WOOD AND PAPER PROPERTIES OF VACUUM AIRLIFT SEGREGATED JUVENILE POPLAR WHOLE-TREE CHIPS[1]

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ABSTRACT

Whole-tree chips from a hybrid poplar clone (*Populus* 'Tristis #1') grown under short rotation, intensive culture (SRIC) were separated into three fractions using vacuum airlift segregation (VAS). The fractions were: accepts, which was predominantly a woody fraction; rejects, which contained less wood and more bark and twigs; and fines, which consisted mostly of bark particles. The raw material quality was evaluated and kraft pulp and paper properties were determined on the whole-tree chips and each VAS fraction as well as on a 50:50 mixture of the accepts: rejects fractions. A 50:50 mixture of VAS accepts and 55-yr-old mill-run jack pine was also studied. Pulp and paper properties of the whole-tree chips, the VAS accepts and rejects, and a 50:50 mixture of accepts: rejects were similar and were only slightly lower in quality than those of mature aspen chips. The 50:50 mixture of VAS accepts and mill-run jack pine was acceptable by industrial standards. These results suggest that whole-tree chips from SRIC poplar stands can be mixed with conifer chips to supplement furnishes for kraft pulping.

Keywords: Beneficiation, kraft pulp, raw material quality, whole-tree chips, scanning electron microscopy, *Populus* hybrid, vacuum airlift segregation (VAS).

INTRODUCTION

Whole-tree harvesting has become a popular method for increasing the biomass yields of forest stands. It is convenient and efficient, particularly when the material

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is chipped on-site. Poplar trees grown under short rotation, intensive culture (SRIC) are ideally suited for whole-tree harvesting. They are grown in plantations and can be harvested at an early age, both of which favor mechanization. Recently, the pulp and paper industry has been testing the feasibility of whole-tree chipping short-rotation poplars. The benefits of this approach include salvage of logging residues, lower transportation costs, fuel conservation, and reduced manpower requirements when compared to conventional harvesting methods (Johnson 1979). However, whole-tree chips contain bark, twigs, and foliage, which cause problems in a pulp furnish—chemical consumption increases, pulp fines increase, "dirt" content of the pulp increases, drainage decreases, and the operation efficiency of conveyors during the pulping process decreases (Marton et al. 1976). Usually pulp from native aspen and hybrid poplar whole-tree chips has lower yields and less strength than that prepared from debarked material (Laundrie and Berbee 1972; Schmidt and DeBell 1973; Hunt and Keays 1973b; Keays and Barton 1975; Zarges et al. 1980). Clearly, better methods are needed to separate and beneficiate (improve) whole-tree chips. Such methods should not only reduce some of the detrimental aspects of using whole-tree chips by removing residual bark and grit, but also should separate wood, bark, and foliage components and make them available for integrated utilization schemes (Isebrands et al. 1979).

Recently, several methods have been developed to beneficiate whole-tree chips (Arola et al. 1976; Sturos and Dickson 1980). One such method is the vacuum airlift segregation (VAS) process. VAS is particularly adept at separating poplar whole-tree raw material into various fractions (Isebrands et al. 1979). One adaptation of VAS allows the material to be separated into wood chips and barky-wood chips[2] (accepts); twigs, knots, and bark flakes (rejects); and small particles of bark, foliage, dirt, and grit (fines).

In this study we examined the kraft pulp and paper properties of the above VAS fractions from SRIC poplar whole-tree chips. Our specific objectives were to: (1) evaluate the raw material properties of 6-yr-old *Populus* 'Tristis #1' grown under SRIC; (2) separate whole-tree chips made from this material into fractions (i.e., accepts, rejects, and fines) using VAS, and classify these fractions into their wood, bark, and twig components; and (3) evaluate the kraft pulp and paper properties of the fractions individually, in mixture with one another, and in mixture with a mill-run jack pine raw material.

MATERIALS AND METHODS

Six-yr-old *Populus* 'Tristis #1' trees[3] grown under SRIC at a 0.6-m-square spacing at the Hugo Sauer Nursery near Rhinelander, WI, were harvested during the dormant season after leaf fall. The study trees averaged 7.5 m in height and 4.4 cm dbh.

