UTILIZATION OF NONTRADITIONAL SPECIES

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ABSTRACT

Forestry practices are changing, and so are the materials being removed from the forests. The days of large, clear cuts of a single or limited number of species are either gone or fading rapidly on public lands. The volume of materials coming from the forests has also decreased. Materials being removed consist of small-diameter trees, mixed species, and mixtures of softwoods and hardwoods. Species are now being included that were considered nonusable or underutilized many years ago.

The Fiber Processes and Paper Properties Research Work Unit at the Forest Products Laboratory (USDA Forest Service) are participants in a National Project on Wood Utilization Options for Ecosystem Management. Several goals of ecosystem management are restoring forest health and biodiversity, reducing insect and disease vulnerability, and reducing the extreme fuel loads in the forest. As part of this project, raw materials were obtained from eastern Washington and western Idaho. The raw materials were lodgepole pine and mixed Douglas-fir/westem larch sawmill residue chips; lodgepole pine, Douglas-fir, and western larch sub-merchantable logs; and lodgepole pine, Douglas-fir, and western larch small-diameter trees and tops. Sub-merchantable logs and small-diameter trees and tops are considered nonusable or underutilized.

In this study, thermomechanical pulp (TMP) was prepared from these raw materials and made into paper handsheets for testing. Small-diameter trees and tops from Douglas-fir and lodgepole pine were equal or better than TMP prepared from the same species sawmill residue chips. TMP prepared from Douglas-fir, western larch. and lodgepole pine sub-merchantable logs and western larch small-diameter trees and tops were lower in properties than TMP prepared from the same species sawmill residue chips.

INTRODUCTION

Various silviculture methods will be applied by forest managers to alter the growth trajectory of stands and increase ecosystem diversity in many U.S. forests. Thinning is one such method, but it can increase public opposition, be expensive, and generate a large volume of small-diameter woody material with only marginal economic value. Another silviculture tool is cutting large tracts of timber that may have been killed by insect or disease outbreaks. This type of treatment has proven to be even more controversial. At the same time, doing nothing might make additional forest resources vulnerable to insect and disease outbreaks, increase fuel load on the ground, and set the stage for stand replacement fires.

Thinning will probably be applied in two entirely different situations. Many young plantations and second-growth stands require thinning to maintain vigorous growth. Without thinning, competition between trees will slow growth, and mortality will increase. In the Interior West, millions of acres of forests are composed of mature trees with small diameters in densely spaced stands. Development of these stands can be slow and may never reach desired structural conditions. These two situations yield entirely different types of wood that will affect their end-use possibilities.

Trees from a young, vigorously growing forest usually contain a large proportion of juvenile wood. Saucier (1) reported that the percentage of juvenile wood can be controlled by rotation length, ranging from 20% in a 40-year rotation to 50% in a 22-year rotation. Juvenile wood has several features that make it different from mature wood, such as low specific gravity, thin-walled cells, shorter tracheids, high lignin and hemicellulose content, and low cellulose content (2). Juvenile wood occupies the center of a tree stem, varying from 5 to 20 growth rings in size, and the transition from juvenile to mature wood is gradual. This juvenile wood core extends the full tree height, to the uppermost tip.

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Low-yield chemical pulp quality is affected when juvenile wood is more than 20% of the chip supply (2). For the same chemical pulping conditions, pulp yield for juvenile wood is about 25% less than pulp yield for mature wood. Paper made from juvenile wood chemical pulp has low tearing and tensile strength values. However, Carpenter (3) reported that southern pine juvenile wood is desirable in the preparation of stone groundwood and refiner mechanical pulp for newsprint.

Another type of forest could consist of densely spaced, small-diameter, mature trees. Structural diversity in this type of forest is often low, and late successional structures develop slowly. These trees might also contain a high proportion of compression wood (4).

Compared with normal wood, compression wood has greater density and slightly more extractives. Compression wood tracheids are shorter in length with thicker cell walls. Compression wood has 30% to 40% more lignin, 20% to 25% less cellulose, about the same amount of xylan, and twice the galactoglucomman of normal conifer wood (4).

