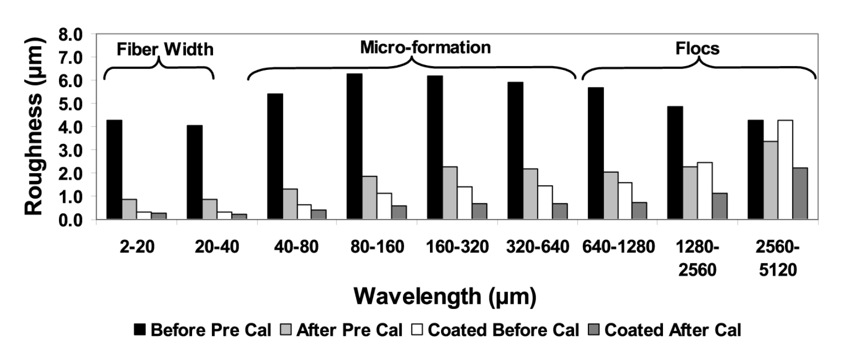
In general, all loblolly pine mechanical pulps have a lower density than spruce TMP and SGW, implying that paper containing these pine pulps will be less dense and consequently have lower air resistance, which may negatively affect coating holdout. Therefore, proper papermaking strategies, such as precalendering, should be used to reduce the sheet pore size and the air per-



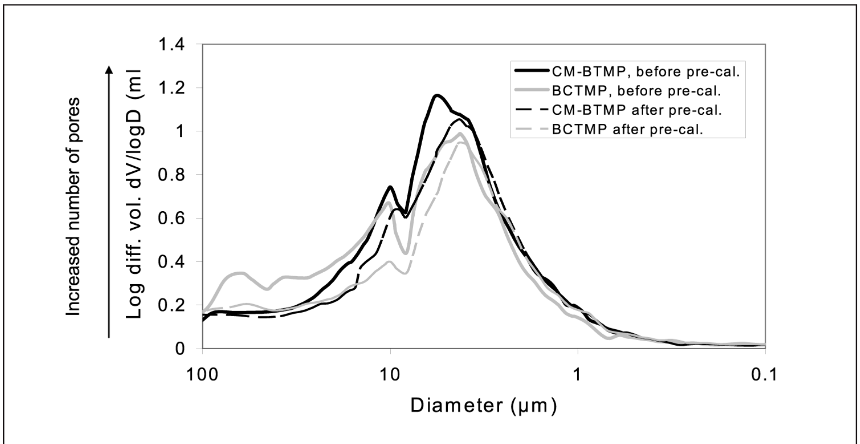
8. Surface profile of the base sheets before precalendering. Compared with the CM-BTMP-containing sheet, the base sheets with pine pulps had a higher surface roughness, especially for the sheet with BCTMP. CM-BTMP is the commercial spruce/aspen BTMP; Juv.-BTMP is the juvenile pine BTMP; L-BTMP represents low-intensity mature pine BTMP; and BCTMP refers to mature pine BCTMP.



9. Pore size distribution of the base sheets before precalendering. Large-sized pores: BCTMP.L-BTMP≈CM-BPTMP.Juv.-BTMP.



10. Precalendering significantly decreased the surface roughness of the base sheet with mature pine BCTMP.



11. Change in pore size distribution before and after precalendering for the base sheets with CM-BTMP had more large pores than the base sheet with mature pine BCTMP after precalendering.

DSF sheet	CM-BTMP	L-BTMP	BCTMP	Juv.-BTMP
Coating quality:				
Penetration, %	5.85	4.05	4.54	3.03
Coverage, %	87	91	91	92
Uniformity, COV, %	77.6	68.9	73.3	65.0
Coated paper:				
Bulk, cm^3/g	1.13	1.04	1.14	0.97
PPS roughness, µm	1.34	1.41	1.54	1.30
Air permeability, mL/min	4.6	4.2	3.8	3.7
ISO brightness, %	67.1	68.2	72.9	69.2
ISO opacity, %	89.4	87.0	84.6	87.4
Gloss 75, MD, %	40.2	41.2	39.3	43.5
Printability:				
Ink demand at a print density of 1.0, g/m^2	0.86	0.81	0.79	0.71
Print gloss at a print density of 1.0, %	70.8	73.2	74.2	76.7
Print-through at a print density of 1.0	0.05	0.07	0.08	0.08

V. Coating quality and printability of the LWC samples.

meability of the LWC base sheet in order to obtain a good coating holdout. This was confirmed by the LWC DSF sheet study, which is described in this report.