Disks were removed from three random trees at three heights within each tree for raw material evaluations (Table 1). Wood and bark specific gravities (SG)

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[2] Wood chips with a ring of bark.

[3] *P. tristis* Fisch. × *P. balsamifera* cv. P. Tristis #1; hereafter P. 'Tristis #1.'

TABLE 1. *Average tree, wood, and bark properties of three random 6-yr-old* Populus *'Tristis #1' trees grown under SRIC.*[1]

Tree				Wood				Bark			
Hgt.	DBH	Disk hgt.	Disk code	Specific gravity	Fiber length	Vessel length	Vessel	Bark	Specific gravity	Fiber length	Fiber
m	*cm*	*m*			*mm*	*mm*	%	%		*mm*	%
8.4	6.0	7.3	Top	0.40	0.55	0.37	20	21	0.35	0.92	8
		3.8	Middle	0.36	0.68	0.46	23	11	0.33	1.00	8
		0.3	Base	0.34	0.80	0.45	25	13	0.36	0.87	8
		Weighted means[2]		0.35	0.75	0.45	24	13	0.35	0.91	8

[1] Grown at 0.6-m spacing in Rhinelander, WI. SRIC = short rotation, intensive culture.

[2] Means in this row were weighted as to the relative areas occupied by each disk. Top = 0.04, middle = 0.30, base = 0.66.

were determined using the maximum moisture content method (Smith 1954). Cell lengths (50 to 60 intact cells of each type) were measured on macerated wood and bark tissue (Franklin 1945). Bark percentages were based on cross-sectional areas of wood and bark. Vessel and bark fiber percentages were determined from microtomed cross-sections (20 μm thick) projected onto a Talos[4] digitizing tablet.

All trees in the plot were chipped using a Morbark Model 12 Chipharvester. Whole-tree chips were transported to the Forestry Sciences Laboratory, USDA Forest Service, Houghton, MI, where they were processed with the VAS. For the purposes of our study, the VAS was adjusted to separate the whole-tree chips into three fractions. The accepts (or lift) fraction contained a higher quantity of wood chips and barky-wood chips and a lower quantity of bark than the original chips; the rejects (or retained) fraction contained a lower quantity of wood, but higher quantities of bark due to the presence of numerous branches and twigs; and the fines fraction was comprised of small particles, mostly bark, that had fallen through the mesh belt of the VAS unit. After beneficiation, subsamples were removed from the whole-tree chip mixture and from each fraction to estimate the quantity of free wood, barky wood, twigs, and free bark in each fraction. Chemical analyses (% oven-dry weight) of each fraction were also conducted to determine total ash (at 550 C), calcium and silica (by emission spectrographic analysis), and alcohol-benzene extractive content (Tappi T204 os-74).

The segregated fractions were pulped by the kraft process, screened, and bleached by a CEHD[5] sequence. Then handsheets were made and their physical properties were evaluated at The Institute of Paper Chemistry, Appleton, WI, using Tappi standard methods. In addition, we evaluated the pulp and paper properties of a 50:50 mixture of accepts and rejects fractions, and a 50:50 mixture of accepts fraction with debarked 55-yr-old mill-run jack pine chips.

Each fraction or mixture was cooked with the following constant conditions—16% effective alkali, 25% sulfidity, and H-factor = 2,000. Processing was in a 0.06 m^3 digestor and the target Kappa No. was 17 (wood charge—40 kg OD basis;

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[4] Mention of trade names is for the convenience of the reader and does not constitute an endorsement by the USDA Forest Service or the University of Missouri.

[5] CEHD = chlorine, sodium hydroxide, hypochlorite, and chlorine dioxide.

liquor to wood ratio—4:1; max. temperature—172 C; time to temperature—90 min). Following cooking, the pulps were beaten at 10% consistency to several freeness levels in a PFI mill.

