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The In-woods Cleaning of Whole-Tree-Chips

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THE IN-WOODS CLEANING OF WHOLE-TREE-CHIPS

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(ABSTRACT)

This research examined Whole-Tree-Chip cleaning methods applicable to field operations in <u>Pinus taeda L.</u> (Loblolly pine) on the coastal plain of South Carolina. Objectives were: 1) to examine current and potential cleaning methods, and 2) develop and test two cleaning approaches suggested by past research.

An open top chip van was modified to: a) determine the dispersion and composition of whole-tree-chip fractions by the installation of sampling buckets and floor pans and b) provide a platform for testing two cleaning systems. System one consisted of anti-clogging screens which pre-screened chips as they were discharged at the mill. It also allowed floor pans to sample the load for fines. System two utilized a radial blade blower which altered chip stream composition during loading by the Whole-Tree-Chipper.

Eight trials were conducted over a six month period using a Morbark 22 chipper. Results indicated floor screens could have been more effectively positioned at the chip dump. As installed, they successfully removed 1% of the load in fines and pin chips. The best chip stream treatment involved double deflection: first from a vacuum assisted primary screen located in the van roof, and then from a passive screen located below and behind the first. This design reduced bark and fines by one-third.

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Table of Contents

APPENDIX A.

APPENDIX B.

APPENDIX C.

List of Illustrations

List of Tables

INTRODUCTION

This study considerd methods of cleaning chips from forest residues. The fiber source consists of logging waste, cull trees, wind falls, thinnings and stands unprofitable to harvest with current industry practices. While many forest product companies do not consider these materials marketable, they represent the largest currently underutilized fiber source.

As shown in Table 1, estimates of unused material (USDA Forest Service 1979) include: 100 million tons of logging residues; 20 million tons of timber stand improvement or land clearing wastes; and close to one-billion tons of dead or non-commercial timber. The combined figure of 1.12 billion tons represent approximately 72 billion cubic feet of fiber. Biltonen and Mattson (1979), estimated this figure to be five times larger than the 13 to 15 billion cubic feet of timber then being consumed annually.

Problems associated with harvest and transportation of the above fiber supply are as large as the source itself. Bark and minerals concentrated in Whole-Tree-Chip mixes create a multitude of problems in pulping, bleaching, and papermaking. As a consequence, after the 1970's energy crisis, many mills began refusing Whole-Tree-Chips. Regardless of their source, Whole-Tree-chips would be acceptable for some processes if methods were available for removing bark and other contaminants before, during, or after chipping.

Debarking practices

Originally, debarking was done with axes, spuds, and draw knives, As technology progressed, machines replaced these

Table 1. - Sources of forest residues by regions in the United States (USDA. Forest Service 1976)

Region	Annual logging residues	Annual salvage timber	Inventory of non-commercial timber
	(In millions of tons, oven dry basis)		
Pacific Coast	26	1.6	148
Rocky Mountain	6	0.2	180
South	52	11.8	375
North	26	6.0	281
Total	110	19.6	984

hand tools. Mechanical debarkers are fairly efficient when used on bole wood, and chips from these stems are low in contaminants. The main opportunity cost associated with this practice is the loss of limbs and tops which compromise up to 50 percent of a tree's total fiber weight.

Technology and economics are interactive. Technologies are available for removing the bark and other impurities, but cost is prohibitive. Technology is driven by necessity and in this instance the necessity is financial. Bark removal after chipping could be a solution.

Processes and products which meet technical, economic and market requirements are developing slowly. Current research in whole tree utilization centers around methods of separating the bonds between wood, bark and foliage; then segregating useable fractions for further treatment. Several methods of achieving this objective have been found, but few have enjoyed commercial acceptance. Benefits of developing a process should include an increased raw material supply and decreased costs. Problems are encountered in the areas of processing speed, raw material waste, economic cycles and market competition from conventional sources.

Whatever problems are associated with existing methods, the primary objective is to develop cost effective means of delivering an uncontaminated product. Separation of bark from wood is critical in this effort because of bark's effect on the pulping process. Not only does it consume liquor and bleach, but it introduces soil, silica, and rock which can damage processing equipment, and result in product degrade.

Objectives

Thus the objectives of this research were twofold. First to review research which led to, and benefited from a effort by the Technical Association of the Pulp and Paper Institute (TAPPI). This was the first major compilation of chip-bark separation and segregation studies during the middle nineteen-seventies. And second to field test methods for in-woods cleaning of Whole-Tree-Chips.

LITERATURE REVIEW

In the mid-seventies Whole-Tree-Chips were thought to be a panacea for conversion of low grade forest stands and logging residues. However, there was controversy as a staff report from Pulp and Paper (June 1975) found contradictory accounts concerning a mill's ability to utilize unscreened whole-tree chips. The phenomena is a result of the varying quality and variety of pulp processing equipment in use throughout the industry. Favorable results are reported by mills using 10% to 100% unscreened whole-tree chips. Most are used in the production of coarse grades of paper or construction board (corrugating medium, roofing, fiber and insulating board). Mills producing higher grade fine paper and bleached board have also used this same furnish to lesser degrees. There is, however, little agreement between mills concerning ratios of whole-tree to mill chips for production of any one grade. Problems encountered were bark, sand, dirt, and non-uniform sized chips. Excess bark results in additional pulping chemical, lower yields, and digester scaling. While sand and dirt cause equipment wear and equipment plug ups.

To utilize more than 20% - 25% whole-tree chips, especially in high-quality mills, bark content should not exceed 4%. Lowe (1975) claims this figure is achievable with commercially available screening equipment. The price paid for each percentage point was estimated by a Canadian firm researching mill runs of whole tree chips. Each percentage point of bark and fines resulted in .35% more alkali charge, .3% increase in bleaching chemicals, and 3.8% decrease in digeater output (Lowe 1975);

CHIP CHARACTERISTICS

Chip quality descriptions normally assume the form of a chip classification table. Size classifications range from material retained on a 1-3/8 inch screen through material which will penetrate a 1/8 inch opening. Size class ranges and bark ratios indicate a number of characteristics which affect chip mix pulping ability.

Disproportionately large oversize classes (>1-3/8") can indicate slow chipper disk speeds or improper knife/anvil settings. Size class distributions skewed toward the smaller sizes, generally indicate dull knives which hammer the furnish into pin chips and dust. High bark concentrations are caused by stand conditions, failure to delimb, or chipping only limbs and tops in integrated harvesting operations.

Historically, screen analysis is accomplished with the aid of wire screens or punched plates installed in a Williams Classifier. Use and interpretation of such devices were outlined in 1961 as Tentative Standard T16 Sieve Analysis of Pulpwood Chips by the Technical Association of the Pulp and Paper Industry (TAPPI).

In 1974 TAPPI rescinded this standard due to mounting evidence that factors which have a large effect on pulp quality were not quantified by the T16 standard. Part of the problem arises from the wide variety of chip characteristics. For example, chips from saw mills and veneer plants were mostly sapwood while Whole-Tree-Chips contain all parts of the tree (Hatton, 1977).

Table 2. Average chip classification of hardwood Whole-Tree-Chips used at a New England mill (Hatton, 1977).

CHIP CLASSIFICATION	WHOLE-TREE	MILL
Chips retained		
on screen size:	%	%
1-3/8 in.	9.3	16.6
7/8 in.	16.3	22.6
5/8 in.	27.7	28.0
3/8 in.	32.2	24.5
3/16 in.	11.6	7.2
Dust	2.9	1.1
Bark, %	4.1	0.4

Individual stems have an assortment of parts each with its own characteristic. Baadsgaard-Jensen (1985), in his paper Micro Fractionation of Whole-Tree Components, describes a tree as composed of macro and micro-fractions. As shown in Table 3, only root, stump and transition wood are omitted from Whole-Tree-Chips.

