WOOD HARVESTING

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TN287

LOGYARD RESIDUE RECLAMATION IN CENTRAL–INTERIOR BRITISH COLUMBIA

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Abstract

During the summer of 1996, the Forest Engineering Research Institute of Canada (FERIC) observed a logyard residue separation system working in the central–interior of British Columbia. The primary equipment used were a trommel screen and a single-knife destoner. FERIC classified the logyard residues, observed productivity, calculated costs and determined the efficacy of separation for the system.

Introduction

Forest companies in British Columbia continue to search for methods and equipment to minimize and utilize the residues generated in logyards. The costs associated with landfilling—acquiring permits, transporting residues to farther sites, and monitoring and maintaining the site in perpetuity—are becoming prohibitive and other alternatives may be more cost effective. The traditional burning techniques no longer meet present air quality standards, and would require significant investment to meet these standards. Paving the logyard and storage sites is a popular technique at coastal locations which helps minimize soil and rock contamination to the residues, which can then be converted to hog fuel for the power boilers at nearby pulp mills. However, most of the central–interior sawmills in British Columbia do not have pulp mills located within an economic transportation radius. In addition, the area needed for the large inventories of logs required to sustain the sawmills' operations through seasonal woodlands closures would make paving the logyards very expensive.

During the summer of 1996, Tolko Industries Ltd. brought in a contractor to clean up a residue accumulation at its Lavington planer mill logyard (unpaved), located east of Vernon in the central–interior of British Columbia. Tolko's objective was to reduce the residue flow to a landfill by reclaiming rock for logyard maintenance and wood and bark for burning, and to find an alternative use for the fines component of the residue. This report presents residue classification information, system productivities and costs, and separation efficacy. This was part of a larger study, funded by the federal Panel on Energy Research and Development (PERD) through the Energy from the Forest (ENFOR) program of the Canadian Forest Service (CFS), investigating the utilization of logyard fines.

Objectives

- Stratify, by size class, the organic and mineral fractions of the logyard residue.
- Identify factors affecting system performance.
- Determine the productivity of the logyard residue separation system and the unit cost based on material input.
- Analyze the fines from the stratification process to obtain moisture, ash and mineral contents.
- Determine whether the selected equipment produced the desired products.

Site and System Description

The site was located in a remote area of the Lavington logyard and occupied approximately 0.5 ha (Figure 1).

Keywords: Sortyard residues, Separation processes, Trommel screens, Single-knife destoner, Productivity, Costs, British Columbia.

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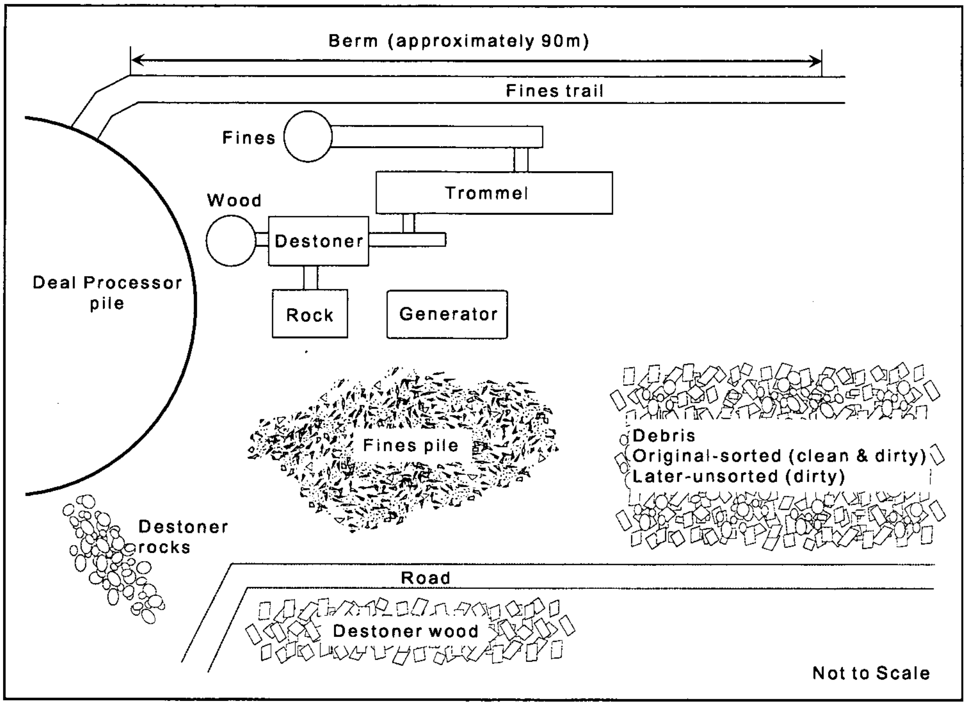

Figure 1. Layout of separation system at Lavington.

Residues had been accumulated since the summer of 1995 and were categorized into the following types:

- Dirty sorted: Residues accumulated when the logyard surface was wet. Larger wood had been removed for chipping.

- Dirty unsorted: Residues accumulated when the logyard surface was wet. Larger wood had not been removed.