Pulp fiber measurements were made on unbeaten pulp samples. Fiber length was determined by measuring 300 fibers (0.3 mm or longer) for each sample except the 50:50 mixture with jack pine. For that sample, 600 fibers (0.3 mm and longer) were measured. All fibers—including those that were cut or broken—were measured. One hundred fibers were measured for fiber width and cell-wall thickness. Fibers were measured at the widest part, but those with swelling or other damage were excluded. Coarseness of unbroken fibers was determined using Britt's (1966) method.

A scanning electron microscope (SEM) was used to investigate samples removed from the interior of the handsheets. Samples were attached to a SEM stub with double-stick tape, sputter-coated with gold-palladium, and examined with an ISI-60 SEM operating at 10kV.

RESULTS

Raw material properties

The following trends in wood and bark properties were observed (Table 1): (1) wood SG increased with tree height; (2) bark SG was generally lower in the midportion of the trees; (3) wood fiber length decreased with tree height; (4) wood vessel length was lowest in the top sample; (5) bark fiber length was generally highest in the middle sample and lowest at the base; (6) vessel % decreased with height; (7) bark fiber % had no general pattern; and (8) bark % increased with tree height. Wood SG and wood fiber length generally followed longitudinal patterns described for hardwood trees (Panshin and de Zeeuw 1980). Furthermore, most of the weighted averages of wood and bark properties were within the ranges of values previously reported for hybrid poplars (FAO 1979; Zarges et al. 1980); however, wood fiber length was shorter because of the juvenile wood origin.

VAS fraction characterization and chemical analysis

The VAS accepts fraction comprised about 75% of the total whole-tree chip furnish by weight (Table 2). It consisted of mostly free wood and barky-wood chips with minimum quantities of twigs and free bark. The rejects fraction made up 23% of the whole-tree furnish. It consisted mostly of barky-wood chips, about 28% free wood, and a small quantity of twigs and free bark. The main differences between the accepts and rejects fractions were the higher free wood composition of the accepts fraction, and the higher barky-wood and twig composition of the rejects fraction. The combined difference was that the accepts fraction had 8% more wood than the rejects fraction. The fines fraction consisted mostly of small bark particles.

The difference in bark component among the fractions was reflected in the chemical analyses. Our total ash contents were higher than values reported for hybrid aspen (Lonnberg 1975) and native aspen (Ellis 1965). These differences no doubt reflect the higher bark content in our material. Calcium levels were also higher than for aspen (Ellis 1965). The accepts and rejects fractions had alcohol-

TABLE 2. *Components and chemical analyses of 6-yr-old SRIC poplar whole-tree chips and VAS fractions.*[1]

		% of components in each fraction						Chemical analysis of each fraction (o.d. wt.)			
VAS fraction	% of input	Free wood	Barky wood[2]	Twigs[3]	Free bark	Combined wood[4]	Combined bark[5]	Total ash	Calcium	Silica	Alcohol-benzene ext.
								%	%	%	%
Whole-tree chips	100	52	38	5	5	84	16	—	—	—	—
VAS accepts	75	59	33	3	5	86	14	2.8	0.9	0.009	2.5
VAS rejects	23	28	58	11	3	78	22	2.3	0.7	0.008	3.0
VAS fines	2	35[6]	—	—	65[6]	35	65	5.2	1.8	0.280	7.0

[1] SRIC = short rotation, intensively cultured, VAS = vacuum airlift segregation.

[2] Wood chips with a ring of bark; includes branchwood >6-mm diameter.

[3] Includes branchwood ≤6-mm diameter.

[4] Determined by adding free wood, 77% of barky wood, and 50% of twigs.

[5] Determined by adding free bark, 23% of barky wood, and 50% of twigs.

[6] Visually estimated.

benzene extractive levels within the range of values previously reported (Bray and Paul 1942; Hunt and Keays 1973a, Marton et al. 1968).

The fines fraction, with its large quantity of bark, showed a marked increase in alcohol-benzene extractives. According to van Buijtenen (1969), higher alcohol-benzene extractives are undesirable in kraft pulping because they are negatively correlated with pulp yield.

