OPTIMIZING LODGEPOLE PINE SUBMERCHANTABLE LOG THERMOMECHANICAL PULP

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ABSTRACT

To restore and maintain ecosystem health and function in the western interior of the United States, many small-diameter stems need to be removed from densely stocked stands. These stems are considered nonusable or underutilized (good, economical uses need to be developed). As of now, the most logical use for the small-diameter resource is pulp. In this study, thermomechanical pulps (TMP) were prepared and evaluated from lodgepole pine submerchantable logs, utilizing different preparation procedures to show that mechanical pulping is a viable option for utilizing this small-diameter resource. Compared with TMP prepared from sawmill residue chips, the unscreened submerchantable log TMP used less electrical energy, retained more of the original fiber length, but had slightly lower physical and optical properties. Wood handling and debarking costs of the submerchantable log resource might be higher because of the small diameters.

Keywords: Lodgepole pine, small diameter, mechanical pulping, thermomechanical pulping (TMP), pulp properties, paper properties.

INTRODUCTION

The focus of forest management on federal land has taken on a more ecological orientation during the past decade (USDA–USDI 1994, 1997; Iverson et al. 1996). Some common ecological concerns in the western United States are lack of diversity at the landscape level, a potential for large-scale disturbances such as insect infestations and fire, and the need for functional late-successional stand structures within watersheds where they are currently in deficit. The extreme fire losses of 2000 and 2002 emphasized the serious conditions existing in many forests. In some cases, active management is required to achieve desired conditions.

Landscape level manipulations can be expensive, and funding for these activities must compete with other priorities in federal and state budgets that may have nothing to do with forest management. Accordingly, whenever possible, government land managers attempt to use timber sale programs to fund ecological management activities. This more ecological forest management means that state and federal land managers will offer a different type of resource for sale than they would have under a program oriented more toward lumber production. This new resource is often smaller in diameter than the traditional resource (USDA–USDI 1994). Also, forest operations required to meet ecosystem objectives are often complex and specify equipment with which operators have relatively little experience. Oftentimes, the combination of the resource's small size and treatment complexity limits economic feasibility (Barbour et al. 1995; Spelter et al. 1996). Managers often find themselves in situations where the timber sales being offered fail to attract bidders and do not cover costs or meet the ecological objective.

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The USDA Forest Service has instituted a program to help public land managers understand the complexity and economic difficulty of integrating biological, ecological, silviculture, and social objectives. Complicating these objectives, most management activities must be self-supporting (Skog et al. 1995; Barbour and Skog 1997). This research is part of that program. Many of the trees removed under ecosystem management are small diameter; that is, less than 254 mm in diameter at breast height (dbh). Pulp is a possible use for this material.

Previous TMP research conducted on several small-diameter resources (Barbour and Skog 1997; Myers et al. 1997, 1999) found lodgepole pine submerchantable log (SML) pulping consumed less electricity during production but yielded low strength paper. Therefore, this study was undertaken to use different TMP procedures in an attempt to improve the properties of paper made from lodgepole pine SML. This study clarifies the characteristics of the resource that could add or detract from its value for TMP. Such information will help entrepreneurs or corporations make better bid decisions on marginal sales offered by public land managers. It will also help public land managers understand the economic viability of the sales they design and enable them to offer sales that are more attractive to potential bidders while still achieving the desired ecological objectives. It also helps identify research needs and opportunities to utilize this material.

EXPERIMENTAL

Raw material

Lodgepole pine submerchantable logs (SML) (*Pinus contorta* Dougl. ex Loud.) were obtained from the Colville National Forest (eastern Washington), had less than 89-mm end diameters, and were primarily tree tops. This small-diameter resource was not removed from young, vigorously growing stands with high juvenile wood content (Zobel and van Buijtenen 1989, pp. 82–100). It was from densely stocked stands, typically 70 or more years old, where crowded growing conditions limited diameter growth. Consequently, juvenile wood should not have been an issue. Lodgepole pine sawmill residue chips (SRC) were obtained from Vaagen Bros. Lumber (Colville, WA). All chips and logs were shipped to the USDA Forest Service, Forest Products Laboratory (FPL), in Madison, WI, for further processing.