- Clean sorted: Residues accumulated when the logyard surface was frozen. Larger wood had been removed for chipping.

- Clean unsorted: Residues accumulated at the log infeed deck to the sawmill when the compacted gravel was dry. Larger wood had not been removed.

- Deal Processor: Residues accumulated after being processed through the Deal Processor to reclaim chippable wood.

The logyard surface consisted of native soil under the log decks, and imported gravel and pit run material on the roads. Residues from a nearby glassware manufacturer were also used as fill in some areas of the logyard.

The main components of the separation system were a Powerscreen 830 trommel and a General Kinematics single-knife destoner with attendant connecting conveyors and stacking conveyors (Figure 2). Two front-end loaders, a Caterpillar 966 and a Caterpillar 950, fed the system and stockpiled the separated wood/bark, rock and fines. The Caterpillar 966 was the larger of the two, and was used to feed the trommel, stockpile fines, forward residues and stockpile fresh residues as they were trucked into the logyard. The Caterpillar 950 had a smaller bucket that could access the trommel oversize and destoner rock collection pits more easily.

The 2.4-m-wide by 9.14-m-long trommel had two screening sections 4.57 m long, with 22-mm mesh at the infeed end to remove fines and 76-mm mesh at the outfeed end. After several days of operation, the 22-mm

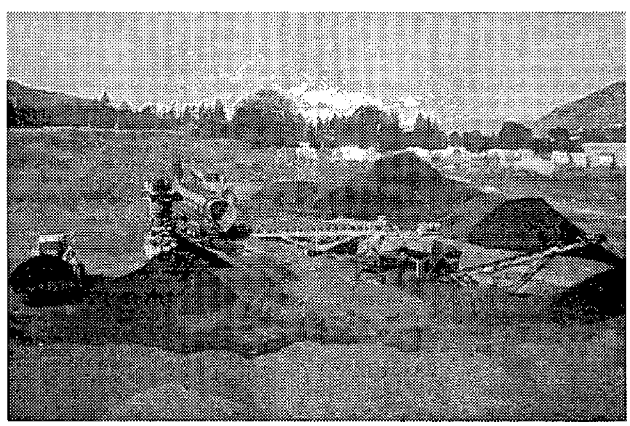

Figure 2. Separation system at Lavington.

mesh was replaced by 16-mm mesh to reduce the amount of fines generated. The material in the 16- (and 22-) to 76-mm size range was routed to the destoner where the wood and rock components were separated pneumatically (Figures 3 and 4). The material >76 mm that passed through the trommel was stockpiled for later sorting. The destoner and its infeed conveyor were powered by a portable 175-kW Discovery diesel generator, while the trommel and another conveyor had their own power sources.

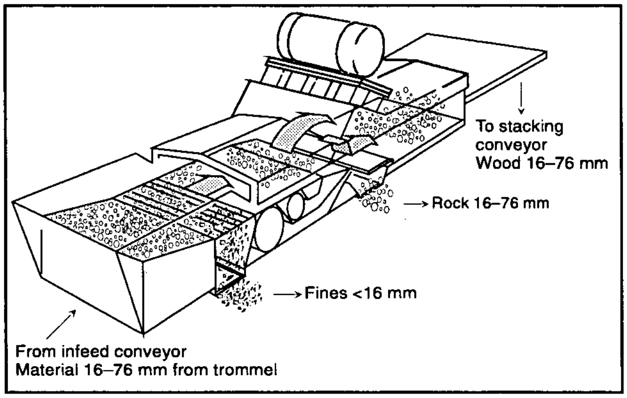

Figure 3. Operation of General Kinematics single-knife destoner.

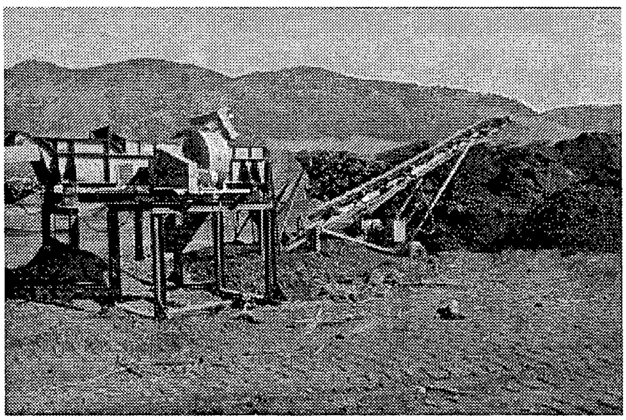

Figure 4. General Kinematics single-knife destoner.

Study Methods

Stratification by size class of the five residue types was done using a statistical quartering method. Samples of material <15 cm in size were placed in airtight bags, weighed and stored for later laboratory analysis. This included drying the residues to determine the moisture content, stratifying the residues, and burning the <13 mm residues to obtain the mineral and ash contents.

Shift-level time for the separation system and support equipment was recorded by FERIC researchers. Productivity was estimated by tallying the number of bucket scoops fed into the trommel infeed hopper by the front-end loader. The level bucket volume for each loader was known and visual estimates were added to determine the volumes of overfilled buckets. Detailed-timing data for the trommel loading cycles were collected, and observations of the operating system were made.

