Evaluation of the APMP process for mature and juvenile loblolly pine

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ABSTRACT: The wood cost of loblolly pine is lower than that of northern softwoods due to its fast growth rate and suitability for plantation harvesting. However, loblolly pine thermomechanical pulp (TMP) is difficult to bleach to high brightness. It also requires considerable refining energy to develop fibers, which limits its use mainly to low-value-added papers. We evaluated the potential for using the alkaline peroxide mechanical pulping (APMP) process for both mature and juvenile loblolly pine, with reference to the TMP process. Results of black spruce APMP were also used for comparison. In pilot plant trials, the APMP process, compared to the TMP process, required less specific refining energy and fewer bleaching chemicals to reach a given strength and brightness, and it produced a pulp with much lower shives content. For mature loblolly pine, 80%+ brightness was obtained with APMP, while the bleached TMP had a brightness ceiling of 76.6% ISO. The APMP process had more effect on juvenile pine than on mature wood with regard to pulp properties, and is therefore more beneficial for use with juvenile loblolly pine to maximize strength. In general, the APMP process is a technically viable method for dark and coarse fiber species such as loblolly pine because of the reduced amount of refining energy and bleaching chemicals required to reach a given strength and brightness.

Application: This research may help mills lower fiber costs for higher brightness papers.

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 to northern softwoods such as black spruce (*Picea mariana*) [1]. However, mature loblolly pine has a relatively larger diameter and thicker fiber wall, a higher percentage of darker latewood fibers, and higher resin content, in comparison with spruce and balsam fir, which are the preferred softwood species for papermaking [2]. Therefore, mature loblolly pine fibers are more coarse and rigid. They require greater chemical or mechanical treatments to collapse the pine tracheids and expose sufficient fiber wall for bonding to develop the pulp properties. For a given grade of TMP, higher specific energy is required to lower the pulp freeness of loblolly pine in southern U.S. mills, as compared to northern mills using spruce and balsam fir [3]. 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]. Because of its short fibers, the low strength of juvenile TMP may require more reinforcing pulp in certain paper grades [3]. Although the use of juvenile pine has increased during the last decade at most southern pine paper mills, a higher sensitivity to refining was observed [4,5].

Janknecht et al. [1] compared the properties of various mechanical pulps from loblolly pine. Comparing with refiner mechanical pulp (RMP), presteaming 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 chemithermomechanical pulp (CTMP) process further increased pulp strength, but again required 10–15% more energy to reach a given freeness. CTMP had lower shives, higher fiber flexibility, and lower light scattering coefficient than TMP. Due to higher temperature in the refining process, the TMP and CTMP pulps are difficult to bleach to a high brightness. With more severe chemical treatment, such as a high charge of sodium sulfite in the semichemimechanical pulp (SCMP) pulping process, even higher strength was obtained, but the light scattering coefficient was greatly reduced. Sabourin et al. [6] reported that increasing the refining intensity for juvenile loblolly pine can lower the specific energy requirement while maintaining pulp properties. Increasing the refining pressure at high intensity was also found to enhance pine TMP strength properties [7].

Alkaline peroxide mechanical pulps (APMPs), developed in the early 1990s, have interesting pulp properties for many paper grades [8-11]. Alkaline peroxide treatment of wood chips softens the lignin and hemicelluloses, resulting in easier fiber separation and fewer shives during refining. The oxidation and hydrolysis of lignin and hemicelluloses by alkaline peroxide also results 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 a high brightness

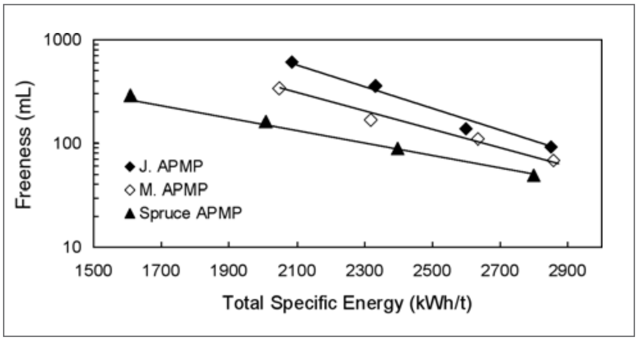

Figure 1. For a given freeness, juvenile loblolly pine APMP (J. APMP) required more refining energy than mature APMP (M. APMP), and loblolly pine APMPs consumed more energy than black spruce APMP.

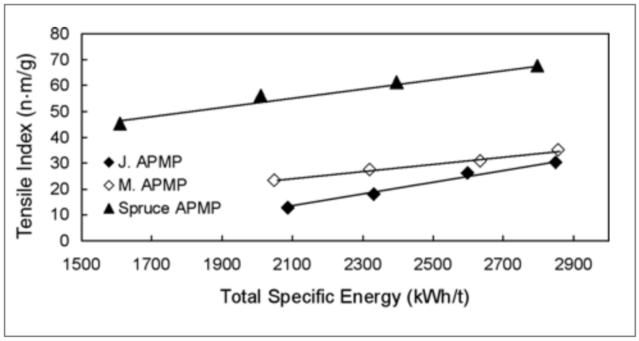

Figure 2. The tensile index of pulp refined at a given specific energy decreased in the order of spruce APMP >> mature loblolly pine APMP > juvenile loblolly pine.