Compression wood is inferior to normal wood for the manufacture of pulp and paper (4). Stone grinding compression wood breaks the thick-walled tracheids into fiber fragments that produce weak paper. Compression wood does not chemical pulp as well as normal wood. Identical kraft cooking conditions will produce a lower yield compression wood pulp that has stiffer fibers with a higher lignin content. Papers made from kraft compression wood pulp are weaker than those obtained from normal wood. Compression wood fibers also do not respond as well to mechanical refining, probably as a result of their short length, thick walls, and high lignin content.

Many forests growing on the eastern side of the Pacific Northwest Cascade Mountains consist of densely stocked, small-diameter trees. These forest resulted from large stand replacement tires and tend to be uniform. They consist of stand types that are abundant in the landscape, but in some cases offer the opportunity to develop structural characteristics such as large widely spaced green trees and snags that are relatively scarce. These features are desirable in providing habitat for certain wildlife species and developing a higher level of diversity on the landscape. However, management in these stand types is costly and will probably generate large volumes of low value raw material. These materials might find a market in the Pacific Northwest pulp and paper mills, returning revenue to the national forests to help offset the high management costs. Therefore, the objective of this study was to establish the suitability of nontraditional woody materials for high yield mechanical pulp feed stock.

EXPERIMENTAL

Raw Materials

All raw materials used in this study were obtained from the Colville National Forest (eastern Washington) or the Idaho Panhandle National Forest (western Idaho). The species selected were Douglas-fir *(Pseudotsugae taxifolia* var. *glauca* (Mayr) Sud.), lodgepole pine *(Pinus contorta* Dougl.), and western larch *(Larix occidentalis* Nutt.). Sawmill residue chips were obtained from Vaagen Bros. Lumber in Colville, Washington. The sub-merchantable logs had less than a 89-mm-end diameter and were the top logs cut from the trees. The small-diameter trees and tops had less than a 127-mm-diameter at breast height, and tops had large end diameters less than 89 mm. The small trees and tops were the entire tree. All chips and logs were shipped to the USDA Forest Service, Forest Products Laboratory, in Madison, for additional processing.

The logs were hand peeled to remove all bark and chipped to a 19-mm length in a four-knife commercial-size chipper. Chipped logs and sawmill residue chips were screened to remove all particles greater than 38 mm and less than 6 mm in length. 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.

TMP Preparation

An Andritz Sprout-Bauer model 12-lCP 305-mm-diameter pressurized refiner, fitted with plate pattern D2B505, was used for fiberization. All raw materials were steamed for 10 to 20 minutes at 206.8 kPa before fiberization. Fiberized pulp was wet screened through a 0.2- or 0.3-mm slot flat screen. Screen accepts and rejects were refined separately in a Sprout-Waldron 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, and dilution water was added to the shredded pulp to adjust refiner consistency to approximately 20%. Multiple passes were necesmry to reduce pulp Canadian Standard Freeness (CSF) to approximately 200 mL, when the accepts and rejects were combined. An additional pass was run on the combined pulp to reduce CSF to less than l00 mL. Energy consumed during fiberization and refining was measured using an Ohio Semitronic 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 (ovendry weight basis), with the idling energy subtracted. 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 minutes, with occasional stirring. Four replicates were prepared for each raw material evaluated.

Pulp Testing, Handsheet Formation, and Testing

CSF was measured according to TAPPI Test Method T227. Shive contents were determined with a Pulmac shive analyzer, using a disk with 0.10-mm slot openings. Average fiber length, fines content, and fiber coarseness were performed using a Kajaani 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 Technibrite Model TB-1 diffuse brightness apparatus according to TAPPI Test Method T525.

Statistics

Each TMP was processed to freeness levels above and below the 100 mL target, and 10 handsheets were made and tested for each pulp. These results were regressed, and values at 100 CSF were estimated (Tables I and II). Individual test results were used to perform a Dunnett's multiple comparison procedure, which provided confidence intervals on ratios of the medians of the original data and statistical significance.

RESULTS AND DISCUSSION

Presentation of Results

Eight raw materials and a minimum of four replicates were run for each raw material. Instead of presenting data for all these runs, the results for each raw material were regressed, and a value predicted for 100 mL CSF. These predicted values are presented in Tables I and II for the eight raw materials.