While "The macro fractionation model" describes chipper infeed material, the Technical Association of the Pulp and Paper Industry (TAPPI) has quantified output. The 1982 TAPPI Official Test Method T 265 om-82, Natural Dirt in Wood Chips presents chip elements in Table 4. This somewhat more pedantic presentation gives an idea of the problems associated with characterizing pulp furnish.

Hatton's (1978) consideration of the problem gives a better feel for contaminant quantification. Table 5 lists his fourteen "Principal chip quality parameters" and the difficulties associated with their measurement.

Other authors have commented on the above characteristics and their effects on various pulping processes. The following discussion will examine some nuances of the fiber source and demonstrate the limited role of sieve analysis in determining chip quality.

Table 3. The Macro Fractionation Model (Baadsgaard-Jensen, 1985).

Macro-fractions	Micro-fractions
roots	root bark
	root wood
stump	stump bark
	stump wood
stem	stem bark
	stem wood
top	stem bark
	stem wood
	branch wood
	foliage
branches	branch bark
	branch wood

Table 4. Chip Contaminants (TAPPI T 265 om-82).

- Bark:
  - Juvenile;
    - inner bark,
    - outer bark,
  - Mature;
    - inner bark,
    - outer bark.
- Knotwood:
  - Hard; light, dark,
  - Normal; light, dark,
  - Pin knots.
- Leaves/needles.
- Dirt, external.
- Internal inorganics:
  - silica,
  - ash,
  - Resin pockets.
- Decayed wood:
  - brown rot,
  - white rot,
  - black streak.
- Pith.
- Insect holes.

Table 5. Principal chip quality parameters (Hatton, 1978)

Parameter	Ease of measurement		
	Practical	Difficult	Impossible
1. Average moisture content	X		
2. Range of moisture content			X
3. Bulk Density	X		
4. Chip "size" factons[a]	X		
5. Chip length		X	
6. Chip width	X[b]	X[c]	
7. Chip thickness	X		
8. Diagonal[d]thickness ratio		X	
9. Compression damage		X	
10. Chip contaminants:			
Bark,	X[e]		
Knotwood,	X		
Leaves/needles,		X	
Extraneous dirt,		X	
Internal inorganics,		X	
Decayed Wood.		X	
11. Species identification		X[f]	
12. Ratio of species in mix		X[f]	
13. Sapwood heartwood ratio			X
14. Sawmill woodroom chip ratio			X

[a] Chips retained on a screen plate with known round or square hole openings.

[b] Feasible for narrow-width chips such as pin chips.

[c] Handsorting and measurement required for wider chips which have widths in excess of chip lengths for the sample.

[d] Diagonal across the face of chip to a combination of chip length and width.

[e] Feasible for loose bark or bark attached to chips of acceptable dimensions.

[f] Could be impossible in unfavorable cases.

Both the range and average moisture content of any chip mix affect digester performance. Amounts of bound water in cell wall material and free water, adhering to cell walls or filling the cell cavity, affect liquor concentrations. When chips are below the fiber saturation point pulping liquors must displace air in cell material via viscous flow. Where passages are smaller than one micrometer vapor molecules pass at rates determined by mean free path between molecule collisions in the passage. When chips are at or above fiber saturation, diffusion speeds liquor penetration. (Panshin and De Zeeuw, 1980).

Chip length is especially critical in sulfite pulping. Individual measures are hard to determine by mechanical screening (possible exception is the Domtar screen) and are normally determined by hand. Variations in chip length affect softwood pulping more than hardwoods. Coniferous specie permeation rates are limited by the small size margo passage to the pit membrane. Hardwoods have a wider range of vessel diameters which give permeability values up to ten times those of softwoods (Panshin and De Zeeuw, 1980).

Chip thickness as it relates to lateral permeability is less important. Travel rates across the grain are hampered by a large number of cell walls. Rates can be 1,000 to 100,000 times slower than penetration along the grain (Comstock, 1968). However, over-thick chips present another problem. They contain large proportions of knotters and other undesirable shapes which result in nonuniform penetration of cooking chemical and high fiber screen rejects (Hatton, 1979).

The diagonal/thickness ratio is a measure of chip shape. It is inversely proportional to bulk density and has a significant effect on production capacity in the wood-handling and digestion systems. Should chip thickness be decreased for improved pulping, a corresponding reduction of the diagonal face must be made to avoid a decrease in chip-packing density (Edberg et al, 1973). Arola offers further illumination..."Conventional pulp chips have a low bulk density due to the high proportion of interparticle void space - the smaller the particle size, the greater the volume of voids. A solid unit of wood, when chipped, expands in volume by a factor of about 2-1/4 to 2-1/2. The bulk density of uncompacted pulp chips generally ranges between 15 and 20 pounds per cubic foot (pcf) based on green weight. This low density adversely impacts their transportation and on site storage" (Arola et al. 1983).

Low density species consume less liquor or require less mechanical energy than higher density wood. Therefore, variations within as well as between species can require different pulping procedures. When species are mixed, chip identification and ratio determination is not practical in a production setting. Early and late wood also have different density characteristics. Ratios vary not only between trees of different ages, but within individual trees. Early wood is characterized by low cell wall thickness to cell wall diameter ratios and is less dense. When cooked along with denser material it yields less pulp causing increased liquor consumption. Such disparities adversely effect tensile, burst and tear strength (Panshin and De Zeeuw 1980).

Similarly, sapwood/heartwood ratios change with furnish source and tree physiology. In a pulping study of young paulownia (Paulownia tomentosa) twice as many extractives were found in the sapwood as in the heartwood. It is hypothesized that higher sapwood extractive content can be attributed to extraction of soluble sugars from the hemicellulose fraction of wood. Sucrose, glucose, and fructose are common in the sapwood of hardwoods (Olson, Carpenter 1982). The amount of heart wood in furnish is important because of higher extractive content and low pulp yields from chemical processes (Hatton 1978). This is especially true considering the amount of sawmill chips or sapwood commonly used as a furnish source. In Kraft processes, fiber length and permeability differences would result in less pulp and liquor recovered and high screen rejects (Panshin and De Zeeuw 1980).

Pin chips and fines adversely effect digester efficiency by impeding liquor flow through a chip mass. Small particles reduce circulation rates and cause a loss of pulp quality in forced circulation digesters. They plug liquor extraction screens and reduce diffusion washing efficiency in continuous digesters (Powell et al. 1975). Some pin chips and fines are always formed during chipping. However, levels increase when chipping frozen wood, or chipper settings are incorrect, chip-handling systems are improperly designed or the chipper is poorly maintained (Arola et. al. 1983).

Mechanical damage incurred during pneumatic transport often takes the form of compression damage. "Bruised" chips cause special concern for sulfite pulp producers (Hatton 1978). Compression damage decreases fiber length through breakage and seals vascular or cellular voids from penetration by pulping liquors. Winter and Mjöberg (1985) studied compression damage across and with the grain in both water-saturated and air-dry specimens. Sinusoidal oscillations of varying durations and pressures were applied to samples and results were measured ... "as a drop in viscosity in relation to the reference after a standardized sulfite delignification." Their findings indicate that regardless of whether compression is applied parallel or perpendicular to the grain, damage is more pronounced and deformation more permanent in air-dry than in water saturated specimens. Implications of this study mitigate against air driven chip handling systems when chips have had a chance to air-dry on storage yards. At the same time these findings indicate that pneumatic transport and mechanical treatments applied at the chipper to van interface, do the least damage as green chips are well above the fiber saturation point.

DEBARKING

In the previous section several factors influencing chip quality were outlined. While extreme variances in any of those characteristics create undesirable conditions, bark and imbedded dirt or silicates represent the major impediment to Whole-Tree utilization.