System costs were derived using FERIC's standard costing methodology. These costs do not include profit, overhead, costs related to lost productivity of one or more shifts, costs of transporting materials to and from the site, or costs related to out-of-shift repairs and maintenance. The derived costs are not the actual costs incurred by the company or contractor.

Samples of the 16- (and 22-) to 76-mm material from both the trommel and destoner's separated wood were taken daily at random intervals and placed in airtight bags for later laboratory analysis. (Collecting samples at the rock outfeed chute from the destoner was too dangerous.) This sampling procedure determined the composition of the material going from the trommel to the destoner and the efficacy of the separation done by the destoner.

Study Results

Stratification of Logyard Residues

Appendix I shows the results of the stratification process for the five residue types by weight. Table 1 summarizes the volume sampled for each residue type. The roundwood >1 m long represented 12 and 17% by volume of the clean and dirty unsorted material, respectively. Each sorted residue type (including that from the Deal Processor) contained less than 6% roundwood of this dimension. Because the logyard was unpaved, rock made up a considerable proportion by weight for all residue types (36–53%) except the clean unsorted material (22%) which was accumulated on the compacted gravel and paved area around the sawmill infeed (Figure 5). This location also had the highest

Table 1. Volume Samples of All Residue Types

Type	Samples (no.)	Volume (m^3)	Roundwood volumes >1 m (m^3)	(%)
Dirty unsorted	15	23.1	4.0	17.3
Clean unsorted	7	12.2	1.5	12.3
Dirty sorted	14	23.3	1.3	5.6
Clean sorted	14	25.7	1.3	5.1
Deal Processor	14	23.7	0.0	0.0

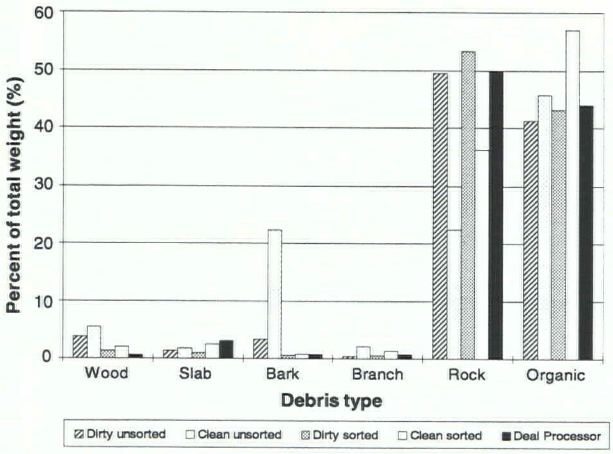

Figure 5. Weight of debris by type and origin.

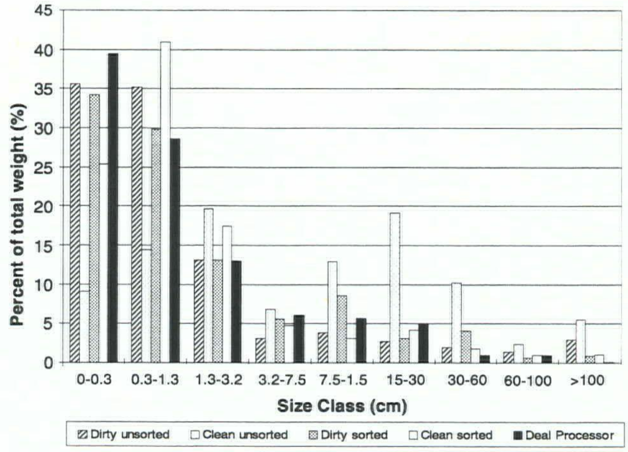

Figure 6. Weight of debris by size and origin.

proportion of bark (primarily Douglas-fir) by weight—22% compared to 1–3% for the other residue types. Table 2 categorizes the residues into >15 and <15 cm by component. Except for the clean unsorted material, more than 90% of the residues are in the <15 cm size class, and 64–71% was less than 13 mm (Figure 6).

Table 3 shows the moisture content for each residue type, for material <15 cm. This ranged from 25% for the clean unsorted material to 41% for the clean sorted material. The moisture content seemed to be influenced by seasonal variations. The driest material was the fresh summer run clean unsorted, followed by summer run Deal Processor material at 27% which had been piled over winter. The dirty unsorted material was fresh summer run and had a moisture content of 28% (heavy rain occurred during sampling). The dirty sorted material at 29% had been stored over winter while the clean sorted material, at the highest moisture content of 41%, had snow still melting in the piles during the stratification process.

Table 4 presents the results of burning the material 3–13 mm and <3 mm to obtain ash and mineral contents. The mineral contents of these two size classes were used to estimate the rock contents in these classes (Figure 5). The <3 mm component had a higher ash content in all residue types but generally a lower mineral content (except in the clean unsorted) compared to the 3–13 mm material. The mineral content in both size classes was lowest in the clean unsorted residue.