Pulp and handsheet properties

Screened pulp yields of whole-tree chips, the accepts, and the 50:50 accepts: rejects pulps ranged from 46 to 48%; the rejects fraction had a screened pulp yield of 44% (Table 3). The VAS rejects pulp also had the highest screened pulp reject levels (i.e., 0.6%), while the other fractions had pulp reject levels of 0.3 to 0.4%. The fines fraction was not tested because of its slow cooking rate and significantly lower yield (i.e., 32% yield at Kappa No. = 34.7).

TABLE 3. *Pulp yield and fiber properties of whole-tree chips and VAS fractions of 6-yr-old* Populus *'Tristis #1' grown under SRIC.*

	Pulp yields		Pulp fiber properties (unbeaten pulp)			
Material	Screened yield	Rejects	Pulp fiber length weighted avg.	Fiber width	Cell wall thickness	Fiber coarseness
	% OD	*% OD*	*mm*	*μm*	*μm*	*mg/100m*
Whole-tree chips						
Kappa no. = 17.8	48	0.4	0.7	27	2.8	13
VAS accepts						
Kappa no. = 18.4	48	0.4	0.7	27	2.8	11
VAS rejects						
Kappa no. = 17.7	44	0.6	0.7	24	2.6	13
Accepts: rejects 50:50						
Kappa no. = 18.6	46	0.3	0.7	25	2.7	11
Accepts: mill-run jack pine 50:50						
Kappa no. = 17.8			1.2	31	3.1	14

TABLE 4. *Physical properties of unbleached kraft pulps and handsheets of 6-yr-old SRIC poplar whole-tree chips and VAS fractions.*

Material	Kappa no.	No. revs.	CSF	Sheet density	Burst index	Tear index	Breaking length	TEA[2]	Shive content
		PFI	*ml*	*kg m^{-3}*	*KPa·m^2 g^{-1}*	*mN·m^2 g^{-1}*	*km*	*J/m^2*	*m^2*
Whole-tree chips	17.8	0	485	630	3.0	6.1	6.3	17.8	5,600
		4,250	220	740	6.1	6.2	8.9	47.8	1,900
VAS accepts	18.4	0	480	670	3.1	5.4	6.8	21.4	600
		4,250	235	760	6.2	6.1	8.9	45.4	100
VAS rejects	17.7	0	465	590	2.7	5.2	6.1	19.5	4,400
		3,500	220	670	5.3	6.4	8.3	50.8	700
VAS accepts: VAS rejects 50:50	18.6	0	485	630	3.2	5.3	6.6	22.2	3,300
		4,250	235	730	6.0	6.1	8.7	47.6	800
VAS accepts: mill-run jack pine 50:50	—	0	600	600	4.5	11.7	7.1	35.7	600
		4,000	310	750	8.1	8.6	10.0	57.7	—
Native aspen standard[1]	—	4,100	300	770	6.2	7.3	10.2	—	—

[1] From Hunt and Keays (1973b).
[2] TEA = tensile energy absorption.

Pulp fiber properties were similar among the whole-tree chip material and each of the VAS fractions except for a slight difference in coarseness (Table 3). The whole-tree chip fraction and the rejects fraction were coarser than the other fractions, approaching that of the accepts:jack pine mixture. As predicted, the jack pine contributed longer, wider, and thicker-walled fibers to the pulp.

The physical properties of the unbleached pulps were evaluated at several different beating levels, two of which are given in Table 4. The rejects fraction produced pulps with lower density, lower burst, and lower breaking length than the pulps from the whole-tree chips, the accepts, or the accepts: rejects fractions. Any differences between the rejects and the other VAS fractions can no doubt be attributed to the higher bark content of the rejects fraction. However, longer bark fibers may have contributed to a higher tear index and, therefore, a higher TEA of the rejects (after beating), but this difference is probably not significant. The properties of the whole-tree, accepts, and accepts: rejects pulps were not significantly different from one another either before or after beating, except for shive content (Table 4). The accepts fraction had the lowest shive content. However, because the physical properties of all fractions were low, it is questionable whether the differences between the rejects fraction and the other fractions are industrially significant. Again, shive content may be the exception.