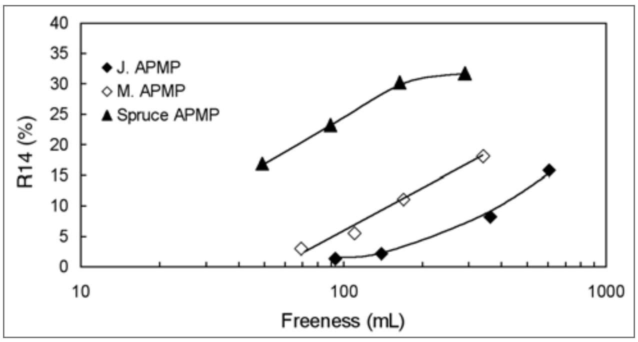

Figure 3. At the same freeness, spruce APMP had much higher R14 fraction than loblolly pine APMPs and juvenile APMP had the lowest R14 fraction among the three.

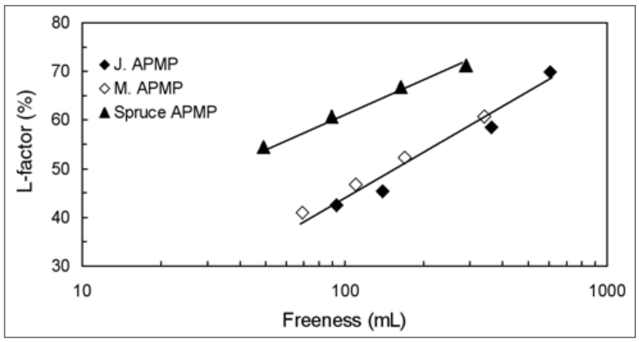

Figure 4. At the same freeness, spruce APMP had higher L-factor than pine APMPs, while the two pine APMPs had a similar L-factor.

[12]. Therefore, there is a potential to use the APMP process for loblolly pine to better develop fiber properties, reduce shives, obtain high brightness, and possibly decrease refining energy. However, there are no published data available on APMP of loblolly pine.

The purpose of this research was to investigate the potential of using the APMP process for both mature and juvenile loblolly pine, with reference to the TMP process. Results of black spruce APMP were also used for comparison. This report presents the resulting pulping characteristics and handsheet properties.

EXPERIMENTAL

Wood

Mature and juvenile loblolly pine chips were obtained from a southern U.S. mill located in Louisiana. Black spruce chips were obtained from an eastern Canadian mill. Chips were screened at Paprican's pilot plant before processing.

Chemical Treatment

To produce APMPs, wood chips were atmospherically steamed for 15 min in a chip bin and then impregnated in two stages using an Andritz-Bauer model 6-in. MSD press-impregnator. The volumetric compression ratio is 4:1. The chips were impregnated with 0.7% diethylenetriaminepentaacetic acid (DTPA) and 0.05% magnesium sulfate ($MgSO_4$) in the first stage, and 3% sodium hydroxide (NaOH), 0.2% DTPA, 1.2% sodium silicate ($NaSiO_3$), and 0.05% magnesium sulfate ($MgSO_4$), as well as various charges of hydrogen peroxide (H_2O_2) in the second stage. After the second-stage impregnation, chips were retained for 60 min at a temperature up to 70°C in a covered drum. To compensate for the temperature rise due to exothermal reactions occurring in the bleaching process, the temperature of the impregnating liquor was kept about 15°C lower than the desired retention temperature for each of the chemical charges used.

Refining

After retention, treated chips were refined in Paprican's pilot plant using an atmospheric, variable-speed Sprout-Bauer 400 double-disc refiner at conventional intensity (disc speed 1200 rpm) in two stages. The NiHard 36104 plate was used. We used four different specific energies to produce pulps at various freeness levels.

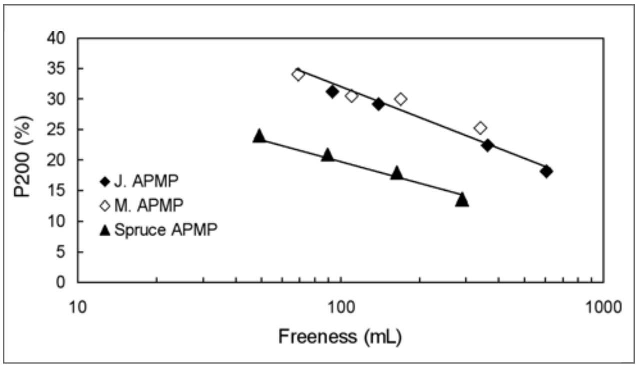

Figure 5. At the same freeness, spruce APMP had fewer fines than pine APMPs, while the two pine APMPs had a similar fines content.