The bole of a standing tree represents essentially clean fiber surrounded by a protective bark sheath. This segment represents up to 80% of the total pulpwood volume for pine and 60% for hardwoods. Residual material in the form of limbs, crown, and stump are normally treated as contaminants because of the effort required to recover clean fiber from these segments (McWilliams, 1988). For this reason delimbing is the minimum pretreatment for almost all pulpwood chipping operations.

The remaining bark contains from five to twenty percent usable fiber, depending on species. Although alpha cellulose production from uncontaminated fiber approaches sixty percent, bark in the chip mix appears as dirt, after pulping, and results include a corresponding decrease in yield. Different processing technologies tolerate bark at varying levels. Progressively decreasing bark contents are required for the following processes: unbleached Kraft, bleached Kraft, bleached sulphite, groundwood, and unbleached sulphite (Erickson 1979).

Along with the well-documented effects of increased bark levels from Whole-Tree-Chipping are the less well-known effects of increased dirt. Silicates and grit are wind blown to the standing tree and imbedded in the bark during logging operations. The abrasive nature of these contaminants increase wear in mechanical systems and may be more important than decreased hand sheet strengths or lower pulp yields. Removing bark from pulp furnish drastically reduces these contaminants and provides additional incentive for bark reduction.

Debarking methods

Bark reduction in chip furnish may be accomplished by a series of operations. There are a variety of techniques designed for this purpose can be brought to bear at various stages of harvesting and processing. Given any particular cleaning process, decisions include: physical location, amount of capital involved, and value added by the process. Other problems include species mix and stem age.

Generally speaking, standard industry practices dictate bark removal prior to chipping. The most widely used device is a drum debarker, normally located at the mill. Alternatively, this same device can be installed at a satellite yard or with the advent of portable drums, they may be placed in the woods on the landing.

In a similar fashion other techniques may migrate from point to point between pulp mill and skid road. Their placement depends on equipment spread and the organizational structure of any given furnish supply line. The following diagram is an adaptation of Erickson's (1972) "Pulpwood debarking alternatives" allegory. It outlines the possible sequences in which debarking can be accomplished.

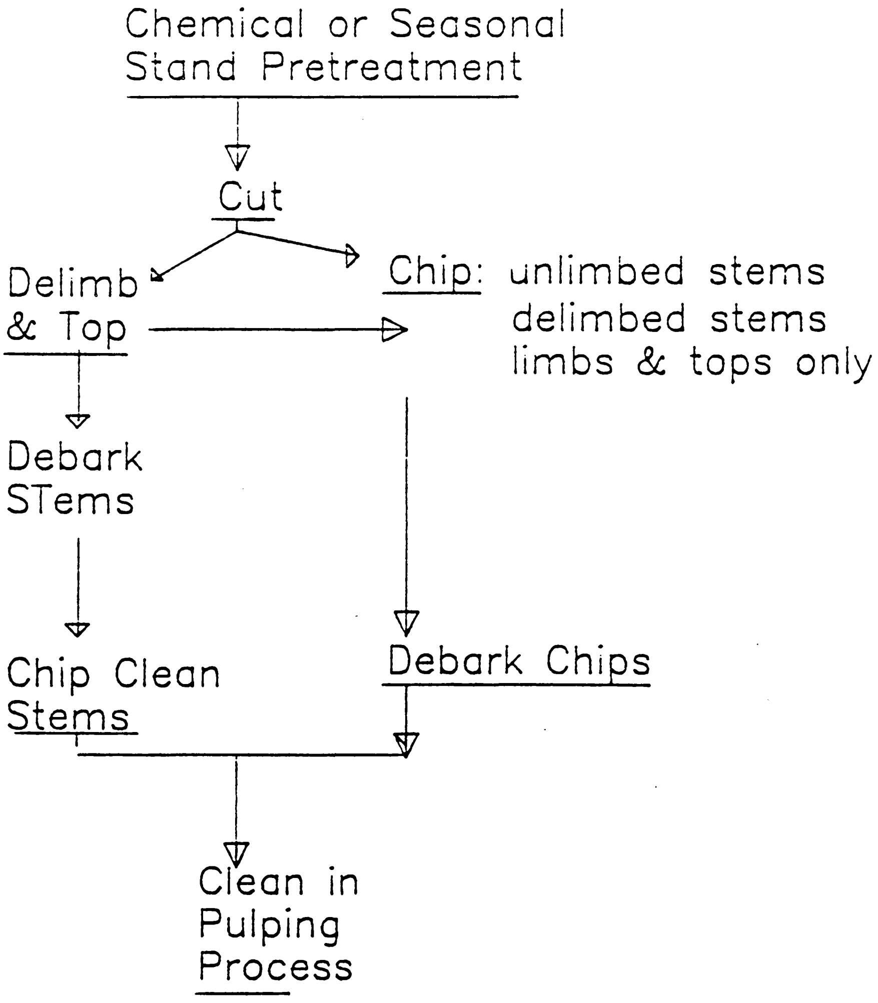


Figure 1. Whole-Tree-Chip cleaning decision tree (adapted from Erickson, 1972)

The Standing Tree

Past efforts at bark reduction prior to harvesting have concentrated on sour felling and seasonal felling. Sour felling after monosodium methanearsonate injection has been investigated in eucalyptus and Douglas-fir. Miller (1975) describes the effect on Douglas-fir.... "bark fell freely from sticks split for chipping. Wood of killed trees left standing for a year dried to 50-60% moisture content with no visible degrade." The study further suggests that bark adhesion follows a cycle inversely related to moisture content. Small diameter material allowed to air dry first increased in bark shear strength five fold, then began to decrease over one year's time.

While initial results sound promising, the act of harvesting standing dead material presents another set of problems. Top breakage while shearing dead trees is a hazard to equipment operators. Further breakage in skidding and subsequent handling may contribute significantly to material loss and subsequent productivity decreases.

Seasonal changes in bark bond strength cause corresponding fluctuations in amounts of attached bark and the distribution of bark within size classes. Arola (1973) noted that 70% more bark could be removed from chips cut during the growing season than from wood harvested under dormant conditions. Erickson (1975) studied six species in conjunction with roll compression debarking experiments at Houghton Michigan. The northern conifers had the strongest dormant season bark bond, with chips from red and jack pine retaining almost half their bark after chipping. Aspen and maple proved least sensitive to winter harvest. In all seasons these two species shed more than 90% of their bark in the chipping process (Table 7).

Bark shear strength is related not only to moisture content and seasonality but more specifically, to dormancy length and its physiological repercussions for any given species. Variations in shear strength are caused by cell diameter and cell wall thickness. As trees enter the growing season cells in the vascular cambium begin to form additional cambial initials and new phloem and xylem cells. These larger summerwood cells have cambial walls composed of what is thought to be loosely dispersed cellulose microfibrils in association with noncellulosic polysaccharides (Panshin and de Zeeuw, 1980). In this fast growing state the cambial cells and the intercellular layer are unlignified and are most susceptible to shear stress.

Wareing (1958) first discussed the physiology of cambial activity and the hypothesis was restated in Larson's (1960) study. Larson researched the bud's regulatory effect on cellular development in conjunction with short versus long day exposure and auxins synthesized by the apical meristem. The two test objectives were: "(1) to determine the relationship between the cessation of terminal elongation and the transition of springwood to summerwood, (2) to determine the effect on growth-ring formation of exogenous applications of a growth hormone to decapitated seedlings." The hormone used was indole-3-acetic acid (IAA). Results were judged on the basis of cell diameter and cell wall thickness of the secondary xylem tracheids.