Loblolly pine mechanical pulps, except for juvenile BTMP, have adequate tensile strength for LWC and SC papers. The optimization of the tensile strength of the juvenile pine pulps can be achieved by further refining the pulp to a lower freeness or by the CTMP or APMP process. A juvenile pine pulp with a freeness of 25 mL and tensile index of 37.4 N·m/g was used in the later LWC sheet study.

Can loblolly pine mechanical pulps be used for LWC paper?

We further investigated the possibility of using loblolly pine mechanical pulps in LWC paper, focusing on base sheet structure and surface roughness as well as their effect on coating quality and printability. The bleached low-intensity mature loblolly pine thermomechanical pulp (L-BTMP), bleached mature pine chemithermomechanical pulp (BCTMP), and bleached juvenile pine thermomechanical pulp (Juv.-BTMP) were combined with kraft pulps and clay fillers to make LWC base sheets with a DSF. **Table IV** lists the physical properties of the pulps used in this study. The base sheet properties, coating, and printability were compared to a control sheet using a commercial spruce/aspen BTMP (CM-BTMP) obtained from a mill in the eastern United States.

Results showed that it is possible to use loblolly pine mechanical pulps in LWC furnish, but precalendering is the key to reducing base sheet porosity and surface roughness in order to obtain good coating holdout and uniform coverage. Compared with the control sheet using a commercial spruce/aspen BTMP, base sheets with pine pulps had higher surface roughness (**Fig. 8**) and porosity (**Fig. 9**) before precalendering. Precalendering is essential for decreasing the roughness and pore size of the base sheets containing pine pulps, as illustrated in **Figs. 10** and **11** for the sheet with mature pine BCTMP.

The base sheet with L-BTMP was smoother than the one with BCTMP (Fig. 8) although L-BTMP had more long fibers than BCTMP (Table II). This further confirmed that long fibers of L-BTMP are more conformable and better developed than control BCTMP.

Table V shows that, overall, all sheets containing the pine mechanical pulps selected for the LWC study had acceptable coating holdout, uniformity, and printability. Low-freeness juvenile BTMP in LWC paper resulted in the best coating quality (coating coverage and uniformity) among the three pine pulps. All four-coated sheets had similar properties except brightness and opacity. The difference in opacity is clearly related to the difference in brightness.

SUMMARY AND CONCLUSIONS

We evaluated various mechanical pulping processes for mature and juvenile loblolly pine. Pilot plant results have shown that:

1. Compared with spruce BTMP, mature loblolly pine BTMP required more specific energy at a given freeness, had similar tear and light-scattering coefficients but lower density, tensile index, and air resistance due to its thick-walled fibers. It also required more bleaching chemicals than spruce TMP to reach the target brightness of 70% ISO, and had a brightness ceiling of 76.6% ISO versus 80%+ for spruce TMP.
2. For mature loblolly pine, APMP and CTMP with sulfonation at pH 6 reduced refining energy to reach a given freeness and increased ISO brightness ceiling to over 80%, but had a marginal effect on strength properties compared with the TMP process. Impregnating pine chips at pH 6 reduced refining energy while impregnation at pH 9 increased energy consumption, compared with TMP at a given freeness.
3. APMP and CTMP with sulfonation at pH 6 had a greater impact on juvenile loblolly pine than on mature wood, with significant improvements in pulp strength and air resistance.
4. Reducing the refining intensity in the secondary refining stage provided mature loblolly pine with more well-developed and conformable long fibers at the same freeness or bulk. The light-scattering coefficient was unaffected.
5. With proper chemical pre-treatment or refining, all loblolly pine mechanical pulps should have adequate strength and light scattering for LWC and SC grades, compared with the general requirements reported in the literature. However, paper containing pine mechanical pulp is rougher on surface, less dense, and has higher air permeability than paper with spruce mechanical pulp. Therefore, proper papermaking strategies, such as precalendering, are essential to reduce sheet surface roughness and pore size before coating. This was later confirmed by the LWC DSF sheet study using three selected loblolly pine pulps.
6. Juvenile loblolly pine is more sensitive to refining and requires a lower refining energy to reach the same freeness. Juvenile pine BTMP had similar density, light scattering, and shives content, but significantly lower tensile, tear, air resistance, and fewer long fibers than mature pine BTMP. The improvement in tensile strength of the juvenile pine pulps can be achieved by further refining the pulp to a lower freeness or by the CTMP or APMP process. Therefore, it is technically justified to segregate juvenile and mature wood and run them on separate production lines with refining optimized for the specific wood characteristics, especially for high-value-added grades. **TJ**

ACKNOWLEDGEMENTS

The authors thank Daniel Gilbert, Michael Hellstern, Jocelyn Mathieu, Mike Stacey, and Derek Dranfield for their excellent technical assistance; Tony Manfred, Maureen O'Neill, Sylvie St-Amour, and Josée Desmeules for various measurements on the LWC paper; and Reza Amiri for useful discussions and review of the manuscript.

LITERATURE CITED

1. Janknecht, S., Dessureault, S., Barbe, M.C., Comparison of loblolly pine mechanical and chemical pulping processes, pulp properties, process features and pulp production cost, *1990 TAPPI Pulping Conference Proceedings, vol. 2*, TAPPI PRESS, Atlanta, Georgia, USA, 1990, p. 695.
2. Harris, G., *TAPPI J.*, 76(6): 55(1993).
3. Koga, S. and Zhang, S.Y., *Wood and Fiber Sci.*, 34(1): 146(2002).
4. Jackson, M., The interaction of wood species and wood quality with TMP process: a review, *1998 TAPPI Pulping Conference Proceedings, vol. 1*, TAPPI PRESS, Atlanta, Georgia, USA, p. 455.
5. Rudie, A.W. and Sabourin, M., *J. Pulp & Pap. Sci.*, 29(9): 63(2002).
6. Sabourin, M.J. and Wiseman, N., Analysis of fiber comminution rates during high-intensity thermomechanical pulping of spruce and pine, *Appita 55th General Pulping Conference Proceedings*, Rotorua, New Zealand, 2002, 195–205.
7. Bohn, W.L. and Sferraza, M.J., Alkaline peroxide mechanical pulping: a revolution in high yield pulping, *1989 International Mechanical Pulping Conference Proceedings*, KCL, Helsinki, 1989, p. 184.
8. Gentile, V.M., Tschirner, U., Wilder, H.D., The Scott Paper alkaline peroxide high yield pulping process, *1991 International Mechanical Pulping Conference Proceedings*, TAPPI, Minneapolis, MN, USA 1991, p. 199.
9. Sabourin, M.J., Cort, J.B., Garvie, M., Belzile, Y., Malette Quebec Inc. starts up APMP mill for production of MFC and ground wood specialty paper grades, 1993 International Mechanical Pulping Conference Proceedings, vol. 2, PPI, Oslo, 1993, p. 1.
10. Xu, E.C., Wang S.-W., Liu B., Wang Y-Q, Li H-B., Shi L., et al., Alkaline peroxide mechanical pulping and its application for newsprint--a successful start-up of the APMP system at Yalujiang Paper Mill, *1997 International Mechanical Pulping Conference Proceedings*, SPCI, Sweden, 1997, p. 37.

11. Lindholm, C.-A. and Kurdin, J.A., in *Papermaking Science and Technology* (J. Sundholm, ed.), KCL & TAPPI, Helsinki, Finland, 1999, p. 223.