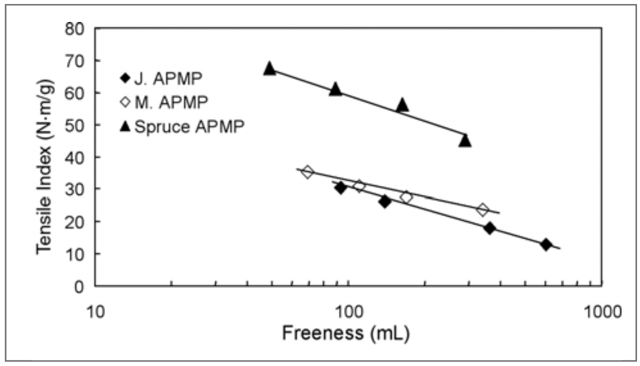

Figure 6. At the same freeness, spruce had a much higher tensile than the pine APMPs and the tensile of mature pine APMP was marginally higher than that of juvenile pine APMP.

Produced pulps were soured using sodium metabisulfite ($Na_2S_2O_7$) to pH 6, thickened using cotton cloth bag, and submitted for testing.

To produce reference TMP pulps, we used a pressurized Andritz 22-1CP single disc refiner as the primary refiner and the previously described atmospheric refiner as the secondary unit. Chips were preheated at 4 bars for 20 s before the primary refining. The pressurized refiner used a D17C002 plate at a rotational speed of 1800 rpm.

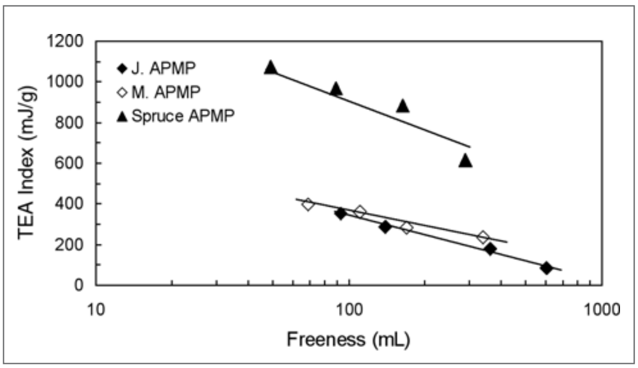

Figure 7. At the same freeness, spruce had a much higher TEA index than the pine APMPs and the TEA index of mature pine APMP was marginally higher than that of juvenile pine APMP.

Bleaching for TMP

The TMP pulp was chelated with 0.2% DTPA at 60°C for an hour. The pulp was washed and bleached with a one-stage alkaline peroxide process. The bleaching conditions were optimized for caustic and peroxide charges to reach the target brightness. The other bleaching chemicals were kept constant at 3% $NaSiO_3$, 0.2% DTPA, and 0.05% $MgSO_4$. The pulp was bleached at 70°C for 3 hours at a consistency of 20%.

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.

RESULTS AND DISCUSSION

Comparison of APMP from loblolly pine and black spruce

Figure 1 shows that juvenile loblolly pine APMP required more refining energy than did mature wood to reach a given freeness, and that mature and juvenile APMPs both consumed more energy than did black spruce APMP. The difference in energy-freeness relationships may be explained by the difference in wood characteristics of these species [13]. To reach a given freeness, pine consumes more specific energy, mainly because its fibers are coarser and stiffer those of spruce, and juvenile pine required more energy mainly because of lower initial fiber length compared to mature pine.

The tensile index of pulp refined at a given specific energy decreased in the order of spruce APMP having a much greater index than mature loblolly pine APMP, which had a somewhat greater index than juvenile loblolly pine APMP, as seen in Fig. 2. The spruce pulp shows the expected superiority of fiber development with increasing refining energy compared to that of loblolly pine pulps. Mature pine APMP had a slightly higher tensile index than did juvenile pine, though the difference became smaller at higher refining energies.

Figure 3 shows that at the same freeness, spruce APMP had much higher R14 fraction of long fibers than did loblolly pine APMPs, and the R14 fraction of juvenile pine APMP approached zero at a freeness below 100 mL. As expected, mature pine APMP had a higher R14 fraction than juvenile pine, although the L-factor of both pulps was similar at the same freeness (Fig. 4). Figure 4 and Fig. 5 show that spruce APMP had a higher L-factor, but lower fines than the pine APMP. At the same freeness, spruce APMP had a higher tensile index (Fig. 6) and tensile energy absorption

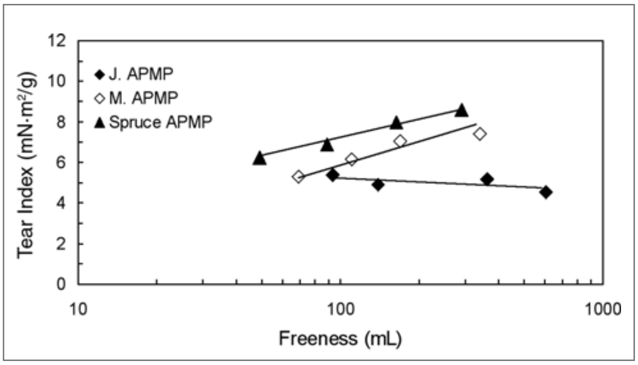

Figure 8. At the same freeness, spruce APMP had a higher tear index than pine APMPs. At a freeness lower than 100 mL, the tear index of juvenile pine APMP was approaching that of mature pine APMP.