Making comparisons between raw materials is not easy, but presenting data in figures does gives a quick overall impression about what is happening. For example, CSF is plotted against energy consumption for all replicates of each raw material in Figure 1. It is immediately apparent that freeness decreases as energy consumption increases. However, detecting differences between raw materials is difficult. Another approach is to plot a pulp property against freeness, as was done for Pulmac shive, and shown in Figure 2. Again, it is immediately apparent that Pulmac shive content decreases as freeness decreases, but distinguishing differences between the different raw materials is difficult.

The easiest way to distinguish differences between raw materials is by computing the percentage of change from the controls, as shown in Figures 3 through 6. In these figures, the sawmill chips were the controls. The sub-merchantable logs and the small trees and tops were considered an alternative, or nontraditional raw material, and we were interested in how they compared to a traditional raw material (sawmill residues). Douglas-fir/western larch sawmill chips were the control raw material for comparison with the nontraditional Douglas-fir and western larch raw materials, and the lodgepole pine sawmill chips were used for comparison with the nontraditional lodgepole pine raw materials. Each figure easily conveys how the nontraditional material compared with the traditional material. The results of a statistical analysis were also added to each figure, and the presence of a capital "S" indicates that a specific property was significantly different from the control raw material.

Pulp Preparation and Properties

Energy consumption is traditionally high in preparing mechanical pulp; therefore, any new raw material that could reduce energy consumption would be desirable. Al1 raw materials saved electrical energy (versus control) during pulp preparation, except for the Douglas-fir and western larch submerchantable logs (Fig. 3). All the energy changes were statistically significant from the control, except for the Douglas-fir sub-merchantable logs. Pulmac shive declined for all but the western larch and Douglas-fir small trees and tops, which showed an increase (Fig. 4). The changes in Douglas-fir sub-merchantable logs and western larch small trees and tops were significantly different. This implies a more complete fiber-to-fiber separation for the nontraditional raw materials. Fiber length was expected to be shorter, based upon the literature and did decline for all the nontraditional raw materials (Fig. 4). The fiber length decline for lodgepole pine sub-merchantable logs was significant. A reduced fines content is always desirable, but the fines content increased for all nontraditional raw materials other than lodgepole pine and Douglas-fir small trees and tops (Fig. 4). The fines might have been generated from fiber breakage and shortening or materials being removed from the fiber surface. Coarseness also decreased for everything except the western larch sub-merchantable logs and small trees and tops (Fig. 4). Because most western softwood species are rather coarse fibered, a reduction in coarseness might be desirable.

After examination of the combined energy consumption and pulp properties, it appears that several of the nontraditional raw materials (lodgepole pine and Douglas-fir small trees and tops, lodgepole pine and western larch sub-merchantable logs) were equal or better than the tradtional sawmill residue chips.

Table I—Test results at 100 CSF (pulp properties)

Input material	Total energy (watt-hour/ ovendry kg)	Pulmac shive <0.004 mm (%)	Kajaani FS-100 Analysis		
			Length-weighted		
			Average (mm)	Fines (%)	Coarseness (mg/m)
Douglas-fir/larch sawmill chips	3761	0.93	1.15	4.50	0.336
Lodgepole pine sawmill chips	5020	0.65	1.17	4.56	0.349
Douglas-fir sub-merchantable logs	4405	0.67	0.86	6.67	0.306
Lodgepole pine sub-merchantable logs	2314	0.10	0.67	8.52	0.323
Western larch sub-merchantable logs	4962	0.82	1.01	5.75	0.389
Douglas-fir small trees and tops	2687	1.06	1.09	4.26	0.318
Lodgepole pine small trees and tops	2958	0.42	1.05	4.43	0.298
Western larch small trees and tops	2256	1.44	0.92	6.29	0.373

Table II—Test results at 100 CSF (paper properties)