The physical properties of the 50:50 mixture of VAS accepts:jack pine was clearly superior to all poplar VAS fractions studied (Table 4). In fact, the properties of the accepts: jack pine mixture were generally well within the range of industrially acceptable raw materials. Marked differences in tear-tensile plots were observed between the 50:50 accepts:jack pine and the other fractions (Fig. 1). The lower tear values of the VAS pulps were probably due to the short, juvenile fibers in those pulps. A tear index-breaking length plot of 100% debarked mill-run jack pine (age 55 years) is also given for comparison (Fig. 1). Note that the values

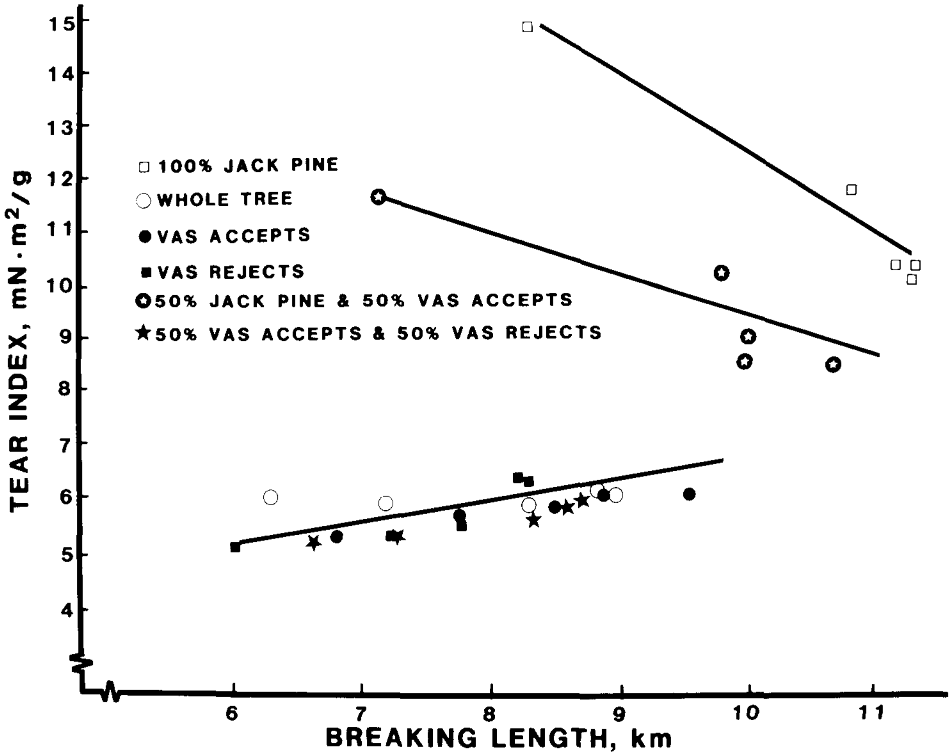

FIG. 1. Tear index and breaking length for pulps made from 6-yr-old SRIC poplar whole-tree chips, VAS fractions, mixtures of fractions, and a mixture of the VAS accepts pulp with 100% mill-run jack pine pulp. The properties of a 55-yr-old mill-run pine pulp are also shown for comparison. Note that negligible differences occurred between the various VAS fraction pulps, but that the addition of a mill-run jack pine pulp to the accept fraction greatly improved the tear-tensile properties.

obtained for the 50:50 accepts:jack pine pulp approached those of the mill-run jack pine.

Even though the shives content of the VAS accepts pulp differed greatly from that of the other poplar fractions (Table 4), the bleach consumptions of the pulps were similar and resulted in equivalent brightness. All pulps produced a bright, clean pulp (86 to 87% brightness and 1.8 to 4.2 ppm dirt).

When viewed under the SEM, the handsheets from most of the VAS fractions (i.e., whole-tree, accepts, and 50:50 accepts:rejects) appeared to have similar structural properties (Fig. 2). These properties were consistent with the physical property data. The rejects handsheets commonly had more thicker-walled (shive) fibers than the other fractions (Fig. 2d) and the accepts:jack pine mixture clearly had larger, longer fibers (Fig. 3).