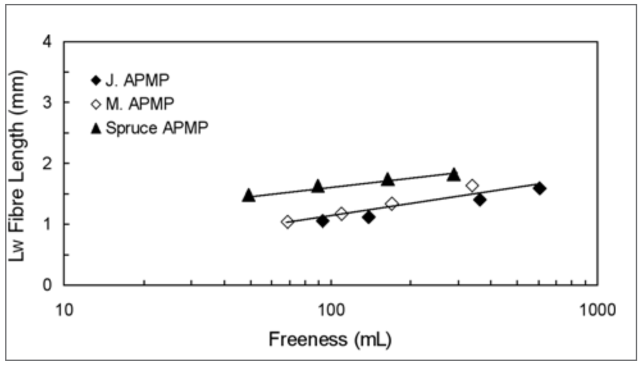

Figure 9. At the same freeness, juvenile pine APMP had a similar fiber length as that of mature pine APMP.

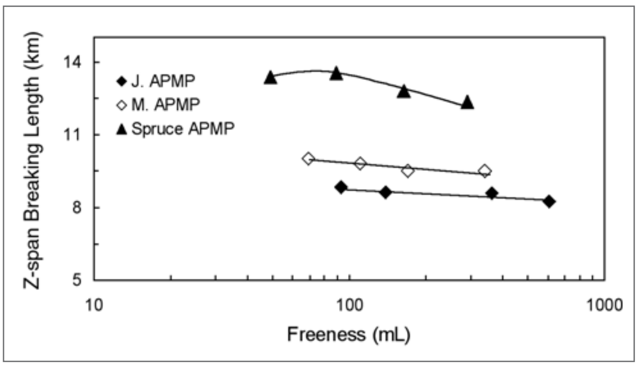

Figure 10. At the same freeness, juvenile pine APMP had a lower z-span breaking length than mature pine APMP.

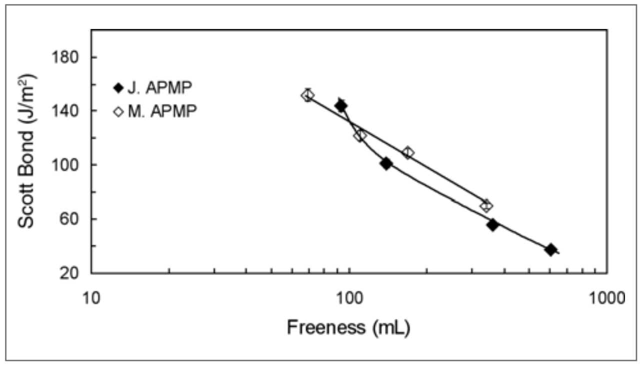

Figure 11. At a freeness higher than 100 mL, juvenile pine APMP had a lower bonding ability than mature APMP. However, at a freeness less than 100 mL, the fiber bonding of juvenile pine APMP was approaching or even higher than that of mature pine APMP.

(TEA; Fig. 7) than did pine APMPs. The APMP of mature pine had a marginally higher tensile index than that of juvenile pine, which is consistent with studies of radiata pine TMP [14,15] and loblolly pine CTMP [16].

Figure 8 shows that at the same freeness, the tear index of black spruce APMP was higher than that of mature and juvenile loblolly pine APMPs. Mature loblolly pine APMP had a similar trend below the black spruce APMP line. However, the tear index of juvenile APMP was not sensitive to refining. It remained almost unchanged with refining, although the R14 fraction of the pulp decreased rapidly at the same time (Fig. 3). At freeness lower than 100 mL, the tear index of APMP produced from juvenile wood approached that of APMP from mature wood. Tear index is mainly a function of fiber length, fiber strength, and fiber-fiber bonding. Compared with mature pine APMP, juvenile pine APMP had similar fiber length (Fig. 9), but lower fiber strength, as indicated by the z-span breaking length (Fig. 10). The fiber bonding ability of the juvenile pine APMP was also lower than that of mature pine at a freeness greater than 100 mL (Fig. 11). This explains why the juvenile pine APMP had a lower tear index at the beginning of the refining. However, the increase in fiber bonding with refining was very fast. At a freeness of 100 mL or lower, the fiber bonding of juvenile pulp approached or even exceeded that of mature pine APMP. As a result, the rapid increase in fiber bonding offset the small decrease in fiber length and fiber strength, and thus maintained tear strength. Another reason is that fibers produced from juvenile pine are by nature weaker than fibers produced from mature pine. Therefore, the fiber bonding had more of an effect on the tear index for pulp from juvenile pine. Apparently the bonding degree at which the maximum tear index occurs is higher for juvenile pine pulp.