Input material	Apparent density (kg/m^3)	Burst index ($kPa\text{-}m^2/g$)	Tear index ($mN\text{-}m^2/g$)	Tensile index (N-m/g)	Stretch (%)	TEA (J/m^2)	Smooth-ness (SU)	ISO Bright-ness (%)	Printing opacity (%)	Scattering Co-efficient (m^2/kg)
Douglas-fir/larch sawmill chips	456	1.13	1.97	26.3	1.50	19.04	197	34.4	99.6	61.0
Lodgepole pine sawmill chips	461	1.47	2.22	33.3	1.81	27.82	173	46.0	98.8	79.2
Douglas-fir sub-merchantable logs	471	1.04	1.67	25.5	1.47	17.47	200	31.8	99.6	44.0
Lodgepole pine sub-merchantable logs	416	0.64	0.93	19.3	1.07	9.30	234	45.2	98.4	49.2
Western larch sub-merchantable logs	443	1.06	3.37	26.8	1.46	17.98	221	32.6	99.3	41.0
Douglas-fir small trees and tops	456	1.36	4.28	29.9	1.70	23.25	191	37.0	98.9	44.9
Lodgepole pine small trees and tops	457	1.31	3.61	30.3	1.56	22.24	201	43.8	97.7	45.2
Western larch small trees and tops	397	0.78	2.74	20.8	1.27	11.95	287	39.3	98.3	40.9

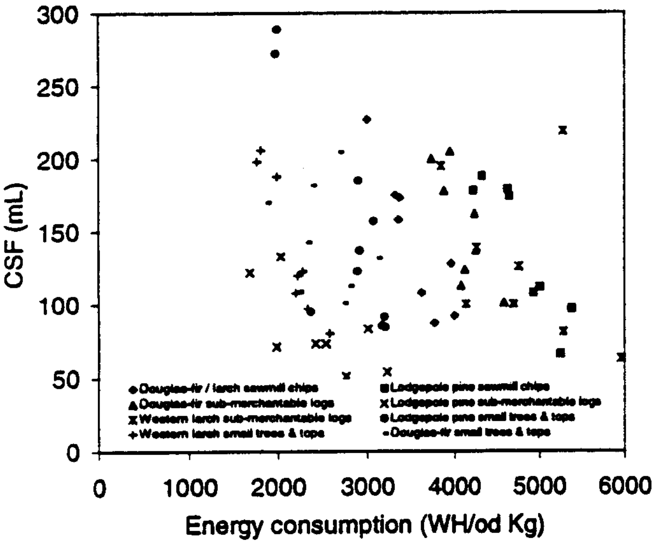

Fig. 1—CSF compared with energy consumption.

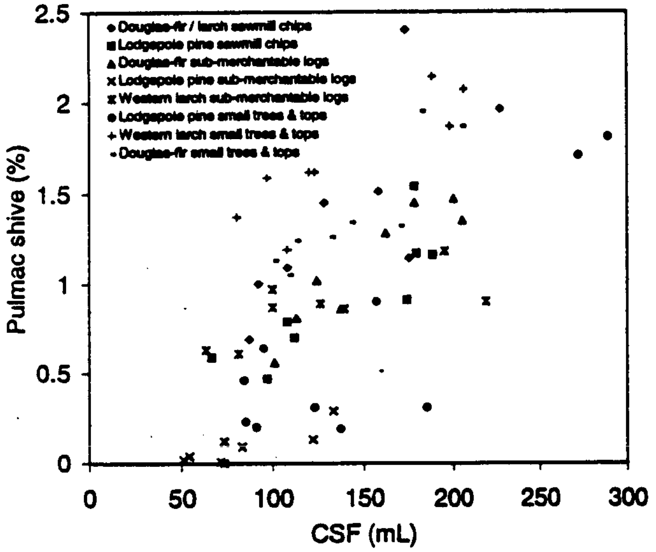

Fig. 2—Pulmac shive compared with CSF.

Strength Properties

Handsheet density changed less than 5 percent, for all but the lodgepole pine Sub-merchantable logs and western larch small trees and tops (Fig. 5), which had significant reductions (versus control). Most strength properties are density dependent; therefore, this decline could affect the strength properties. Burst index decreased for all nontraditional raw materials except Douglas-fir small trees and tops, and the decreases were significant for lodgepole Pine sub-merchantable logs and western larch small trees and tops (Fig. 5). The most spectacular changes occurred in tear index. Tear index had four increases and two decreases, and all the increases were large and statistically significant. The lodgepole pine sub-merchantabie logs had a large and significant decrease (Fig. 5). Tensile index and tensile energy absorption (TEA), for the most part, followed the general trend of burst index. The Douglas-fir small trees and tops were the only nontraditional raw material to show an increase in all strength properties. Surface smoothness increased for all nontraditional raw materials except the Douglas-fir small trees and tops, which had a small decrease.