Logs were hand-peeled at FPL to remove all bark and then chipped to 19 mm long in a four-knife commercial-size chipper. Log chips were screened to remove all particles greater than 38 mm and less than 6 mm long. Screened chips were thoroughly mixed in a large V-mixer, weighed into 4- or 5-kg samples, placed in polyethylene bags, and stored at 4°C until used for pulping. The screening, mixing, bagging, and storage procedures were repeated for the SRC.

In this study, SRC is the control representing raw material currently used for pulping; SML is the small-diameter resource.

TMP preparation

An Andritz Sprout Bauer (Muncy, PA) model 12-1CP 305-mm-diameter pressurized refiner, fitted with plate pattern D2B505, was used for fiberization and some pressurized refining. All chip batches were steamed for 10 to 20 min at 206.8 kPa before fiberization. Some fiberized SML and all fiberized SRC pulps were wet-screened through a 0.2- or 0.3-mm-slot flat screen. Screen accepts and rejects were refined separately in a Sprout-Waldron (Muncy, PA) model 105-A 305-mm-diameter atmospheric refiner, also fitted with plate pattern D2B505. A constant volume of shredded pulp was delivered to the refiner inlet by a constant-speed belt conveyor, with dilution water added to achieve approximately 20% refiner consistency. Multiple passes were necessary to reduce pulp Canadian Standard Freeness (CSF) to approximately 200 mL. Then accepts and rejects were combined. An additional pass was run on the combined pulp to reduce CSF to less than 100 mL. These pulps are designated as screened.

Some fiberized SML pulps were not screened and are designated as unscreened. Fiberized unscreened SML pulps were refined in the Sprout-Waldron refiner at atmospheric pressure or in the Andritz Sprout Bauer refiner at 206.8 kPa of steam pressure. A constant volume of shredded unscreened pulp was delivered to the atmospheric refiner inlet by a constant-speed belt conveyor as above or to the pressurized refiner disks by a constant-speed auger, with sufficient water added to both refiner cases to achieve approximately 20% refiner consistency. Multiple passes were needed to achieve CSF above and below 100 mL.

Latency was removed from the pulp after fiberization and each refining step by soaking the pulp in 90°C water for a minimum of 30 min, with occasional stirring. Four replicates were prepared for screened SRC and screened SML, three replicates for unscreened SML, and one for all-pressurized SML (unscreened). Pulp yield was not determined.

Energy consumed during fiberization and refining was measured using an Ohio Semitronic (Hilliard, OH) model WH30-11195 integrating watt-hour meter attached to the power supply of the 44.8-kW electric motor, measuring amperes, volts, and power factor. Energy consumption values for fiberizing and refining were reported as watt-hours per kilogram (oven-dry weight basis), with the idling energy subtracted.

Pulp samples were withdrawn above and below 100-mL CSF for pulp testing, handsheet preparation, and paper testing.

Pulp testing, handsheet formation, and paper testing

The CSF was measured according to TAPPI Test Method T227. Shive contents were determined with a Pulmac shive analyzer (Pulmac Instruments International, Montpelier, VT), using a disk with 0.10-mm slot openings. Average fiber length, fines content, and fiber coarseness were performed using a Kajaani (Norcross, GA) FS-100 analyzer. Handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T205. Burst and tear indexes were measured according to TAPPI Test Methods T403 and T414, respectively. Tensile breaking properties and paper smoothness were measured according to TAPPI Test Methods T494 and T538, respectively. Brightness, printing opacity, and light-scattering coefficient were measured with a Technidyne Corporation (New Albany, IN) Technibrite Model TB-1 diffuse brightness apparatus according to TAPPI Test Method T525.

Statistics

Each TMP was processed to two freeness levels—one greater than and one less than 100 mL CSF. A set of 10 handsheets was made and tested for each level. The individual test results were used to perform a Dunnett's multiple comparison procedure, which provided statistical significance at a 95% confidence interval. Mean, standard deviation, and coefficient of variation were computed for each property tested in a handsheet set. Mean values from the four replicates were combined and averaged to provide a value for each level greater and less than 100 CSF. These two values were interpolated to estimate a value for 100 CSF.

RESULTS AND DISCUSSION

Presentation of results

Instead of presenting data for all TMP evaluations, the values closest to 100-mL CSF are presented in Table 1 for the three SML and one SRC raw materials.