Although pine APMPs had a much higher fines content than did spruce APMP, at the same freeness, pine APMPs had more bulk than spruce APMP (Fig. 12), which partly contributes to the lower strength properties of pine APMPs. This is most likely due to the more rigid and thick-walled pine fiber. At the same freeness, APMPs

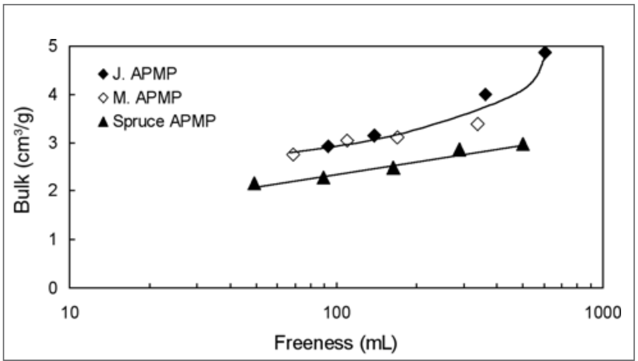

Figure 12. At the same freeness, juvenile and mature pine APMP had a similar bulk which is higher than that of spruce APMP.

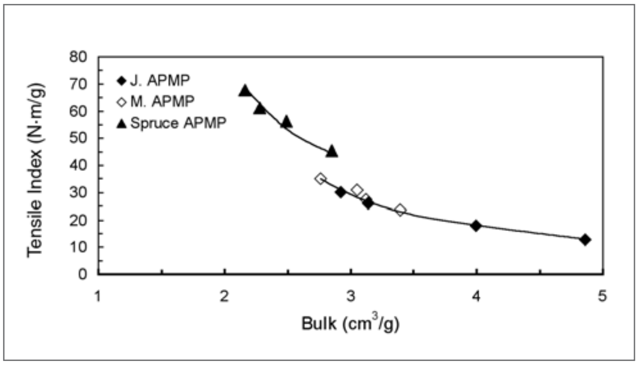

Figure 13. Pine APMPs had a lower tensile at the same bulk.

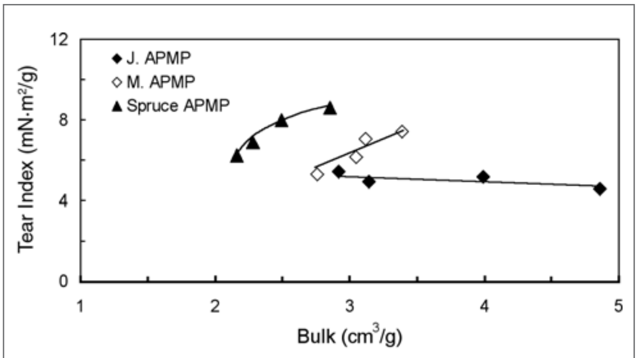

Figure 14. At the same bulk, spruce APMP had a higher tear index than pine APMPs, and the tear index of juvenile pine APMP remained almost constant at a bulk from 2.9 cm³/g to 4.8 cm³/g.

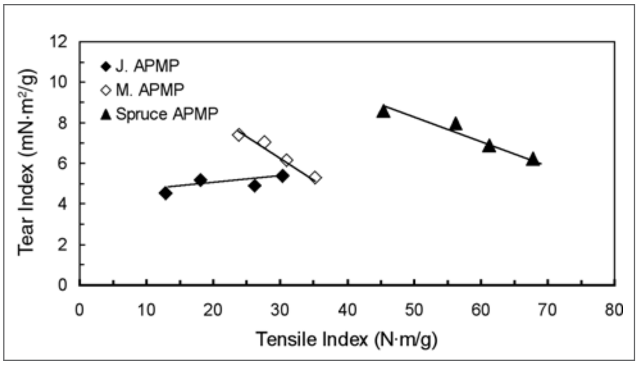

Figure 15. Spruce APMP is superior than pine APMPs in terms of both tensile and tear. Mature pine APMP had a higher tear than the juvenile one at the same tensile.

produced from mature and juvenile pine chips had similar bulk. Similar to the strength-freeness relationships, pine APMP had lower tensile index (Fig. 13) and tear index (Fig. 14) than did spruce APMP at the same bulk, and the tear index of juvenile pine APMP remained almost constant at a bulk of 2.9–4.8 cm^3/g. Figure 15 plots the tear index against tensile index for these three APMP pulps. Apparently pulps from black spruce are superior to those from pine in terms of tensile and tear strength. In contrast to the mature pine APMP, tear index of juvenile pine APMP increased slightly with increasing tensile strength. As the tensile index approaches 30 Nm/g, both pine pulps had a similar tear index. This implies that juvenile pine APMP should be refined to a relatively lower freeness than mature pine APMP to maximize its other strength properties, such as tensile index and burst index.