Table 7. Percent of total bark separated from wood during chipping (from Erickson, 1972)

Month	Maple, %	Aspen, %	Red pine %	Jack pine %	White spruce %	Balsam fir, %
		Fresh Bolewood				
May	99.5	97.8	90.4	95.9	98.7	99.8
July	100.0	99.0	98.6	98.2	95.7	98.3
Sept.	96.5	92.3	81.0	84.5	54.4	85.8
Nov.	99.2	93.2	76.5	73.8	35.7	53.8
Jan.	96.5	93.4	81.6	72.5	65.5	90.6
March	98.1	96.3	87.3	75.4	54.8	70.8
Best month	July	July	July	July	May	May
Worst month	Sept.	Sept.	Nov.	Jan.	Nov.	Nov.
		Fresh Topwood				
May	98.5	100.0	95.0	98.4	95.6	99.5
July	100.0	93.1	98.2	94.6	94.5	98.8
Sept.	90.9	56.8	76.9	77.8	58.8	87.4
Nov.	97.5	90.3	56.9	47.2	36.6	48.0
Jan.	91.7	84.7	66.9	65.8	59.4	77.1
March	89.5	87.4	73.1	58.3	30.9	57.9
Best month	July	May	July	May	May	May
Worst month	March	Jan.	Nov.	Nov.	Nov.	Nov.

Larson chemically induced springwood cells with small amounts of IAA. Reaction was analogous to late season renewed extension growth or a "second flush". These are generally not vigorous enough to stimulate basipetal production of springwood cells in farther portions of the plant. However, in the tops and branches, these large diameter, thin wall, cells result in low bark shear strength. Conversely, with the termination of cambial activity, bark adhesion was observed to increase as cell diameter decreased.

IAA induced activity can be replicated by herbicides which have modes of action characterized by epinastic growth. The proper chemical combination for each species and stand age have yet to be researched. Should these stand level treatments become available, it may be possible to perform some measure of competition control in conjunction with harvest activity. The effect would be not only to increase the value of chips harvested in this manner but also charge suppression costs against harvest income.

At the stump and on the skid road

One of the objectives associated with processing material at the earliest opportunity is to avoid handling and processing of factions which will eventually be discarded. The Beloit Harvester and Busch Combine are early representatives of harvesting equipment designed to limb and top at the stump. Carlson and Blonsky (1973) list twenty-three patented devices for delimbing at or near the stump, prior to or after felling.

With the exception of manual chainsaw limbing and topping activities, operations in the woods or on the skid road are most commonly performed on bunches. While most device are constructed to remove limbs, all remove a portion of the bark. Individual stem "knife" type delimbers account for the most bark loss, but bunch delimbing with gates or flails can make a contribution. Carlson and Blonsky (1973) list nine technical releases or papers which describe delimbers or processors for use en route to the landing. None of which were patented.

One problem arising from in-woods debarking is transporting material to roadside without soil contamination. Forwarders contribute to material cleanliness by carrying material free of the ground. Dust or mud, which would normally be in direct contact with skidded material, is avoided. Variations on the forwarder concept have spanned all harvesting activity locations.

It is also possible to forward chips rather than stems. The chipper is carried to the bunches by mounting it on a forwarder chassis. Removable chip containers are in turn, forwarded to the to the roadside (Stuart, 1971). Concept became reality in 1977 with development of the TT Terrain Chipper 1000 F in Finland (Melkko, 1977) and again in 1979 with chipper based on a Lokomo 925 forwarder described by Skory (1979).

As pointed out in Stuart's 1971 study, forwarder based equipment is capital intensive. When stems must be processed one at a time, economic feasibility is heavily influenced by tree size, or, the number of trees which must be processed in order to obtain one ton of furnish. This is probably the most influential factor in determining which chipping systems have survived the last twenty years. Expensive single tree processors have not faired well.

At the landing

Landings for Whole-Tree-Chip operations afford an opportunity for transferring developed cleaning processes from the mill to the road side. A ready example is the current generation of portable drum debarkers, screens, and flails. Alternatively, the Swedish tree section system moves all chipper operations to a central plant. Where bundled whole trees are received for fractionation into energy fuel and pulp furnish. Given the mobility of some equipment and processes, further discussion of chip cleaning will pertain to concepts and machinery designed for use before, during and after Whole-Tree-Chipping.

Prior to Chipping

Dwell time or duration of treatment has proven to be important in determining contaminant removal effectiveness. Within a Swedish tree section harvesting system, Bredberg and others (1975) classified delimbing systems as either single tree or bunch delimbers. The Logma serves as an example of single tree machines while the Norwegian "Rispekvistaren" and Canadian "Morard Delimber" were categorized as bunch machines. Trees left in "Skruven" delimbers beyond the time required for delimbing soon began to resemble telephone poles. Not only was the bark removed, but the augers started removing bole fiber.

Dwell time is also important to drum debarking equipment. This is the most successful means of bole bark removal. The major reason for its economic success has been throughput capacity and low operating costs. Price Industries sales literature claims a capacity of ten to fifteen cords per hour for their smallest portable unit. Stationary installations commonly service the entire capacity of the largest pulp mills. Furnish technical requirements are satisfied by bark contents of one to two percent (Brattberg, 1977).

Chain flail delimbers are similar to drums in that bark is removed by impact and abrasion. They consist of a revolving member to which short lengths of chain are attached. The device may be attached to a skidder for use in woods, or to a front end loader for use on the landing (Folkema and Giguere, 1979). Initial designs were intended to simply beat limbs off trees, however recent efforts have been directed toward bark removal. Helgesson (1978) reported results from a prototype flail mounted vertically in front of a chipper infeed. Two flail shafts rotated while trees were fed to the chipper. Operating in Norway spruce, results were recorded for both cleanings (DBH 7.0 cm or 2.75 in.) and thinnings (DBH 11.8 cm or 4.65 in.) (Table 8). While debris content is lower for flail treated material, it was felt results could have been improved by slower feed rates than those allowed by the chipper infeed.

Even as energy costs ameliorated and whole-tree-chipping lost some of its economic impetus, other efforts at cleaning chips with flails continued. Ylä-Hemilä (1980) reported a boom mounted flail developed in Finland using chains with each end attached to opposed vertical disks. By 1985, Weyerhaeuser had built and tested a double drum flail setup suitable for satellite yard installation. Although the original design was intended as a multiple stem delimber, development work eventually rendered it capable of removing large amounts of bark. Rumor places acceptable chip bark content around 2%.

Table 8. The composition of chips cut with and without chains mounted in front of the feed rolls. (Helgesson 1978)

Chip assortment	Thinnings uncleaned	Thinnings cleaned	Cleanings uncleaned	Cleanings cleaned
Dry matter %	49	59	74.9	77.1
Wood chips %	69	87.6	59.8	83.4
Fines %	0.7	0.7	0.7	0.4
Bark %	12.6	8.8	13.4	9.7
Needles %	10.2	0.7	3.5	0
Branches & Twigs	7.5	2.2	22.6	6.8
Sand g/kg ovendry chips	0.314	0.11	0.368	0.064

Coinciding with Weyerhaeuser's effort in Plymouth, North Carolina, Peterson Pacific Corporation had a similar but much smaller design in progress. In 1985 Peterson offered their portable (18,000 lbs.) flail for use in Douglas fir and Lodgepole pine (Major, 1985). In 1986 Union Camp at Savanna, Georgia arranged for trials in coastal plain Loblolly pine stands. Flail modifications were found necessary due to different bark characteristics. The original 264 steel tipped rubberized straps were replaced by chains and drum speeds were increased. Within a next year, two modified Petersons were supplying clean chips to Westvaco near Charleston, South Carolina. Results from both the Savannah and Charleston trials meet or exceeded industry's goal of less than 2% bark content.

Flails in their various forms have proven their worth. Development has increased their efficiency, but some of the earliest problems still remain. In 1979, Folkema documented chain life at 15 to 45 hours, a figure which has not improved significantly. Fines or small pins (material less than 1/16" diam.) may be increased by the chain's fiberizing action on small diameter material. Other facets of their operation create economic side effects. The cost of handling waste slash and bark accumulation can be offset against energy fuel expenses in Scandinavian countries. However, lower energy costs in the United States make this possibility less attractive (Baadsgaard-Jensen, 1985).