Comparisons between raw materials were accomplished by computing a percentage change from the controls (SRC) using values interpolated to 100-mL CSF. (Figs. 1 to 3). This provides a visual comparison to the traditional raw material (SRC). The results of the statistical analysis were added to Figs. 1 to 3.

Pulp preparation and properties

Refining unscreened pulp in the pressurized refiner was noticeably different than in the atmospheric refiner. Refining run times in the pressurized refiner were extremely short, whereas the run times were much longer in the atmospheric refiner. Refining consistencies were

TABLE 1. *Pulp and paper properties before interpolation to 100 mL Canadian Standard Freeness (CSF).*

	Pulp						Paper									
			Kajaani FS-100 analysis													
				Length weighted												
Input material[a]	Total energy (WH/od kg)	CSF (mL)	Shive content (%)	Fiber length (mm)	Fines content (%)	Coarseness (mg/m)	Apparent density (kg/m^3)	Burst index (kPa-m^2/g)	Tear index (mN-m^2/g)	Tensile index (N-m/g)	Stretch (%)	TEA[b] (J/m^2)	Smoothness (SU)	ISO brightness (%)	Printing opacity (%)	Scattering coefficient (m^2/kg)
All pressurized unscreened SML	1,334	205	0.68	0.81	7.36	0.243	383	0.49	1.85	15.1	1.00	6.85	303	37.6	98.9	45.5
Unscreened SML	1,577	128	0.24	0.81	7.55	0.215	434	0.66	2.08	19.4	1.17	10.16	235	36.2	99.0	45.6
	2,229	167	1.08	1.16	5.49	0.309	411	1.08	3.72	27.1	1.45	17.75	260	45.4	97.3	46.3
	2,748	97	0.24	1.15	5.59	0.269	479	1.56	3.91	35.0	1.63	25.50	129	44.9	98.3	52.5
	3,145	84	0.60	1.32	3.96	0.253	482	1.91	4.92	39.8	2.12	38.43	139	46.0	97.4	49.4
	2,535	165	0.75	1.43	3.91	0.366	438	1.48	5.04	30.6	1.61	22.36	216	45.8	97.1	47.2
	3,387	75	0.39	1.30	4.36	0.296	489	1.86	4.70	39.4	1.91	33.27	135	46.0	98.0	54.1
Screened SML	1,683	122	0.13	0.61	9.51	0.294	398	0.43	1.20	14.6	0.83	5.28	294	44.6	98.0	47.4
	1,980	71	0.01	0.60	9.78	0.293	449	0.67	1.62	20.9	1.06	9.96	209	44.8	98.2	49.0
	3,005	83	0.09	0.69	8.57	0.362	427	0.84	2.34	23.2	1.16	12.33	207	45.2	98.5	50.1
	3,225	54	0.04	0.75	7.78	0.262	461	1.07	2.56	29.8	1.34	18.15	150	45.0	98.4	50.4
	2,031	133	0.29	0.75	6.98	0.303	404	0.65	2.10	20.2	1.21	11.11	271	45.2	97.9	47.1
	2,415	73	0.12	0.76	7.14	0.234	445	0.89	2.30	25.1	1.22	14.01	190	45.2	98.4	49.6
	2,533	73	0.00	0.68	7.92	0.294	440	0.79	2.04	23.7	1.18	12.84	182	44.7	98.5	49.4
	2,759	51	0.02	0.71	7.57	0.281	465	1.00	2.38	28.7	1.27	16.56	156	44.1	98.4	48.8
Screened SRC	4,222	178	1.54	1.32	4.01	0.338	391	1.34	5.00	30.1	1.83	23.86	248	47.4	97.8	71.3
	4,935	108	0.79	1.17	4.55	0.394	458	1.38	4.33	32.3	1.78	26.64	182	46.1	99.0	82.8
	4,632	179	1.17	1.36	3.49	0.323	407	1.33	4.84	30.6	1.80	25.38	217	46.8	98.3	72.7
	5,243	66	0.59	1.15	4.81	0.353	481	1.74	4.66	37.8	1.85	32.27	139	45.6	98.9	78.4
	4,653	174	0.91	1.29	3.53	0.268	427	1.38	4.82	32.0	1.75	26.00	210	46.5	98.0	68.8
	5,375	97	0.47	1.15	4.65	0.344	464	1.48	4.33	33.2	1.77	26.87	149	45.5	98.7	76.6
	4,327	188	1.16	1.22	3.76	0.340	502	1.40	4.66	32.4	1.82	27.59	165	47.7	97.6	70.0
	5.007	112	0.70	1.16	4.50	0.313	461	1.40	4.47	31.9	1.85	27.31	197	46.6	98.5	78.4

[a] SML, submerchantable logs; SRC, sawmill residue chips

[b] TEA, tensile energy absorption.