Figure 16 shows that at freeness below about 200 mL, loblolly pine APMPs had higher light scattering coefficient than did black spruce APMP. However, at freeness higher than 200 mL, spruce pulp had higher light scattering coefficient than loblolly pine pulps, although the latter had more fines than the spruce pulp, indicating that the fines quality from spruce and loblolly pine APMPs may be different. Fines produced from loblolly pines are most likely from fiber cutting, either because of the rigid fibers of mature loblolly pine or the young and weak fibers of the juvenile ones. Figure 17 plots the light scattering coefficient against the fines content of these three pulps. The slopes of pine APMPs were steeper than those of spruce APMP, indicating that fines from spruce APMP may participate more in bonding than scattering, compared with the rigid fines from pine APMPs. This is supported by Fig. 18, which shows that TEA of spruce APMP increased much faster than the light scattering coefficient. At the same light scattering coefficient, the TEA of black spruce APMP is much higher than that of pine pulps, and its light scattering coefficient only increased slightly with the increase of TEA, that is, the increase of refining energy. For pine APMPs, the light scattering coefficient increased at a faster rate than for spruce. Juvenile pulp had a marginally higher light scattering coefficient than did mature pulp at the same TEA.

Figure 19 plots the coarseness of long fiber fractions against freeness for the APMPs from pine and spruce. It shows that spruce APMP had the lowest coarseness among these three pulps. Juvenile pine used in this study had a higher coarseness than spruce pulp. It has coarseness closer to the mature pine than to the spruce.

Figure 20 shows that the shives content for these three pulps are all very low and follow the same trends as a function of freeness, especially at a low freeness range.

Loblolly pine APMP versus BTMP

To compare the APMP process with TMP process, TMPs were also made from the same batch of chips, as described in the Experimental section. After the refining, TMPs were bleached by alkaline peroxide to a target ISO brightness of 70% so that the pulps could be compared at the same brightness level.

Figure 21 is the Bauer McNett fiber classification results for the APMP and BTMPs, interpolated at a freeness of 100 mL. In general, pulps from mature pine had more long fibers, but fewer middle fractions, than the corresponding pulp from juvenile wood. However, the fines content was similar, all close to or slightly above 30%. For mature pine, BTMP had more long fibers, but fewer middle fractions than APMPs. For juvenile pine, APMPs had slightly higher long fiber fractions than BTMPs.

Figure 22 compares the specific energy required to reach the same tensile index. Table I compares the pulp properties and specific energy results for both processes, interpolated at a freeness of 100 mL. For mature loblolly pine, alkaline peroxide pretreatment on chips in the APMP process reduced energy consumption to either a given freeness or tensile index, compared with the TMP

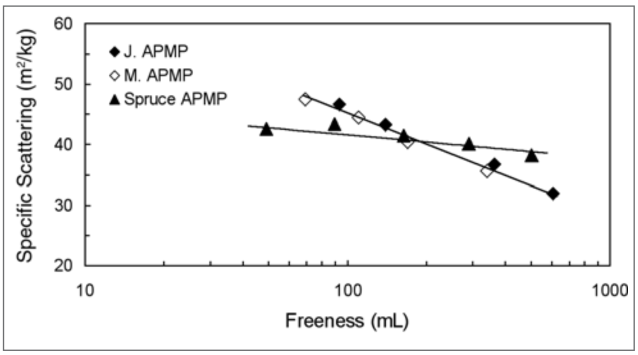

Figure 16. At a freeness below about 200 mL, loblolly pine APMPs had higher light scattering coefficient than black spruce. However, at a freeness higher than 200 mL, spruce pulp had higher light scattering coefficient than loblolly pine pulps although the latter had more fines than the spruce pulp.

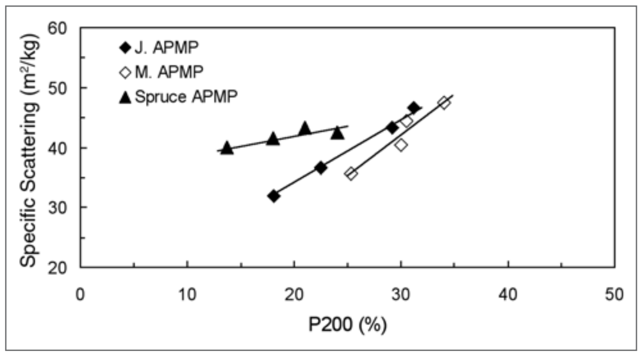

Figure 17. The slopes of pine APMP were steeper than those of spruce APMP, indicating that fines from spruce APMP may participate more in bonding than scattering, compared with the rigid fines from pine APMPs.

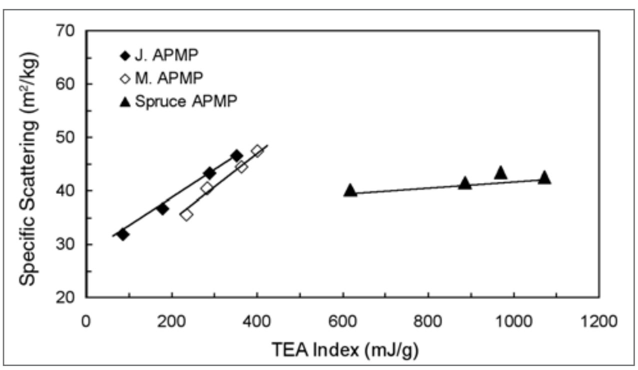

Figure 18. TEA index of spruce APMP increased much faster than light scattering coefficient compared with the pine APMPs. At the same light scattering coefficient, the TEA of black spruce APMP is much higher than that of pine pulps.