DISCUSSION

In recent years the forest products industry has been utilizing more and more juvenile wood for pulp and paper (Zobel 1981). SRIC systems have the potential to produce large quantities of juvenile woody raw material in a short period of

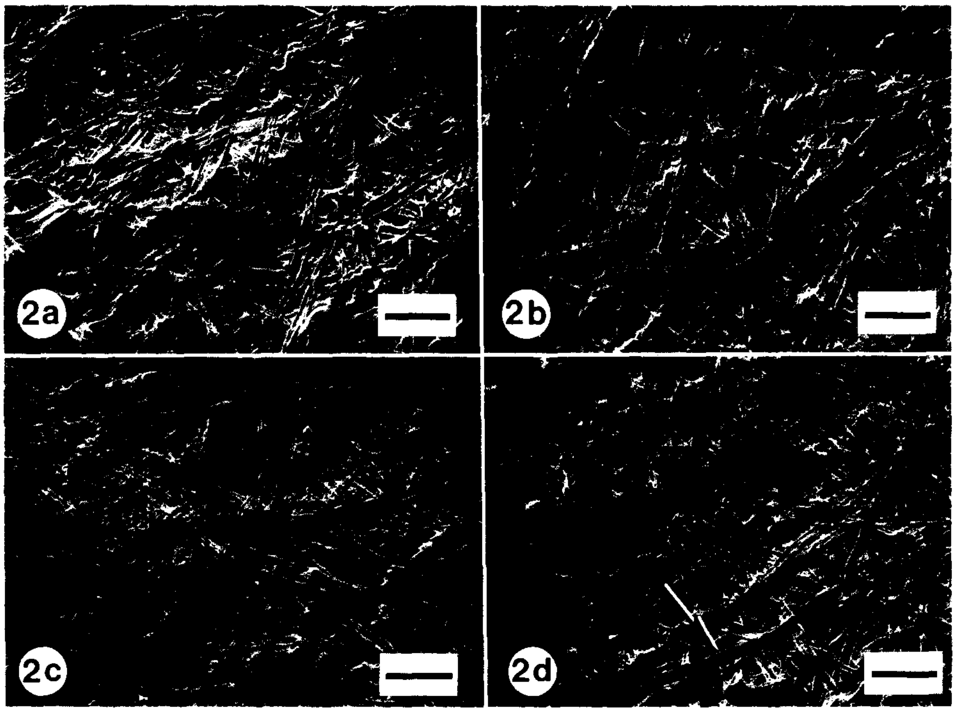

FIG. 2. Scanning electron micrographs of the surfaces of handsheets made from the various VAS fractions. a. whole-tree, 220 CSF, PFI beaten (4,250 revs.); b. VAS accepts, 235 CSF, PFI beaten (4,250 revs.); c. 50:50 accepts:rejects, 235 CSF, PFI beaten (4,250 revs.); d. VAS rejects, 220 CSF, PFI beaten (3,500 revs.). Note the similarity of appearance of a, b, and c; d shows thick-walled bark fibers (arrow). Bar equals 100 μm.

time (Isebrands et al. 1979). In this study we investigated the kraft pulp and paper properties of juvenile raw material from a single SRIC poplar plantation.

Most pulping studies of juvenile poplars have indicated that debarked aspen and debarked *Populus* hybrids make a suitable kraft pulp and paper furnish (Bray and Paul 1942; Uprichard 1971; Einspahr 1972, Laundrie and Berbee 1972; Bella and Hunt 1973; Hunt and Keays 1973a; Holder et al. 1979). In fact, pulp produced from debarked juvenile *Populus* hybrids, has even been shown to have some superior strength properties (primarily in burst and breaking length) than those produced from debarked mature aspen (Bray and Paul 1942; Holder et al. 1979; Zarges et al. 1980).