During Chipping

The costs of handling and transporting whole trees or tree sections are adversely affected by low bulk density resulting from the bridging of limbs. This situation dictates the use of comminution equipment at the first opportunity.

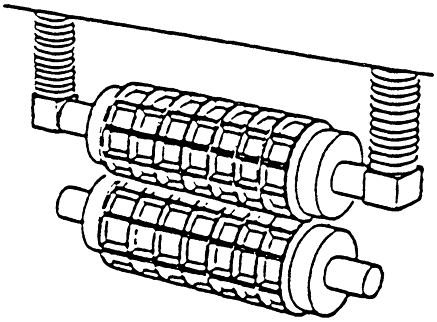
Chunkers, hammermills, shredders and roll crushers have been designed for this task (Figure 2.), but few satisfy the requirements of the American paper industry. Many designs produce material more suited for energy wood, and others achieve operating energy cost parity only when processing dry material (Jones 1981). Few machines have gained the level of acceptance enjoyed by disk chippers (Figure 3.).

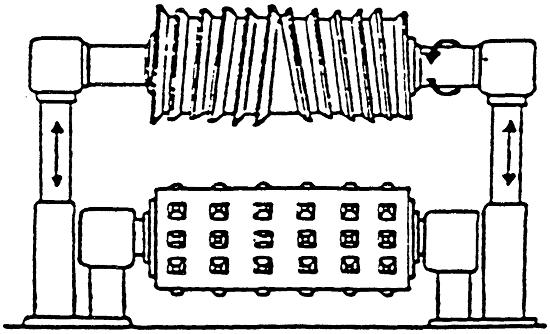
Comparisons between drum and disk chipping indicate one possible approach toward increasing disparity between bark contents of small and large chips. Young and Hatton (1976) compared the two methods in white spruce and found drum chipping to offer the following advantages. Chips which passed through a 5/8" screen contained approximately 70% of the total needle content after drum chipping but only 37% after disk chipping. The drum produced more fines along with less oversized material which would normally have to be rechipped. In addition, size classes 5/8 inch and above were more uniform in dimension. They concluded that chip handling problems are likely to be less severe for drum-chipped material because of smaller quantities of overlong wood and twigs. Additional work on cutter head geometry could augment bark reduction while maintaining uniform dimensions and increasing the proportion of larger, less contaminated chip sizes.

When any of the above processes comminute whole trees or tree sections some separation of factions does occur. Morbark Industries has installed a dirt and twig separator developed by Domitar Incorporated on many of their chipharvester models. The disk mounted separator uses energy expended in comminution to effect separation. It works by capturing material which remains on the input side of the disk rather than being forced through the knife slots to the back or output side of the disk. This material is caught in a low pressure area created by the knife edge's high speed passing of the chipper anvil. A seal around the disk's perimeter isolates material on either side. Material on the input side is judged too small for proper control during cutting and discharged through a opening forward of the chip spout.

Morbark claims 80% removal of twigs longer than 10 cm., 50% removal of dirt, foliage and detached bark and 10% of attached bark. Between 0.5% to 5% of the input weight is removed depending on the material being chipped (Weldwood, 1979).

a) The Russian Roll Crusher





b) The TVA Fiberizer

c) The VPI Crusher

Figure 2. Roll crusher types

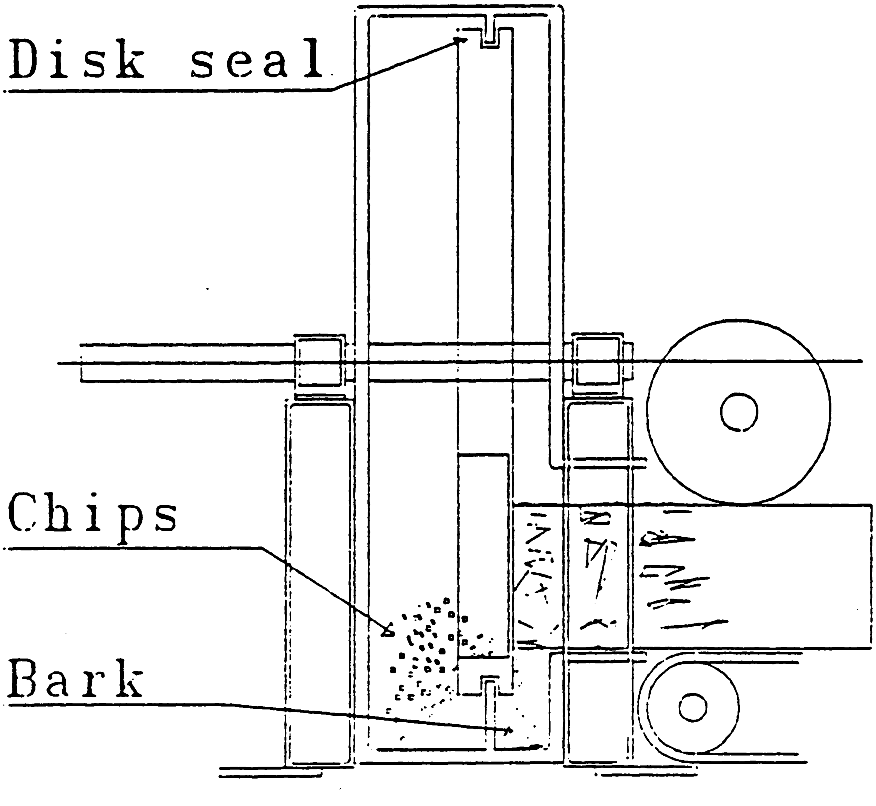


Figure 3. Cross section of a disk chipper

After chipping

Methods for chip contaminant removal after comminution fall into three categories:

1. In-Woods. Operations which take place between the chipper and truck.
2. Satellite Yards. Techniques used at dump sites or collecting yards
3. Central Processing Facilities. Mechanisms, which because of their size, are best suited for mill level use.

The following section will examine processes which fall into the first two categories.

Of the possible treatments, screening remains the most popular. Hatton (1977) experimented with segregating components of chipped softwood branches. He concluded that mechanical screening, per se, was not effective in separating various components into essentially pure fractions. However, satisfactory initial separations of wood and needles could be made. While Hatton's findings cannot be argued with, it may be possible to reduce contaminants by sacrificing a portion of the input.

Hillistrom (1976) profiled the output from the Houghton Bark Chip Separation and Segregation (HBCSS) process and noted that larger chip size classes contained less bark. Using four size classes, chips were screened through 5/8, 3/8, and 3/16-inch screens. Analysis of Hemlock chips showed most residual bark concentrated in material retained by the 3/16" screen. If only 5/8" size chips were utilized, bark content would be 1.5%. Unfortunately, this size class represents only 15% of total input. By adding 3/8" size chips, wood fiber would be 64% of input with total bark content of 2.4%. In the same manner, addition of material retained on the

3/16" screen would increase bark content to 4.1% with 92% wood recovery.

Hillistrom obtained this contaminant profile from material cleaned by the Houghton Bark-chip Separation-Segregation (HBCSS) process (described in the next section). While unprocessed Whole-Tree-Chips would not be as clean at the 92% level, one could expect a similar trend. Larger chip classes should contain proportionately less bark and smaller classes would suffer the higher bark contents. Certain equipment may serve to enhance this disparity and make "scalping" of a chip mix less wasteful.