Shift-Level Study

Table 5 shows the results of the shift-level studies, with productivities ranging from 71 to 89 m^3/PMH (productive machine hour) across the three residue types observed. It was not possible to isolate the clean and dirty sorted residues during separation, nor could the clean and dirty unsorted residues be differentiated during processing. The fines were rescreened to remove the 16–22 mm material because a larger volume than

Table 2. Summary of Residues >15 cm and <15 cm

	Dirty unsorted (%)	Clean unsorted (%)	Dirty sorted (%)	Clean sorted (%)	Deal Processor (%)
>15 cm					
Roundwood	4	6	1	2	1
Slab	1	2	1	3	3
Branch	<1	2	1	1	1
Rock	0	5	5	2	2
Bark	3	22	1	1	1
Total	9	37	9	9	8
<15 cm					
Organic	41	46	43	57	44
Rock	50	17	48	34	48
Glass	<1	0	<1	<1	<1
Total	91	63	91	91	92

Table 3. Moisture Contents of Material <15 cm

	Moisture content (%)				
	Dirty unsorted	Clean unsorted	Dirty sorted	Clean sorted	Deal Processor
Average	28.2	24.6	29.1	41.0	26.8
Maximum	35.0	31.2	37.9	46.4	34.2
Minimum	16.4	17.0	14.5	36.1	19.1
No. of samples	15	7	14	14	14

Table 4. Summary of Burn Tests to Obtain Ash and Mineral Contents

Residue Source	<3 mm		3–13 mm	
	Ash [a] (%)	Mineral [b] (%)	Ash (%)	Mineral (%)
Dirty unsorted	91.2	44.7	87.8	73.9
Clean unsorted	62.4	21.4	23.9	17.0
Dirty sorted	87.2	40.7	85.3	59.0
Clean sorted	79.6	40.4	72.1	45.6
Deal Processor	89.6	34.6	85.4	67.9

[a] (Weight of ash)/[original weight (including mineral component)] × 100.
[b] (Weight of material >425 μm)/[original weight (including ash component)] × 100.

Table 5. Shift-Level Study Summary

	Mixed clean and dirty		
	Unsorted residue	Sorted residue	Rescreen fines 16 and 22 mm
Processing time			
Productive time (h)	31.46	72.54	24.83
Maintenance (h)	1.12	2.83	0.73
Repairs (h)	6.01	22.76	8.8
Non-mechanical delays (h)	4.60	8.31	-
Total (h)	43.19	106.4	34.36
Volume (m^3)	2 610.80	6 459.15	1 763.08
Productivity			
m^3/SMH	60.5	60.7	51.3
m^3/PMH	83.0	89.0	71.0
Out-of-shift maintenance (h)	-	7.1	1.5
Availability (%)	83	76	72
Utilization (%)	73	68	72

anticipated was generated during the initial stages of the project (thus a new residue type was introduced). The 16-mm screens were then left in the trommel for the rest of the material to be screened. The low productivity (71 m^3/PMH) during the rescreening of the fines was intentional; the loader operators feeding the trommel felt that too much of the material <22 mm in the first section of the trommel could blind the screens and result in excessive carryover of the <16 mm material to the next screening section and then to the destoner. At the destoner, the fines would plug the finger screen and be separated out with the wood or rock stream.

While Table 5 shows system availabilities ranging from 72 to 83%, Table 6 shows the availability for each system component exclusive of wait time. These ranged from 88–100% across the residue types.

Table 6. Shift-Level Delay Summary

Mechanical delays	Unsorted residues [a]	Sorted residues [a]	Rescreen fines [a]
Trommel			
Plugged hopper (h)	0.60	0.72	-
Plugged outfeed conveyors (h)	1.38	-	-
Clean drum (h)	0.18	-	-
Repair hopper guard screen (h)	-	1.50	-
Change screens (h)	-	9.08	-
Replace hydraulic filter (h)	-	-	0.28
Misc. welding (h)	-	0.70	-
Subtotal (h)	2.16	12.00	0.28
Availability (%)	95	89	99
Destoner			
Motor overheating (h)	3.33	-	-
Electrical (h)	-	1.78	0.98
Repair motor (h)	-	0.92	3.15
Adjust pneumatics (h)	0.32	-	-
Subtotal (h)	3.65	2.7	4.13
Availability (%)	95	98	88
Conveyors			
Misc. delays (h)	0.18	5.95	-
Availability (%)	100	94	100
Generator			
Misc. delays (h)	-	0.33	-
Availability (%)	100	100	100
Wait			
Parts (h)	-	-	0.83
Electrician (h)	-	1.15	3.55
Welder (h)	-	0.63	-
Subtotal (h)	-	1.78	4.38
Non-mechanical delays			
Breaks (h)	3.13	8.30	-
Safety meeting (h)	0.22	-	-
Pick up crew (h)	1.25	-	-
Subtotal (h)	4.60	8.30	-
Total (h) [a]	10.59	31.06	8.79

[a] Differences with Table 5 due to rounding.

Overall, mechanical delays represented 14–26% of time lost (Table 5). The 9 hours spent changing screens in the trommel (Table 6) was the longest mechanical delay, followed by 6 hours repairing and adjusting the attendant conveyors. Over 3 hours was attributed to the destoner motor overheating during very warm temperatures (38° C), which may have contributed to the failure of the motor and the loss of a shift.[1]

With a system cost of \$419.73/h (Appendix II), the unsorted residue costs \$6.94/m^3 to separate, the sorted residue \$6.92/m^3, and the fines \$8.18/m^3. These costs are based on productivities per scheduled machine hour.