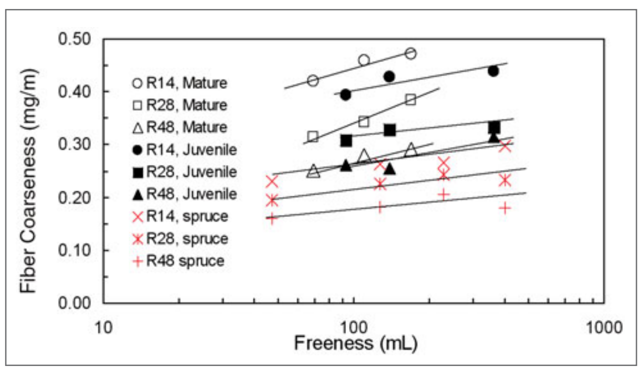

Figure 19. Spruce APMP had the lowest coarseness among three pulps. Juvenile pine used in this study had a higher coarseness than spruce. It has coarseness closer to the mature pine than to the spruce.

	Juvenile		Mature	
Process	**BTMP**	**APMP**	**BTMP**	**APMP**
Spec. energy, kWh/ton	2610	2845	2928	2600
Bulk, cm^3/g	3.33	2.98	3.25	2.94
Tensile index, Nm/g	20.1	29.5	30.6	32.0
Tear index, $mN.m^2/g$	3.8	5.3	6.8	5.9
Burst index, $kPa.m^2/g$	0.88	1.33	1.63	1.55
TEA, mJ/g	220	340	375	360
Specific scattering, m^2/kg	47.8	45.2	49.2	45.0
Somerville shives, %	0.34	0.025	0.23	0.01

TABLE I. Comparison of BTMP and APMP of loblolly pines at a freeness of 100 mL.

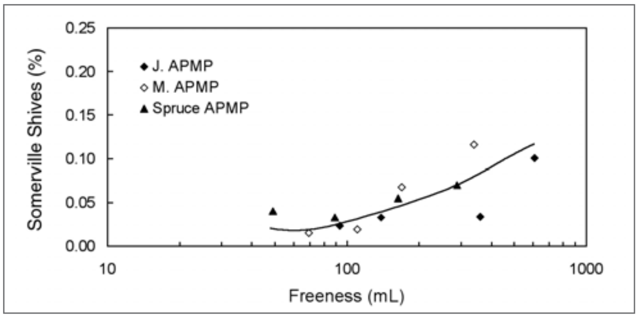

Figure 20. Low shives content were detected for these three pulps.

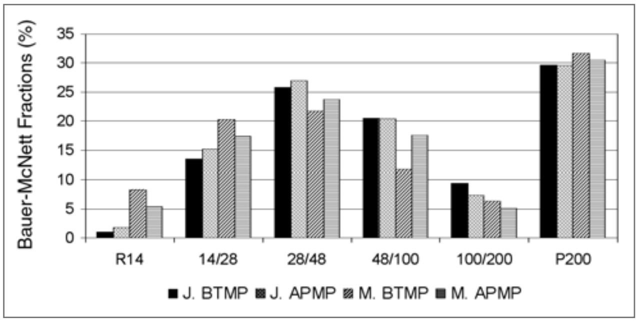

Figure 21. Bauer-McNett fractions of loblolly pine BTMPs and APMPs at a freeness of 100 mL. In general, pulps from mature pine had more long fibers but fewer middle fractions than the corresponding pulp from juvenile wood. However, the fines content was similar.

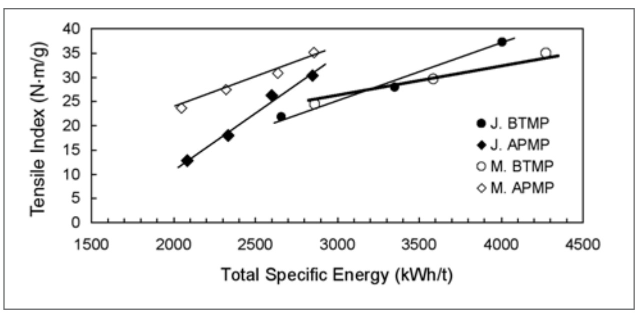

Figure 22. For both mature and juvenile pine, the APMP process required less specific energy than TMP to obtain the same tensile strength.

process. Table I also shows that at the same freeness, mature pine APMP had a slightly lower tear index and light scattering coefficient, but a slightly higher tensile index, as compared with BTMP.