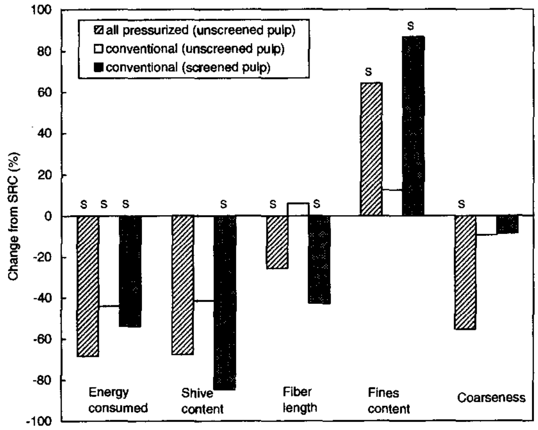

FIG. 1. Differences between lodgepole pine submerchantable logs and sawmill residue chips (SRC) (screened) thermomechanical pulps (S, statistical significance; all pressurized indicates pressurized fiberization and pressurized refining of the unscreened pulps, and conventional indicates pressurized fiberization and atmospheric refining of the screened or unscreened pulps).

calculated to be 20% in the pressurized refiner, which were nearly identical to refining consistencies in the atmospheric refiner.

Energy consumption for the SML resource was significantly lower than that for the SRC (Fig. 1), which is highly desirable for TMP preparation. Energy savings were greatest for the all-pressurized unscreened pulp and the least for conventional unscreened pulp. The very large differences between pressurized and atmospheric refining might be explained by pulp feed rates; atmospheric was approximately 3.6 times slower. Previous research with loblolly pine juvenile wood showed that a slower feed rate, which indicates a bulkier fiber, consumed more energy but yielded a higher quality fiber and better handsheet properties (Myers 2002).

There were some apparent and significant differences between fiber properties of SML and SRC resources (Fig. 1). There were also differences between the all-pressurized, conventional, screened pulp, and unscreened pulp SML. All three SML TMPs yielded pulps with lower shive content and lower coarseness than the SRC. Unfortunately, fiber length was shortened except with conventional unscreened SML, and more fines were produced with all three TMP procedures. Conventional TMP from unscreened SML appears to be a higher quality pulp than that from SRC because more of the original fiber length was retained, fewer fines were generated, and there was some reduction in shive content and fiber coarseness.

The other two TMP procedures used with SML reduced shive content and fiber coarseness more than screened SRC. The all-pressurized procedure was especially effective in reducing fiber coarseness, perhaps the result of higher temperatures and a very high fiber feed rate that created more fiber-on-fiber action. Unfortunately, both procedures shortened the fibers more and generated more fines.

Strength properties

Handsheet densities of all SML pulps were lower than SRC pulp (Fig. 2). All paper strength properties were lower (Fig. 2), which was anticipated because burst index, tensile index (Koran 1994), and tensile energy absorption (TEA) relate strongly to density. Tear index depends

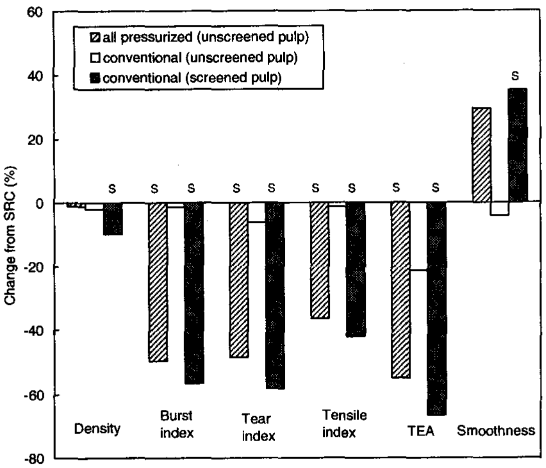

FIG. 2. Differences between lodgepole pine submerchantable logs and sawmill residue chips (SRC) (screened) thermomechanical pulps (TEA, tensile energy absorption; S, statistical significance; all pressurized indicates pressurized fiberization and pressurized refining of the unscreened pulps, and conventional indicates pressurized fiberization and atmospheric refining of the screened or unscreened pulps).