Detailed-Timing Study

Detailed timing of the loaders dumping material into the infeed hopper of the trommel was carried out to determine if the dumping rates had any effect on separation efficacy. The lowest average dumping rate for the Caterpillar 966 and 950 loaders were 77 and 98 m^3/h, respectively, while reprocessing the fines (Table 7). As noted earlier, the low productivity while reprocessing the fines was intentional in order to avoid excessive carryover of small material in the trommel

[1] Lost shifts, i.e., shifts when no work was done, are not included in the shift-level data analysis.

Table 7. Detailed Timing of Loaders

	Sorted		Unsorted		Fines		Deal Processor	
	Cat 966	Cat 950	Cat 966	Cat 950	Cat 966	Cat 950	Cat 966	Cat 950
No. of observations	75	78	127	114	87	79	167	201
Average cycle time								
Wait time (min)	0.6	0.5	0.5	0.6	0.6	0.6	-	-
Dump time (min)	3.0	2.4	3.8	2.4	4.2	3.0	3.0	1.9
Total (min)	3.6	2.9	4.3	3.0	4.8	3.6	-	-
Total dumped (m^3)	412.2	375.3	702.6	557.2	471.5	382.4	986.7	1060.6
Dump rate	108.4	121.2	86.7	121.7	76.8	98.6	117.0	163.3
Average (m^3/h)	108.4	121.2	86.7	121.7	76.8	98.6	117.0	163.3
Range (m^3/h)	63.9–234.3	80.2–280.8	47.5–259.2	57.6–269.4	50.3–154.3	62.5–200.0	72.3–263.7	75.7–308.9

and on to the air separator. The highest dumping rate for both loaders occurred when processing the residues from the Deal Processor, with the Caterpillar 966 and 950 loaders dumping 117 and 163 m^3/h, respectively, into the trommel infeed hopper .

Table 7 also shows that (except for the Deal Processor) 12–19% of the loaders' cycle times were spent waiting for each other. The dump rate was decreased for the Caterpillar 966 in the unsorted material, and this was reflected in the shift-level productivities. When dumping, extra care had to be taken to prevent the larger pieces from becoming jammed in the trommel infeed hopper.

Separation Efficacy

Before separation, the wood component of the <76 mm material averaged 31–40% (Table 8) by weight across all residue types except for the fines. After separation, the wood component almost doubled to 63–77% in each type. Much of the rock component (39–52%) was ejected by the destoner, but 5–9% still managed to get through with the wood component. Some of the fines component carried over from the trommel and then from the destoner, and contributed 17–32% by weight to the separated wood samples.

Prior to rescreening, the fines were composed of 28% wood, 38% rock and 34% material (by weight) <16 mm. After screening, these ratios changed to 47% wood, 3% rock and 50% material <16 mm. Although the destoner was equipped with a vibrating finger screen to remove carried-over fines and to spread the material before reaching the pneumatic separation chamber, the high moisture content and volume of the fines kept this screen plugged (Figure 7). The fines buildup on the screen was frequently removed through manual scraping, but clods of material fell out with the rock in the separation chamber while the smaller fractions were removed with the wood/bark.

Adjusting the loaders' feed rate when rescreening the fines (which originated from the sorted residues)

Table 8. Separation Efficacy for Material <76 mm

	Sorted		Unsorted		Fines		Deal Processor	
	Before	After	Before	After	Before	After	Before	After
Wood & bark								
% (by weight)	40	77	31	68	28	47	39	63
Range (%)	27–53	67–85	29–34	62–76	23–35	40–59	30–54	22–83
Rock								
% (by weight)	52	6	46	9	38	3	39	5
Range (%)	39–64	3–9	37–57	6–11	33–42	2–3	22–52	2–10
Glass								
% (by weight)	<1	<1	0	<1	0	0	<1	<1
Range (%)	<1	<1	0	<1	0	0	<1	1–<1
Fines (<16 mm)								
% (by weight)	9	17	23	24	34	50	22	32
Range (%)	3–22	9–24	8–35	18–29	28–44	39–57	8–47	9–74

Figure 7. Plugged finger screen at entrance to destoner.

does not appear to have taken care of the carryover problem. The sorted residues that were initially screened with 22-mm screens had a lower proportion of fines before and after separation in the destoner than the other residue types that were screened with 16-mm screens in the trommel. The slightly lower feed rate for the Caterpillar 966 loader could also have helped achieve the lower proportions of fines carried over.

Residue Utilization

Table 9 summarizes the utilization of the residues. These results do not precisely reflect the trommel screen mesh size of 16 mm as the laboratory screen used was 13 mm. As a result, the utilized rock and wood/bark will be slightly high while the unutilized fines will be low.

Reclaimed rock for use in the logyard ranged from 10–15% across all residue types. Wood/bark to be burned represented 4–16%, bringing the total residue utilized to 16–26%.