Other problems which screens have been moderately successful in dealing with include: attached bark, grit or fines adhering to green chips and chip thickness disparities. Mills (1980) advocated... "the development of screening equipment that imparts a kick or tumble to chips, dislodging sand and bark." Hatton (1977 b) suggests a combination of slotted and round hole screens which produced clean chips, chips for upgrade and fines suitable for mulch. "Chipped softwood branches and tops need only be screened through two screens, a slotted top screen of slit width 8 or 10 mm., and either a slotted bottom screen of slit width 2 mm., or a 7 mm. punched-plate round-hole screen. The middle fraction would be upgraded to provide pulp chips. And lower fractions could be treated to provide essentially pure needles for chemical conversion or as animal fodder supplement."

Morbark Industries first produced a portable screening system which relied on sizing for the major part of its chip cleaning ability. Arnold (1975) reported that the Morbark Class-A-Fiber system provides four chip grades:

1. Class A chips are 3/4" to 1 1/2" in length. Bark content is 2.5% with no fines or grit. They are intended for high quality paper furnish in continuous digesters cooking to high yield.
2. Class B chips vary in length from 1/4 to 3/4 inch and are useful for products which can tolerate a higher chemical extraction.
3. Class C chips are less uniform and have more bark.
4. The Class D fraction is fine bark and grit particles.

It should be understood that discrepancies between reported chip size class distributions are common. The most common bias is the difference induced by laboratory round hole screens and square hole wire normally purchased for production applications. Given that a chip's width determines the smallest screen opening through which it will pass, a one inch round hole will not pass as large a chip as will a square hole. Wire screens on one inch centers can theoretically pass a chip oriented across two opposing corners measuring 1.414 inches. On the other hand, a round hole will admit nothing larger than its diameter.

A second cause of variation between screens is the chip orientation as it attempts to pass a given screen. Laboratory screens measure chip length by inducing a motion which encourages chips to lie flat. If chips are turned on edge or end with respect to a screen they are accepted or rejected on the basis of their second largest dimension, namely width. Makela (1977), in a study of the Williams chip classifier found that chip grain length was greater than indicated by screen results. "The mean length of pulpwood chips was 4 to 11 mm. greater, and of Whole-Tree-Chips 6 to 15 mm. greater, than the diameter of the round screen holes through which the chips passed last."

Makela's study demonstrates not only the distribution shift caused by failure to control chip orientation, but also indicates a difference in distribution range between chippers. When comparing chips from two chippers, any given chip length class can have range variances induced by either mechanical adjustment, or basic design.

Both air movement and chip elasticity have been explored as means of cleaning chips. Modern Whole-Tree-Chippers blow chips into 40 foot closed vans at speeds ranging from 60 to 90 miles per hour. Berlyn (1976) studied a bounce deflection separation technique which relies on elasticity differences between bark and wood. Pure wood factions maintained more velocity after impact with a plate and landed in the farthest container. Material consisting mostly of bark went in a container nearest the deflector where it was recycled and again thrown at the plate. The hypothesis was that as bark softened, reject distance became shorter while repeated impact tended to separate some of the attached bark. It is suspected that another principle is also effecting separation. With all particles traveling at the same initial speed, heavier material retains more energy and travels farther after impact.

Sturos (1973) tested two methods of directing air flows across chip streams for segregation of bark and foliage on aspen (Populus tremuloides Michx.), sugar maple (Acer saccharum Marsh), jack pine (Pinus banksiana Lamb.), red pine (Pinus resinosa Alt.), balsam fir (Abies balsamea L.), and loblolly pine (Pinus taeda L.). The first method allowed chipper output to free fall into an air stream oriented at 45 degrees from the ground. Air flow directs lighter bark and foliage away from the accepts area allowing heavier wood chips to collect in a hopper under the air stream. The second, and most successful, method considered transverse air flow. Here, the blower directed air moving at 36 miles per hour at a 90° angle to the chip stream. Best results were obtained from species with greater density differences between chips and bark. Leaves were more consistently rejected than were needles, and needle clusters. Silica or grit reductions were not reported (Tables 9 and 10).

FIXED INSTALLATION FACILITIES

Before Whole-Tree-Chipping became an alternative to conventional harvesting methods, mills assured furnish quality by direct processing controls. When supply problems forced acceptance of contaminated Whole-Tree-Chips, part of industry's response was a search for fixed installation cleaning equipment. Stand-alone operations could then be located either at satellite yards or on mill grounds as a second furnish entry point.

The Houghton Bark Chip Separation & Segregation Process

In the early seventies, trials were conducted at the North Central Forest Experimental Station testing ideas for segregation and separation of Whole-Tree-Chips. These culminated in two projects which used the Hosmer Machine Company's compression debarker as their main treatment. Subsequent development coupled various pre- and post-treatment methods designed to improve compression debarking action.

One of the first combinations used air segregation, which has seen many different applications. Baadsgaard-Jensen (1985) describes the Bahco, Radar and Flakt suction fall towers or air segregaters. Pressurized air flotation screens operate on much the same principle and are effective where

Table 9. Foliage removal results for various transverse air velocities with the chips in free fall[1] (Sturos 1973).

Species	Transverse air velocity	Foliage content Input	Foliage content output	Foliage segregated	Wood recovered
	Ft./sec.	Percent	Percent	Percent	Percent
Sugar Maple	49	10.9	5.5	53.4	97.6
Do	59	12.3	4.9	66.3	91.8
Do	66	10.6	3.4	74.7	84.0
Loblolly	49	16.1	13.1	24.1	97.3
Do	59	0.8	7.6	39.9	89.1
Do	66	7.4	5.3	41.6	85.4
Jack Pine[2]	59	24.0	19.3	27.8	96.4
Do	66	24.0	16.9	41.5	91.9
Do	73	19.2	11.8	51.0	88.3
Balsam fir[2]	66	9.5	5.4	52.7	87.3
Do	73	15.0	7.1	64.1	82.1
Do	75	15.4	5.5	73.7	80.3

1. Each percentage value is the mean from three test runs except as noted elsewhere.
2. Results from single test run at each air setting.

Table 10. Foliage removal results for various transverse air velocities with the chips moving at 53 ft./sec.[1] (Sturos 1973).

Species	Transverse air velocity	Foliage content Input:	Foliage content output	Foliage segregated	Wood recovered
	Ft./sec.	Percent	Percent	Percent	Percent
Sugar Maple	62	6.19	1.4	80.0	88.9
Do	81	9.2	1.7	85.5	83.3
Do	85	7.0	1.1	87.6	86.8
Loblolly	62	6.9	4.0	47.6	93.7
Do	81	7.4	3.4	60.4	90.3
Do	85	6.3	2.3	70.1	84.8
Jack Pine	85	20.2	12.9	47.8	90.1

1. Each percentage value is the mean from three test runs except as noted elsewhere.

distinct differences exist between a species' bark and chip density (Erickson 1972).

These devices operate on the principle of differing terminal velocities and owe much of their conceptual framework to earlier investigations by John Sturos. Sturos began investigating Vacuum Airlift Segregation (VAS) trials with Whole-Tree-Chips around 1971. VAS is based upon the principle of differing terminal velocities which are ..."the maximum (constant) velocity the particle attains while falling freely through a viscous medium such as air" (Sturos 1973). In the case of wood chips, this occurs when the accelerating force of gravity is canceled by the resisting force of drag generated by the chip's surface area. Conversely, upward air flow may raise a particle only if it exceeds that particle's terminal velocity (Sturos 1973).

When coupled with HBCSS as a pretreatment, the device consisted of three vacuum hoods arranged over a mesh conveyor. Presized chips were then fed one layer deep onto the belt allowing some fines to drop through. Depending on air flow intensity and conveyor speed, particles were removed from the chip mix by their different terminal velocities. Results indicated that wood loss became unacceptable when the treatment was stringent enough to produce accepts with four to five percent bark (Tables 11 & 12). Thus VAS was recommended only when coupled with other processes (Sturos 1978).