However, whole-tree chips from juvenile trees contain a high percentage of bark, branches, and foliage, which often creates problems when used as a pulp furnish. Bella and Hunt (1973) considered bark removal to be a critical problem in the use of young aspen trees. Marton et al. (1976) came to similar conclusions when analyzing pulp made from sugar maple and red pine whole-tree chips. However, Fellegi et al. (1974) found that NSSC pulps made from branches (containing bark) had similar strength properties to those made from the debarked stemwood of beech and hornbeam, but pulp yields were slightly lower than the debarked material.

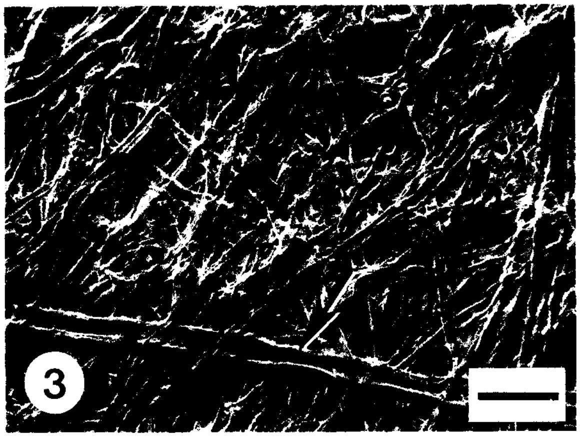

FIG. 3. Scanning electron micrographs of the surface of a handsheet made from 50:50 VAS accepts: jack pine, 310 CSF, PFI beaten (4,000 revs.). Note the long, thick-walled jack pine tracheid (arrow). Bar equals 100 μm.

Vacuum airlift segregation removed small but significant quantities of barkywood and twigs from our whole-tree poplar chips (i.e., 13% and 3%, respectively). However, the difference between the whole-tree chips and the accepts chips in combined wood and bark percentage was only 2% (Table 2). Such a small difference suggests that the type of VAS processing used in this study may not have removed sufficient quantities of bark to be industrially feasible. Perhaps small juvenile trees are not as amenable to beneficiation with VAS as older trees. In an earlier case study, Isebrands et al. (1979) successfully removed large quantities of bark from 5-yr-old SRIC poplar grown at 1.2-m spacing using VAS. The difference in bark removal in the study by Isebrands et al. (1979) and this study suggests that each raw material may require specific adjustments of VAS process variables to be feasible.

Sturos and Dickson (1980) recommended that compression debarking follow VAS. They suggested that this addition would increase the quantity of clean chips by approximately 30%. Perhaps this scheme would be a better approach for improving SRIC poplar chips. In addition, Einspahr (1972) described several other possible beneficiation methods. These include compression debarking, water flotation, or a combination of compression debarking, screening, and water flotation.

The strength properties of handsheets made from fractions of our SRIC raw material were similar or only slightly lower than the properties reported for handsheets made from mature aspen chips pulped under similar conditions (Hunt and Keays 1973b) (Table 4). By contrast, the handsheet strength properties of the 50:50 VAS accepts:jack pine pulp mixture were well within industrially acceptable limits for those properties (Hunt and Keays 1973a). This result suggests that kraft pulps from SRIC poplar chips can be mixed with more traditional conifer pulps. Thus, it is feasible that pulp from SRIC raw materials can be used as a supplement to conifer pulp (Isebrands et al. 1982). Conventional hardwood pulps are frequently mixed with conifer pulps to improve formation, texture, softness, and printability (Schmidt and DeBell 1973).

SUMMARY

Although we observed few differences in the pulp quality of fractions of whole-tree chips from the *Populus* hybrid after VAS processing, we still believe that VAS has potential as a separation process for beneficiating whole-tree poplar chips. Process modifications may be required for different clones, for larger trees, or for different aged material, etc. VAS may offer more potential in conjunction with other beneficiation systems (i.e., compression debarking, flotation, and/or screening). Moreover, VAS appears promising for removing foliage from material harvested during the growing season.

The most encouraging result of this study is the potential for using SRIC poplar whole-tree chips in mixture with debarked, mature jack pine as a furnish for pulp and paper. Raw material from SRIC plantations appears to have potential for supplementing conventional conifer pulps.

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