Fines (<13 mm) represented the bulk of the unutilized sorted residues. Organic material (including wood, bark and branches) and rock (both >7.5 cm) that remained unsorted after screening accounted for 12–50% of the residues. Of this, 1–5% is comprised of wood >30 cm that is potentially suitable for chipping. When a density factor (derived from Table 1) is applied, this wood represents 9–25% by volume of all materials sampled.

Discussion

Due to the high proportions of material <13 mm in most of the residues, the 22- and 16-mm screens in the first section of the trommel could not completely separate out the fines. Consequently, the carried-over fines moved through the system, plugged the vibrating finger screen at the destoner, and were pneumatically separated out with the 16–76 mm wood. Although the fines component was less when the 22-mm screens were used in the trommel, they were still 17–32% (by weight) of the wood product. A cleaner product probably could have been delivered to the destoner if the material was drier or if the trommel was equipped with 16-mm screens throughout and preceded by a scalping screen. This scalping screen would divert the >76 mm residues to a picking belt for the manual separation of wood for chipping, rock for the logyard and organics for the burner. This would result in a 12–50% increase by weight (Table 9) of reclaimed material. During the trial, the tumbling action of the trommel tended to break down the bark pieces, resulting in more fines, while coating them with sand prior to being conveyed to the destoner. This would

Table 9. Summary of Residues Utilization by Weight

	Dirty unsorted (%)	Clean unsorted (%)	Dirty sorted (%)	Clean sorted (%)	Deal Processor (%)
Utilized					
Rock 13–75 mm	11	10	14	13	15
Wood/bark 13–75 mm	5	16	5	9	4
Total	16	26	19	22	19
Not utilized					
Rock >75 mm	2	9	13	3	7
Organic >75 mm	7	36	3	7	6
Fines <13 mm	71	24	64	66	68
Wood >30 cm [a]	4(25) [b]	5(14) [b]	1(9) [b]	2(9) [b]	1
Total	84	74	81	78	82

[a] Wood >30 cm potentially suitable for chipping.
[b] Numbers in parentheses represent % by volume.

add to the processing cost but could result in increased production and a lower cost per cubic metre overall, as the loader operators would not have to be as restrained in their dump rates. The fines component in the separated wood caused excess clinker formation in the burner because of the high mineral content, and this material was stockpiled. Tolko is currently considering using this wood/bark/fines mix as a mulch.[2]

Appendix III presents a cost analysis based on the stratification of the dirty unsorted residues (weight to volume conversion and values are as noted). The calculations also assume the reclamation of the rock and wood >13 mm with the wood >30 cm being chipped for pulp furnish. The total cost of $9.25/m^3$ of residue generated is 15% higher than the landfill cost ($8/m^3$). However, because there would be a 67% reduction in materials landfilled, landfill life would be extended. If a no-cost use for the fines and bark/wood <75 mm (e.g., composting, soil amendment) could be found, thus eliminating burning and landfill costs, the total cost could be reduced by $3.64/m^3$. This would result in a total sorting cost of $5.61/m^3$ which is well below the landfill cost.

Conclusions

Five distinct residue types were identified for stratification by size class: dirty unsorted, clean unsorted, dirty sorted, clean sorted and Deal Processor (the first four were based on season and content, and the last one was based on source.) Wood >1 m in length represented 12–17% by volume in the two unsorted residues while contributing <6% by volume to the sorted residues. Rock made up 36–53% by weight of four of the residues from the logyard, with only 22% from the area around the sawmill infeed. Following this same trend, fines (material <13 mm) comprised 64–71% in the former and 24% in the latter. Moisture contents followed seasonal accumulation trends and ranged from 25 to 41%.

System availabilities ranged from 72 to 83%, with individual component availabilities between 88 and 100%. Productivity was 51–61 m^3/PMH and costs ranged from $6.92 to $8.18/m^3$ of input material. Separation efficacy, based on the wood/bark recovery material stream, realized 63–77% wood/bark; 5–9% rock; and 17–32% fines (<16 mm). Rescreened fine material <22 mm down to 16 mm resulted in 47% wood/bark, 3% rock and 50% fines.

Because of the high proportion (64–71%) of material <13 mm in all but the clean unsorted group, the screens in the trommel could not separate out the fines completely in the first section of the trommel. Consequently, the carried-over fines moved through the system, plugged the fines screen at the infeed of the destoner, and were pneumatically sorted with the wood/bark component. This, in turn, caused excess clinker formation in the burner, and the material was stockpiled for possible use as a mulch. A solution to reduce the plugging of the destoner fines screen could be to use a 76-mm scalping screen at the trommel infeed and use the same size mesh throughout the length of the trommel.

A cost analysis based on the stratification results for the dirty unsorted residues arrived at a cost of $9.25/m^3$ for sorting, burning and landfilling. This also includes the values for reclaimed rock and chippable wood. Although this costs 15% more than straight landfilling ($8/m^3$), there would be a 67% volume reduction in materials landfilled, thus extending landfill life. If a no-cost use for the fines and burnable bark/wood (e.g., composting, soil amendment) could be found, the total cost could be reduced by $3.64/m^3$, resulting in a total sorting cost of $5.61/m^3$.