Compared with the TMP process, juvenile pine APMP also consumed less specific energy to obtain a given tensile strength (Fig. 22). However, more specific energy was required for APMP to reach the same freeness of 100 mL. Table I also shows that for BTMP pulps, juvenile pine had much lower strength properties than mature wood at a similar bulk and freeness, which is in agreement with the results for radiata pine [14,15,17]. However, alkaline peroxide treatment in the juvenile pine APMP process significantly increased tear, tensile, burst, and TEA indexes, compared with the TMP process. It improved the properties of juvenile pulp to a level close to mature BTMP and APMP. As shown in Table I, the APMP process had more effect on juvenile pine than on mature pine for pulp properties. Therefore, the APMP process is more beneficial for juvenile loblolly pine to increase strength properties.

In general, APMP process required less refining specific energy to reach a given strength. At the same freeness, APMP pulps had a lower bulk, slightly lower light scattering coefficient, and much lower shive content, as compared with the corresponding TMP process.

Bleaching response of loblolly pine APMP and TMP

Pulps lose brightness due to thermal darkening in the TMP refiner. Some of the darkening reactions may be irreversible, limiting the maximum brightness achievable in the following bleaching process. One way to minimize darkening is to apply hydrogen peroxide at the pretreatment stage, together with alkali, as in the APMP process. Table II summarizes the bleaching chemicals used and the brightness obtained for TMP and APMP produced from mature and juvenile wood. TMP was bleached with one-stage alkaline peroxide under optimized bleaching conditions, while the APMP chemical charges have not yet been optimized. The other bleaching conditions were described in the Experimental section.

As shown in Table II, APMPs required less peroxide to reach a target ISO brightness of 70%+. APMP of mature pine with 80% brightness was obtained with 4.5% peroxide, while TMP of mature wood had a brightness ceiling of 76.6%.

SUMMARY AND CONCLUSIONS

Pilot plant trials of mature and juvenile loblolly pine have shown:

Compared with the TMP process, the APMP process required less refining specific energy to reach a given strength, used fewer bleaching chemicals to obtain a target brightness, and produced a pulp with much lower shives content. For mature loblolly pine, 80%+ brightness was obtained with APMP, while the BTMP had a brightness ceiling of 76.6% ISO.

The APMP process had a greater effect on juvenile pine than on mature wood for pulp properties. It significantly increased tear, tensile, burst, and TEA indexes, compared with the TMP process. It improved the properties of juvenile pulp to a level close to those of mature BTMP and APMP. Therefore, the APMP process is more beneficial for use with juvenile loblolly pine to increase strength and reduce shives content.

Compared with black spruce APMP, loblolly pine APMPs required more specific energy to reach a given freeness or tensile index. At the same freeness, loblolly pine APMP had fewer long fibers and more fines, and consequently had lower strength, but a higher light scattering coefficient at a low freeness.

Compared with mature APMP, juvenile APMP required more specific energy to reach a given freeness or tensile index. At the same freeness, juvenile APMP had a lower tear index, but a similar bulk, TEA, tensile index, and light scattering coefficient. The tear index of juvenile pine APMP remains almost constant with increased refining energy; therefore, juvenile pine APMP could be refined to a low freeness to maximize the other strength properties. **TJ**

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Pulp	H_2O_2, %	NaOH, %	ISO Brightness, %
TMP, Juvenile	3.5	3.5	72.1
APMP, Juvenile	2.0	3.0	72.6
TMP, Mature	2.9	2.5	71.0
APMP, Mature	2.5	3.0	74.1
TMP, Mature	6.0	6.0	76.6
APMP, Mature	4.5	3.0	80.1

TABLE II. Bleaching response of TMP and APMP of loblolly pines

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INSIGHTS FROM THE AUTHORS

The wood cost of loblolly pine is lower than that of northern softwoods due to its fast growth rate and suitability for plantation harvesting. However, loblolly pine TMP is difficult to bleach to high brightness. It requires considerable refining energy to develop fibers, which limits its use mainly to low-value-added papers. Therefore, the potential of using the alkaline peroxide mechanical pulping (APMP) process for both mature and juvenile loblolly pine was evaluated.

There is a potential to use the APMP process for loblolly pine to better develop fiber properties, reduce shives, obtain high brightness, and possibly decrease refining energy. However, there are no published data available on APMP of loblolly pine.

The most difficult aspect of this study was to get the representative mature and juvenile wood chips. This was done with the help of a U.S. paper company.

We learned that the APMP process had a larger effect on juvenile pine than on mature wood with regard to pulp properties, and is therefore more beneficial for juvenile loblolly pine to maximize strength.

The APMP process, compared to the TMP process, required less specific refining energy and fewer bleaching chemicals to reach a given strength and brightness, and produced a pulp with much lower shives content. For mature loblolly pine, 80%+ brightness was obtained with APMP, while the bleached thermomechanical pulp had a brightness ceiling of 76.6% ISO. This creates an opportunity in some paper grades where southern pine can not be used or is too costly to produce.

Our next step is to test the APMPs of southern pine in some value-added mechanical papers.

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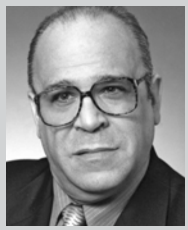
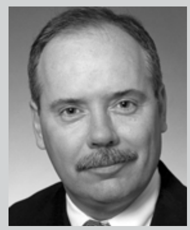


Heitner



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