Based on strength properties alone, the Douglas-fir and lodgepole pine small trees and tops appear to be better than their corresponding sawmill residue chips. The remaining nontraditional raw materials were not as good as their corresponding sawmill residue chips.

Optical Properties

High opacity and light scattering properties are a strong point for mechanical pulps, which are heavily used to produce various printing and writing papers. None of the nontraditional raw materials had optical properties that were better than their corresponding sawmill residue chips. Brightness decreased for all nontraditional raw materials except western larch and Douglas-fir small trees and tops (Fig. 6). Printing opacity was high for all nontradtional raw materials, and even though several of the changes were significant they were small changes. Scattering coefficient had some large and significant decreases for all the nontraditional raw materials (Fig. 6). Scattering coefficient is affected by a change in fiber length, fines content and characteristics, and fiber-to-fiber bonding.

Suitability of Nontraditional Raw Materiais

Based upon a combination of several results during pulp preparation and handsheet testing, two nontraditional raw materials were equal or better than their corresponding sawmill residues. The Douglas-fir and lodgepole pine small trees and tops appear to be suitable for producing TMP. Both saved electrical energy during pulp preparation, although they yielded pulps with shorter fiber length, less fines, and were not as coarse as the pulps produced from sawmill chips. Paper made from the pulps had nearly equal or better strength although optical properties (capacity, and light scattering) were reduced.

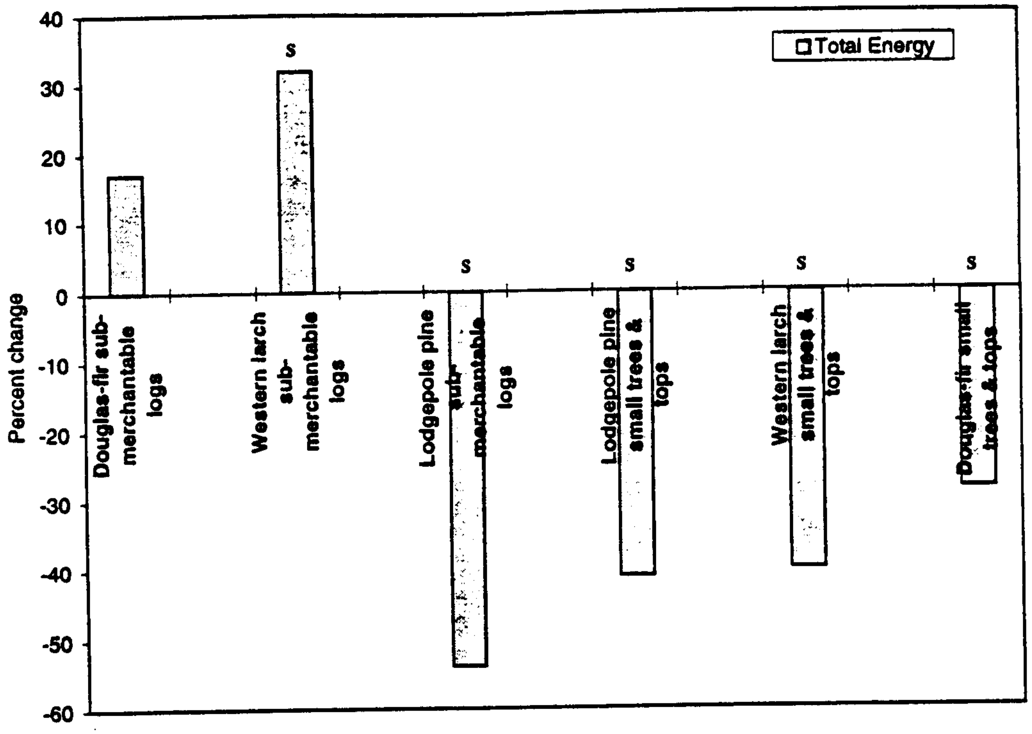

Fig. 3—Percentage change from sawmill residues.