greatly on fiber length (Seth and Page 1988) and, with the exception of conventional unscreened TMP, mirrors the changes in fiber length (Fig. 1). Tear index increased for all three SMLs but decreased for the SRC as energy consumption increased. The strength properties of all-pressurized unscreened TMP and conventional screened TMP are significantly lower than the screened SRC TMP. The conventional unscreened SML TMP strength properties are closest to the SRC TMP. The conventional unscreened SML TMP had the smoothest paper surface of all pulps evaluated, probably the consequence of better fiber properties (Fig. 1).

Previous publications (Barbour and Skog 1997; Myers et al. 1997, 1999) reported lodgepole pine SML screened TMP to have marginal strength properties, and those properties were poorest of the three procedures evaluated in this study (Fig. 2). Fiber tests revealed that screened SML TMP was a coarse, short fiber length, low shive content pulp. The fibers must have been fairly stiff or poor bonders, as indicated by low handsheet density and rough paper surfaces. The original intent behind screening after fiberization was to separate the pulp into coarser and finer fractions, because each fraction refines and develops differently (Carpenter 1985; Corson et al. 1996). Either the coarser fractions were not properly developed or the finer fractions were severely damaged. Therefore, screening and separate refining of the two fractions appeared to gain nothing.

Optical properties

High opacity and light scattering properties are typical of mechanical pulps, which are mostly used to produce various printing and writing papers. None of the SML pulps had better optical properties than the SRC (Fig. 3). Brightness was lower for all SML pulps compared with SRC, with the all-pressurized being the lowest (a significant decrease) due to the elevated refining temperatures. The actual printing opacity (Table 1) was high for all SML pulps, but the percentage changes were small and only conventional unscreened SML was significant.

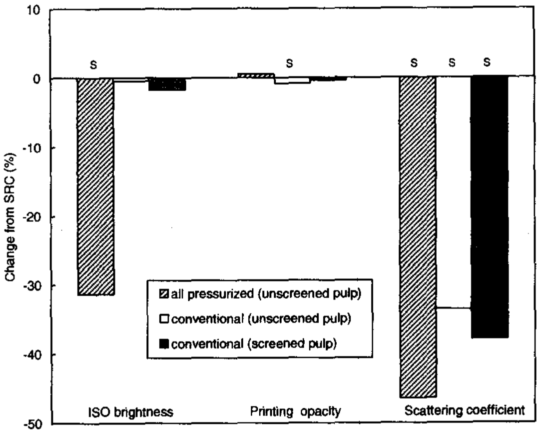

FIG. 3. Differences between lodgepole pine submerchantable logs and sawmill residue chips (SRC) (screened) thermomechanical pulps (S, statistical significance; all pressurized indicates pressurized fiberization and pressurized refining of the unscreened pulps, and conventional indicates pressurized fiberization and atmospheric refining of the screened or unscreened pulps).

Scattering coefficient, which is affected by fiber length, fines content and characteristics, and bonding, had some large and significant decreases for all the SML pulps compared with SRC (Fig. 3). The patterns of brightness and scattering coefficient (Fig. 3) are very similar in appearance to the pattern for energy consumption (Fig. 1). Higher energy consumption was expected to lower brightness due to additional thermal input and to lower scattering coefficient due to better bonding. Apparently, the behavior was controlled by the TMP process rather than energy consumption.

CONCLUSIONS

Conventional unscreened TMP appears to be the best procedure for optimizing the properties of lodgepole pine SML pulp. This study has shown that conventional unscreened SML TMP consumed 44% less energy than screened SRC TMP and had slightly lower strength and optical properties. Wood handling and debarking costs might be higher for the SML resource because of the smaller tree diameters.

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