Weyerhaeuser sponsored the next effort using VAS at their research facility in Tacoma, Washington. A single airlift hood was used for foliage and bark removal. Next followed a presteaming treatment to loosen bark and make it tacky for better nip roll adhesion during compression Miller (1975). Processed chips usually had least bark (2-5%) if presteamed

TABLE 11. Mean Measurements of Slash Pine Wood and Bark Chips used in VAS (Sturos 1978)

Chip	Chip	Length	Width	Thick	M.C.	S.G.	Terminal Vel.	
Size	Type				%	*	Mean	Std.Dev.
		Inches	Inches	Inches			Ft/Sec	Ft/Sec
5/8	Wood	.85	.84	.15	45	.92	15.6	2.1
5/8	Inner bark	.76	.77	.09	70	.98	15.1	2.3
5/8	Outer bark	.80	.81	.19	27	.71	14.6	2.6
3/8	Wood	.74	.52	.12	32	.88	14.3	2.2
3/8	Inner bark	.68	.42	.09	71	1.00	17.0	2.8
3/8	Outer bark	.76	.52	.15	24	.71	14.4	2.8
3 16	Wood	.68	.24	.08	39	.89	13.0	2.3
3/16	Inner bark	.71	.19	.07	65	.96	15.0	3.2
3/16	Outer bark	.46	.28	.08	21	.72	11.1	1.9

* Green weight over green volume.

Table 12. Mean Measurements of Slash Pine Wood and Bark Chips used in VAS (Sturos, 1978)

Chip Size	Chip Type	Length	Width	Thick	M.C. %	S.G. *	Terminal Vel. Mean	Terminal Vel. Std.Dev.
		Inches	Inches	Inches			Ft/Sec	Ft/Sec
5/8	Wood	.94	1.01	0.18	51	0.92	16.2	2.1
5/8	Inner bark	.92	.72	.07	66	.93	13.8	1.9
5/8	Outer bark	.96	.73	.22	24	1/<.67	13.8	3.3
3/8	Wood	.73	.47	.12	47	.86	14.8	2.5
3/8	Inner bark	.90	.37	.06	68	.97	13.3	1.9
3/8	Outer bark	.61	.44	.15	7	1/<.67	13.2	3.2
3 16	Wood	.60	.26	.07	27	.80	10.9	2.3
3/16	Inner bark	.58	.21	.05	55	.96	11.6	2.2
3/16	Outer bark	.40	.27	.08	46	1/<.67	10.6	2.2

1/ All outer bark particles floated in the density-gradient column. Therefore the mean specific gravity is < 0.67.

---

* Green weight over green volume.

at elevated pressure (2.1 kg./cm.^{2} for 5 min.). Accept material from the compression rolls passed finally through a drum screen for fines removal and mechanical attrition of the remaining bark (Sturos & Marvin 1978). Acid insoluble silicates were reduced by approximately half and residual bark ranged from two to four percent (Table 13).

Evans (1977) reported a similar large-scale pilot plant for compression bark removal at the St. Anne-Nackawic Pulp and Paper Company of Nackawic, New Brunswick. The system produces 10 oven-dry tons of chips per hour using 30 psi. steam for five minutes to loosen the bark-chip bond. Twelve percent barky chips were first screened and then presteamed for roll compression debarking. Bark content of accepts is 6% before final screening and 3-4% afterwards. "Compression of chips opens them up and reduces cooking time. Roll nip breaks up knots and reduces knotter and screen rejects."

Other devices used with compression debarking include Hammermills and ball mills. Mattson (1974) recommended using a hammermill on compression debarked chips in the 3/16" to 5/8" size class. This completed bark/chip separation. Out put from the mill could then be recycled through the rolls to complete segregation. Chips less than 3/16" comprised 5.5 to 15.0% of the total output. Ball milling the 3/16-inch chips lowered residual bark content and kept wood loss to a minimum. Discarding the 3/16-in. chips reduced residual bark, but also increased wood loss to as much as 20%.

Table 13. Percent of total weight removed, with the Weyerhaeuser Co. combined system.(Sturos & Marvin 78)

Process Equip.	Foliage	Bark	AIA (Grit)	Fines	Wood	Input
VAS	59.5	44.1	62.0	74.6	14.1	20.3
HBCSS	6.1	28.5	10.7	7.7	1.5	5.3
Drum Screen	11.8	11.7	6.8	11.4	1.6	3.7
Total	77.4	84.3	79.5	93.7	17.2	29.3
Input	1.1	10.4	0.205	9.5	83.0	
Output	0.3	2.1	0.087	1.5	97.0	

Whole-Tree-Chip washing

The Forest Engineering Research Institute of Canada (FERIC) and the Pulp and Paper Research Institute of Canada (PAPRICAN) jointly took a different tack in debarking Whole-Tree-Chips. Basic elements of the Canadian process included: conditioning, agitation in water and wet screening. The operation relied on the principle that bark is inherently weaker than wood fiber and can be fragmented without damaging wood. Bark particles, once reduced in size could be screened for segregation (Berlyn, Hutchinson & Goode, 1979).

Based on earlier research by Erickson (1975) and others, Berlyn and Hutchinson (1976) experimented with chip storage as a means of reducing bark bond strength. Conditioning may consist of either storage in conical piles or presteaming. Both processes weaken the internal structure of bark and foliage. Steaming for six to ten minutes is equal to approximately six weeks of storage.

A modified commercial digester agitated the chips in water. Chips made up between 13 to 20% of the slurry by weight and energy was imparted through the rotor. Bark, dirt, foliage and fines were drawn off through a perforated floor plate after a reduction period of about 15 minutes. Hot water may be used to successfully process unconditioned chips, however, where conditioning is used, water temperature has no effect.

Agitation alters the size distribution of chips, bark and foliage. Larger chips are split along the grain improving mix uniformity, while contaminants are broken down to a point which allows screen rejection.

Segregating wood chips from their contaminants requires wet screening through a floor plate with appropriately sized openings. A separate vibrating screen was also tested, both methods produced satisfactory results (Berlyn, Hutchinson & Goode, 1979). Whole-Tree-Chips from softwoods cleaned by the process showed bark contents reduced from 20% to 2% while losing 4 to 9% wood fiber. Wood loss figures also contain 1 to 4% fines generated in chipping and carried over to the debarking process (Tables 14 & 15).

Table 14. Effects of conditioning and of agitation on wood loss and on the bark content after processing. (Berlyn, Hutchinson & Goode, 1979)

	Conditioning period	Agitation	Wood Loss%	Bark Cont.%
	(Weeks)	(Min.)		
Effect of conditioning	0	10	3.3	8.4
	6	10	5.2	2.8
Effects: of duration	6	5	4.1	3.5
of agitation	6	10	5.2	2.8
	6	15	6.1	1.7

*Initial bark content of chips (full tree softwood):18.1%

Table 15. Effects of conditioning and of agitation on chip size. (Berlyn, Hutchinson & Goode, 1979)

Conditioning period	Duration of agitation	Percentage distribution of chips retained on screens				
(weeks)	(min.)	3/16"	3/8"	5/8"	7/8"	1-1/8"
0	0	9	28	26	19	18
0	10	16	43	27	11	3
6	10	20	47	23	7	3

Pressurized centrifugal screens

Improving chip clean up at the paper mill has resulted in the refinement of pressurized screening techniques. Conventional pressurized centrifugal screens, used in the processing of Neutral Sulfite Semi-Chemical and high-yield Kraft pulp, have relatively large holes. Evans (1977) reports... "Accept pulp from these screens must be refined further to produce usable fiber. A more efficient technique involves screening the pulp with a pressurized centrifugal screen that has relatively fine slotted openings. These small openings prevent the passage of shivs, uncooked bundles, bark and debris associated with Whole-Tree-Chips." The USDA Forest Service trials at their Madison, Wisconsin laboratory have pulped unbarked chips using this method. Auchter and Horn (1973) found that the use of pressurized screens allowed southern and west coast species with approximately 10% bark to be pulped. Maintaining brightness required the use of 0.2% more bleaching chlorine but increased pulp yield 4% from a rough cord.