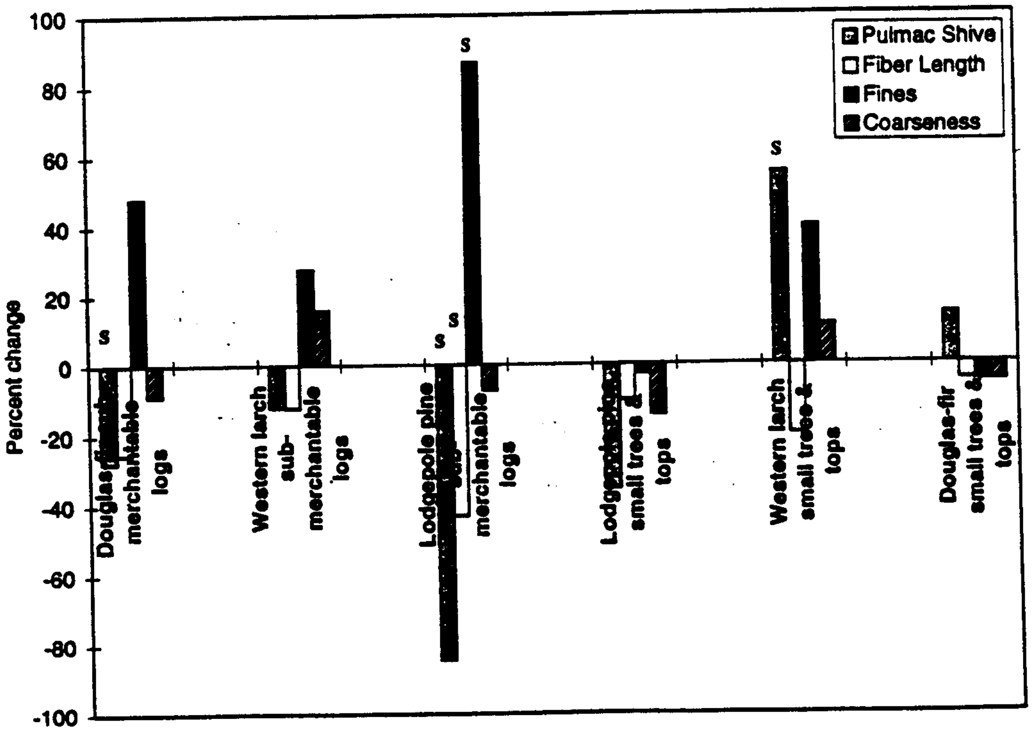

Fig. 4—Percentage change from sawmill residues.