12. McDonald, D. and Miles, K., Chip refining at higher specific energy, Paprican Technical Report, *PPR 1537*, Paprican, Pointe Claire, 2001.

13. Miles, K., US Pat. No. US 6,336,602 B1, 2002.

14. Yuan, Z. and Heitner, C., Evaluation of loblolly pine mechanical pulps in LWC paper, *2007 Coating and Graphic Arts Conference Proceedings*, TAPPI PRESS, Atlanta, Georgia, USA, 2007.

15. Yuan, Z., Heitner, C., McGarry, P., *TAPPI J.*, 5(7): 24(2006).

16. McGarry, P. and Heitner, C., Southern pine bleached chemithermomechanical pulp: a comparative evaluation of pulp properties, Paprican Technical Report, PRR1737, 2007.

17. Miles, K. and Omholt, I., Improving the strength properties of TMP, *2003 International Mechanical Pulping Conference Proceedings*, PAPTAC, Quebec, 2003, p. 179.

18. Sauret, G. and Lanvert, J., *Technique et Recherches Papetières*, 43(5): 65-70 (1965).

19. Amir, R., Silviers, G.D., Wood, J.R., J. Pulp & Paper Sci., 19(1): J26(1993).

20. Anczurowski, E., Jones, A.Y., Rutland, D.F., *Pulp Pap. Can.*, 84(12): T283(1983).

21. Bernard, E. and Bouchayer, H., *ATIP*, 4(29): 113(1975).

22. Charles, L.A. and Waterhouse, J.F., *J. Pulp & Paper Sci.*, 14(4): J59(1988).

23. Allem, R., *J. Pulp & Paper Sci.*, 24(10): 329(1998).

24. Mokvist, A., Jackson, M., Heikkurinen, A., Court, G., Li, Z., The production of SC and LWC pulps on large capacity conical disc refining systems, *2001 International Mechanical Pulping Conference Proceedings, vol. 2*, KCL, Helsinki, 2001, p. 239.

25. Argyropoulos, D.S. and Heitner, C., *J. Pulp & Pap. Sci.*, 17(5): J137(1991).

INSIGHTS FROM THE AUTHORS

Although the wood cost of loblolly pine (*Pinus taeda*) is lower than that of northern softwoods due to its fast growth rate and suitability for plantation harvesting, loblolly pine mechanical pulps tend to have poor quality and are mainly used in low-value grades such as newsprint. We evaluated various mechanical pulping processes for mature and juvenile loblolly pine as well as the potential of using these pine pulps in value-added grades, especially in lightweight coated (LWC) paper. We included results for black spruce for comparison purposes.

Our research is continuing. In this work, we focused on the comparison of various mechanical pulping processes for loblolly pine. In previous work we focused on the use of loblolly pine pulps in LWC paper. It required considerable experience to accurately simulate the mill pulping and papermaking conditions using the DSF machine; that was one of the most challenging aspects of this work.

We found that low-intensity refining or chemical pretreatments can significantly improve the mature pine pulp quality and make it possible to be used in high-value grades. Our next step is to develop strategies for commercialization of the technology. For southern U.S. mechanical pulp producers, the information this study provides may be used to produce high-quality mechanical pulps from loblolly pine for value-added papers like LWC and SC.

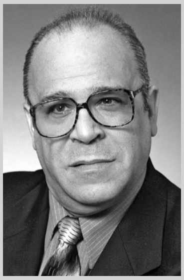
Yuan is a senior scientist, Miles and Omholt are principal scientists, and Browne is program manager of mechanical pulping, FP Innovations, Paprican Division, Pointe-Claire, Quebec, Canada. Heitner is retired from FP Innovations, Paprican Division. McGarry is a scientist, A&C American Chemicals Ltd., Montreal, Quebec, Canada; email Yuan at Zhirun.yuan@FPInnovations.ca.


Yuan


Miles


Omholt


Browne


Heitner


McGarry