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[2] Kim Young, Tolko Industries Ltd., personal communication October 1998.

Appendix I

Summary of Residue Types by Weight

Type	Roundwood (kg)	Slab (kg)	Bark (kg)	Branch (kg)	Rock (kg)	Glass (kg)	Organic (kg)	Total (kg)	Total (%)
Dirty unsorted									
>1 m	614.7	64.5	21.7	10.7	-	-	-	711.7	3.0
60–100 cm	221.3	48.8	49.1	14.9	-	-	-	334.1	1.4
30–60 cm	47.5	145.6	243.4	42.7	-	-	-	479.2	2.0
15–30 cm	48.6	65.4	508.5	33.9	-	-	-	656.4	2.7
7.5–15 cm	-	-	-	-	471.0	-	467.7	938.8	3.9
3.2–7.5 cm	-	-	-	-	582.9	-	166.5	749.4	3.1
13–32 mm	-	-	-	-	2 022.4	2.6	1 120.2	3 145.2	13.1
3–13 mm	-	-	-	-	5 697.1	-	2 753.5	8 450.6	35.2
0–3 mm	-	-	-	-	3 150.0	-	5 413.3	8 563.3	35.6
Total	932.2	324.4	822.7	102.1	11 923.4	2.6	9 921.2	24 028.5	-
%	3.9	1.3	3.4	0.4	49.6	0.0	41.3	-	-
Clean unsorted									
>1 m	248.0	18.7	7.4	19.5	-	-	-	293.6	5.5
60–100 cm	30.1	9.5	71.0	15.5	-	-	-	126.1	2.4
30–60 cm	11.2	38.6	321.8	23.0	150.4	-	-	545.0	10.2
15–30 cm	6.1	26.9	790.4	58.2	139.5	-	-	1 021.1	19.1
7.5–15 cm	-	-	-	-	182.3	-	506.8	689.0	12.9
3.2–7.5 cm	-	-	-	-	235.8	-	129.1	364.9	6.8
13–32 mm	-	-	-	-	297.9	-	748.9	1 046.7	19.6
3–13 mm	-	-	-	-	105.0	-	661.6	766.6	14.4
0–3 mm	-	-	-	-	85.7	-	401.2	486.8	9.1
Total	295.4	93.6	1190.6	116.3	1 196.5	0.0	2 447.5	5 339.8	-
%	5.5	1.8	22.3	2.2	22.4	-	45.8	-	-
Dirty sorted									
>1 m	177.7	7.2	5.6	8.0	-	-	-	198.5	0.9
60–100 cm	75.0	35.3	1.9	38.2	-	-	-	150.3	0.7
30–60 cm	34.2	64.8	21.6	51.0	752.0	-	-	923.7	4.1
15–30 cm	-	114.6	115.2	42.2	439.7	-	-	711.7	3.1
7.5–15 cm	-	-	-	-	1 759.7	-	183.2	1 942.9	8.6
3.2–7.5 cm	-	-	-	-	1 140.2	-	125.0	1 265.2	5.6
13–32 mm	-	-	-	-	1 951.0	25.1	997.0	2 973.1	13.1
3–13 mm	-	-	-	-	3 496.0	-	3 274.0	6 770.0	29.8
0–3 mm	-	-	-	-	2 570.9	-	5 201.3	7 772.2	34.2
Total	286.9	221.9	144.3	139.5	12 109.5	25.1	9 780.5	22 707.6	-
%	1.3	1.0	0.6	0.6	53.3	0.1	43.1	-	-
Clean sorted									
>1 m	194.2	2.1	0.2	10.6	-	-	-	207.0	1.1
60–100 cm	113.7	50.6	-	33.4	-	-	-	197.7	1.0
30–60 cm	19.5	232.6	20.3	73.1	-	-	-	345.6	1.8
15–30 cm	42.9	209.9	137.0	123.5	288.0	-	-	801.3	4.2
7.5–15 cm	-	-	-	-	274.7	-	308.6	583.3	3.1
3.2–7.5 cm	-	-	-	-	807.4	-	97.3	904.7	4.8
13–32 mm	-	-	-	-	1 560.3	0.8	1 752.8	3 313.9	17.5
3–13 mm	-	-	-	-	2 563.3	-	5 191.2	7 754.4	41.0
0–3 mm	-	-	-	-	1 365.7	-	3 426.8	4 792.5	25.4
Total	370.3	495.2	157.4	240.7	6 859.4	0.8	10 776.7	18 900.5	-
%	2.0	2.6	0.8	1.3	36.3	0.0	57.0	-	-
Deal Processor									
>100 m	3.2	23.1	-	3.3	-	-	-	29.6	0.1
60–100 cm	111.2	84.6	7.8	8.6	-	-	-	212.2	1.0
30–60 cm	33.1	123.8	4.6	55.2	-	-	-	216.8	1.0
15–30 cm	-	439.0	148.5	113.0	362.9	-	-	1 063.4	5.0
7.5–15 cm	-	-	-	-	1 037.3	-	178.6	1 215.9	5.7
3.2–7.5 cm	-	-	-	-	1 124.6	29.4	137.8	1 291.8	6.1
13–32 mm	-	-	-	-	2 036.7	18.7	710.4	2 765.8	13.0
3–13 mm	-	-	-	-	3 684.7	-	2 381.7	6 066.4	28.6
0–3 mm	-	-	-	-	2 362.3	-	6 021.8	8 384.1	39.5
Total	147.5	670.5	160.9	180.1	10 608.6	48.1	9 430.3	21 246.0	-
%	0.7	3.2	0.8	0.8	49.9	0.2	44.4	-	-