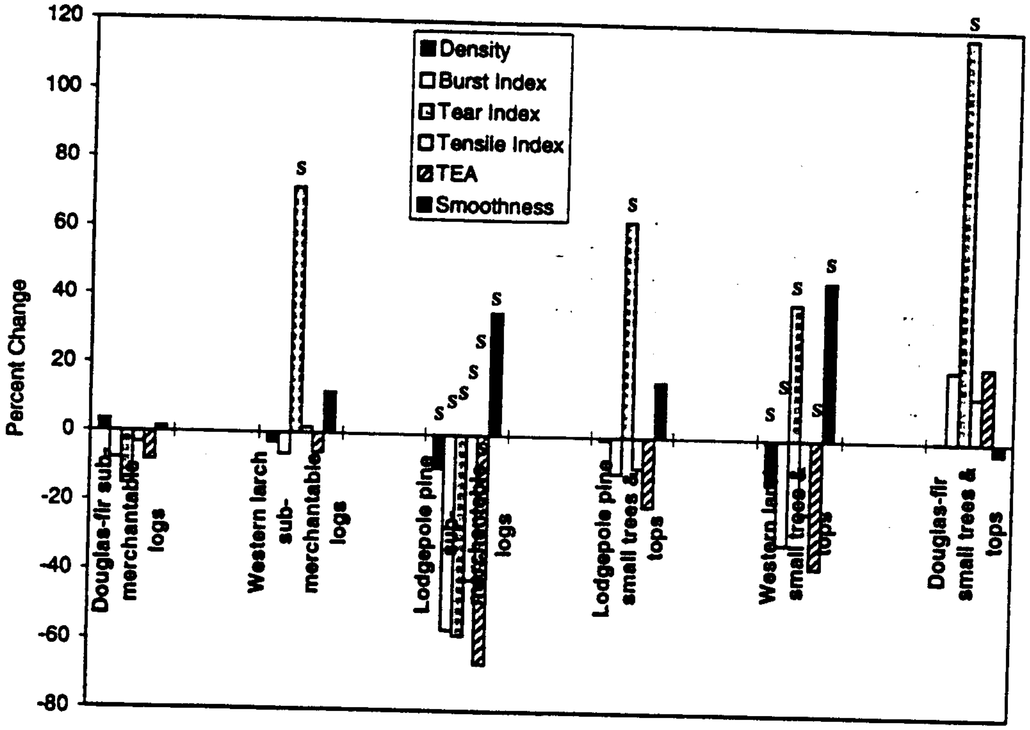

Fig. 5—Percentage change from sawmill residues.

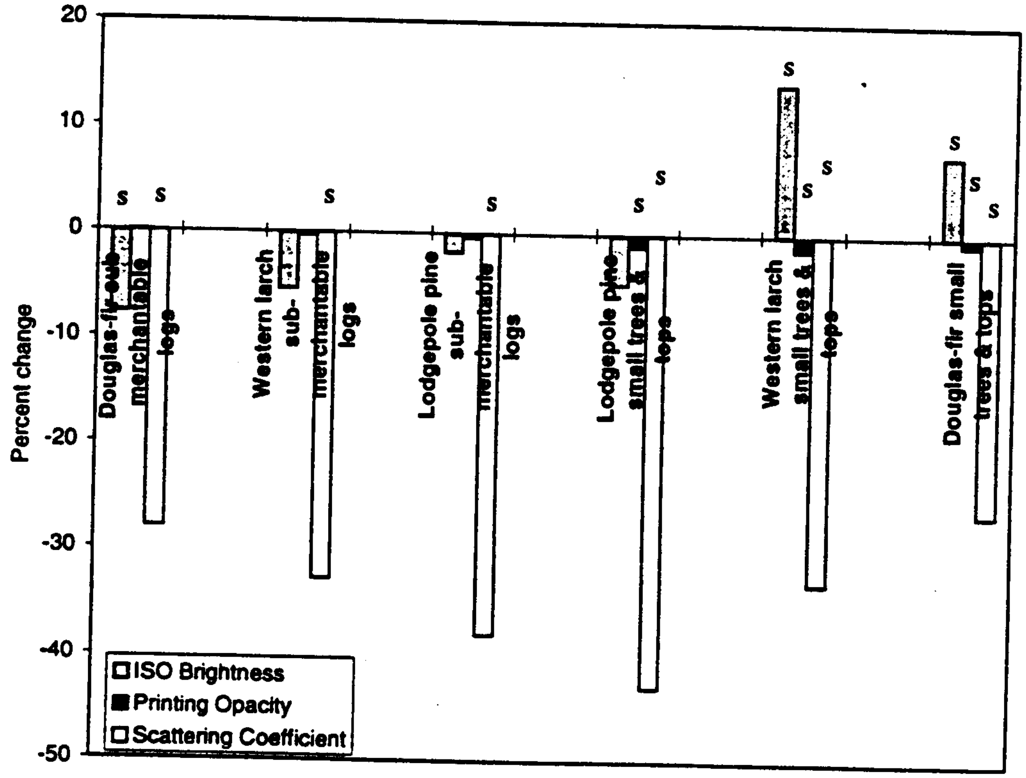

Fig. 6—Percentage change from sawmill residues.

CONCLUSIONS

Douglas-fir, western larch, and lodgepole pine sub-merchantable logs and small trees and tops were evaluated as raw materials for thermomechanical pulps (TMP) production. Lodgepole pine and Douglas-fir small trees and tops were equal or better than TMP prepared from their corresponding sawmill residue chips. Douglas-fir and western larch sub-merchantable logs produced TMP and paper that were slightly inferior to their corresponding sawmill residue chips. The TMP and paper with the least properties were made from lodgepole pine sub-merchantable logs and western larch small trees and tops

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