Appendix II

System Cost Calculations

	Caterpillar 950 front-end loader	Discovery diesel generator	Powerscreen 830 trommel	Caterpillar 966 front-end loader	Conveyors	General Kinematics destoner
OWNERSHIP COSTS						
Total purchase price (P) $	270 000	49 935	289 000	392 000	57 750	79 520
Expected life (Y) y	8	20	6	8	6	20
Expected life (H) h	11 520	28 800	8 640	11 520	8 640	28 800
Scheduled hours/year (h)=(H/Y) h	1 440	1 440	1 440	1 440	1 440	1 440
Salvage value as % of P (s) %	30	30	30	30	30	20
Interest rate (Int) %	7	7	7	7	7	7
Insurance rate (Ins) %	3	3	3	3	3	3
Salvage value (S)=((P•s)/100) $	81 000	14 980	86 700	117 600	17 325	15 904
Average investment (AVI)=((P+S)/2) $	175 500	32 458	187 850	254 800	37 538	47 712
Loss in resale value ((P-S)/H) $/h	16.41	1.21	23.41	23.82	4.68	2.21
Interest ((Int•AVI)/h) $/h	8.53	1.58	9.13	12.39	1.82	2.32
Insurance ((Ins•AVI)/h) $/h	3.66	0.68	3.91	5.31	0.78	0.99
Total ownership costs (OW) $/h	28.60	3.47	36.45	41.52	7.28	5.52
OPERATING COSTS						
Fuel consumption (F) L/h	16	27	14	21	5	-
Fuel (fc) $/L	0.45	0.45	0.45	0.45	0.45	-
Lube & oil as % of fuel (fp) %	10	10	10	10	10	-
Annual tire consumption (t) no.	1	-	-	1	-	-
Tire replacement (tc) $	5 200	-	-	6 860	-	-
Annual operating supplies (Oc) $	-	500	6 500	-	2 520	500
Annual repair & maintenance (Rp) $	28 550	1 000	41 667	42 140	7 000	3 976
Shift length (sl) h	8	8	-	8	-	-
Operator wages ($/h)	22.03	-	-	22.03	20.10	50.00 [a]
Wage benefit loading (WBL) %	35	-	-	35	35	35
Fuel (F•fc) $/h	7.20	12.15	6.30	9.45	-	-
Lube & oil ((fp/100)•(F•fc)) $/h	0.72	1.22	0.63	0.95	2.25	-
Tires ((t•tc)/h) $/h	3.61	-	-	4.76	0.23	-
Operating supplies (Oc/h) $/h	-	0.35	4.51	-	1.75	0.35
Repair & maintenance (Rp/h) $/h	19.83	0.69	28.94	29.26	4.86	2.76
Wages & benefits (W•(1=WBL/100)) $/h	29.74	-	-	29.74	27.14	67.50
Total operating costs (OP) $/h	61.10	14.41	40.38	74.16	36.23	70.61
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	89.70	17.88	76.83	115.68	43.51	76.13

[a] The cost for a full-time supervisor/mechanic with a shop truck is included to reflect an operational rather than a trial system.

Appendix III

Net Value and Cost of Sorting Residues

Recovered Materials	Volume of sorted residues (m^3/m^3)	Value ($/$m^3$)	Value of sorted residues ($/$m^3$)	Cost ($/$m^3$)	Cost of sorted residues ($/$m^3$)
Wood >30 cm	0.25	2.79 [a]	0.70	-	-
Rock >13 mm	0.08 [b]	7.85	0.63	-	-
Wood and bark 13 mm–30 cm (to burn)	0.34 [c]	-	-	2.94 [d]	1.00
Fines <13 mm (to landfill)	0.33	-	-	8.00 [d]	2.64
Sorting cost	-	-	-	6.94 [e]	6.94
Total	1.00	-	1.33	-	10.58
Net cost to sort residues [f]	-	-	-	-	9.25

[a] Based on value of $8/BDU for pulp chip furnish at 2.87 m^3 SWE (solid wood equivalent).
[b] Based on 1.70 t/m^3 for 30 cm minus rock (Per Construction Aggregates Ltd., personal communication January 1999).
[c] Average bulk density of lodgepole pine, white spruce and amabilis fir barks @ 50% moisture content (Neilson, R.W.; Dobie, J.; Wright, D.M. 1985. Conversion factors for the forest products industry in Western Canada. Forintek Canada Corp., Vancouver, B.C. Special Publication No. SP-24 R. 92 pp.)
[d] Per Kim Young, Tolko Industries Ltd., personal communication October 1998.
[e] From Appendix II and Table 5.
[f] Total sorting cost = sorting cost in this study + landfill cost + burn cost - value of sorted residues.