Other Whole-Tree-Chip Cleaning Projects

ECAR Products Co., Division of Garden State Paper Co., Bennington, Vermont evaluated debarking with a Micar chip abrader. The device uses a horizontal shell and close fitting internal rotor. Both are fitted with bars and vanes which seek to abrade the bark while leaving chips undamaged. Bark content of accepts were reduced approximately 25% (Arola, Sturos & Mattson 1976).

Joutseno-Pulp uses crushed stumps in a washing, skimming and screening process to achieve a grit and bark content less than one percent. The process recovers clean chips, furfural and acetic acid. Using Whole-Tree-Chips resulted in a loss of furfural yield of one percent. This was attributed to a corresponding diminution in the quantity of wood.

Battelle Research developed the Vac-sink process which saw service at Union Camp Corporation's Savannah, Georgia mill. Chips were first subjected to a vacuum then dumped in a tank containing water or a petroleum base liquid. Wood sank being void of air, while bark floated. The system effectively removed 90 to 100% of the bark depending on species (Erickson, 1971).

Summary

Few species are better suited for Whole-Tree-Chipping than Loblolly pine. General physiological traits which contribute to their suitability are small live crown ratios and brittle limbs that facilitate removal of highly contaminated factions. Although older trees can develop two inch bark sheaths, bark of pulpwood sized trees seldom exceeds 5/8". Given a butt diameter of six to eight inches, these stems contain eight to ten percent bark and weigh 300 to 350 pounds. Aside from gate delimbing, additional bark is removed by: shearing, grapple skidding, feed roll action, and the chipper's separator. Not known is how much contaminant is removed at each stage, but all actions result in an average four to six percent bark for normal chip mixes.

Thick, brittle, mature bark is more easily fractured by rough handling than is thinner, more resilient, juvenile bark. This more elastic bark faction is not easily differentiated from clean chips of approximately the same size. As a result, post chipping treatments which seek to remove this faction must cause a change in its physical nature. Such a change in so small a portion of the load must be very specific or the end result will be wasted useable fiber. Given the above difficulties, pre-chipping treatments would seem to yield more useable fiber. In fact, both drum and chain flail debarkers are available which yield acceptable commercial chips with less than two percent bark content. Problems arise with these solutions when the added investment is considered. Compared to conventional logging operations, Whole-Tree-Chipping operations are initially capital intensive. While some companies pay a premium for chipping low value stands for site conversion purposes, the general practice relies on throughput capacity for acceptable return on investment. When contractors are paid on a par with conventional logging operations, they often argue that production rates cannot offset the handicap imposed by current fixed costs. Any additional investment only exacerbates this situation especially if the cleaning device slows production.

Yet another situation mitigates against in-woods efforts to decontaminate Whole-Tree-Chips. Mill chip mix analysis techniques are slow and cumbersome. They prohibit the extensive load sampling which would be necessary to reimburse contractors for efforts at chip cleaning. As a result, there is little positive reinforcement for chipper maintenance, much less extra expenditures for bark removal.

While proven in-woods chip cleaning operations are expensive, alternatives may represent even greater opportunity costs. Load Scalping can greatly reduce silica and cut bark concentrations in half, but load loss may equal 20% or five to six dollars a ton. Converting this faction to fuel may ameliorate costs slightly, however, the faction has a high concentration of silicates which causes glazing problems in chip fired systems. Alternatively, long wood systems require larger diameter trees for cost effective harvest and transportation activities. Larger trees mean longer rotations and therefore less return on stand establishment activities. Once harvested and delivered, further capital investment in debarking equipment and yard space is required.

Processes which would result in an acceptable furnish from Whole-Tree-Chipping operations would broaden forest management options. Species, stocking densities and rotation ages now considered impractical or uneconomic could become both feasible and perhaps desirable. The cleaning process should not impede normal chipping operations nor substantially add to overhead or operating costs. These above criteria are potentially met by the proposed system.

Design influences

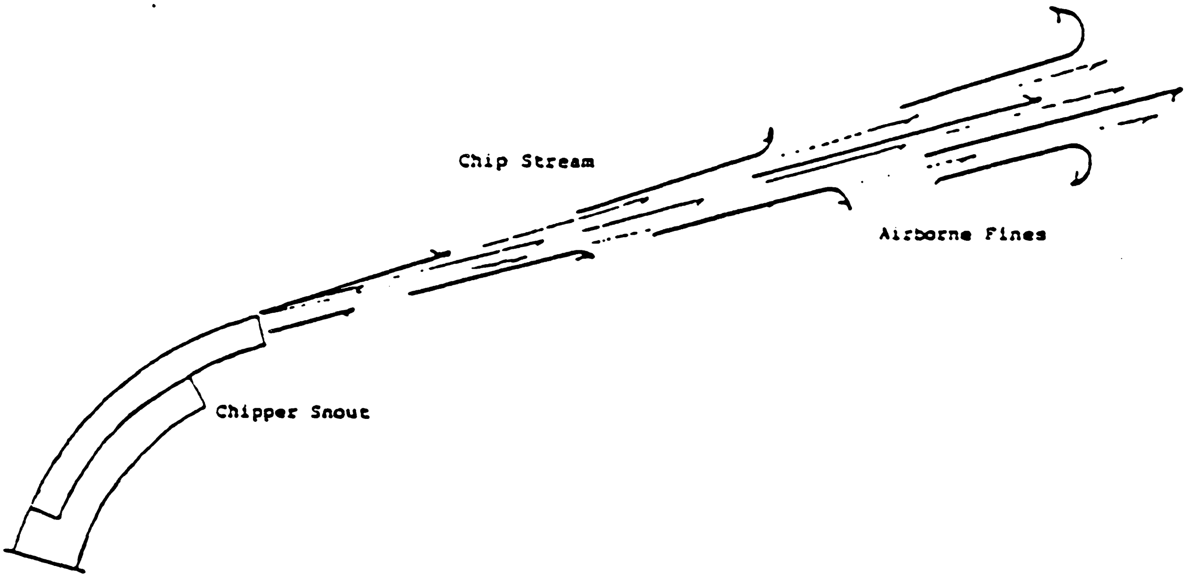
Research contributing to system design drew heavily on the following authors. Winter and Mjöberg's 1985 work showing how green wood was less susceptible to compression damage than dry wood. Sturos' Vacuum Air Lift segregation work when combined with Berlyn, Hutchinson, and Goode's work on bounce deflection suggested the vacuum deflection screen. The latter authors' also developed chip washing which suggested the fracturing of cards into useable sized pulp chips. Harkin and Crawford suggested screening equipment which tumbled chips to loosen grit and fines adhering to chips. Their suggestion gave a reason to remove these particles before they are allowed to settle out in a chip pile. These authors and others, more or less directly effected conceptualization of cleaning and sampling designs constructed for this study.

METHODS AND PROCEDURES

Research efforts concentrated on the chipper to van interface. Whole-Tree-Chippers expend a great deal of energy converting trees to chips, and blowing them into a van at a speed ranging from 60 to 90 miles per hour. It was intended that maximum benefit be gained from this expenditure. The central hypothesis is that a chip stream is composed of segregated free bark, dirt and fines which have been separated by the chipping process (Figure 4.). Under normal conditions, these particles are allowed to mix with a chip mass and stick to the surface of wet green chips. Removing these particles while suspended in the chip stream will yield several advantages:

1. Each truck load of Whole-Tree-Chips will contain a higher percentage of useable fiber.
2. Contaminants will be removed which normal screening techniques can not address.
3. Reject material need not be dealt with at the mill.
4. Larger percentages of Whole-Tree-Chips may be used in the digester.

To achieve the above goals, a Strick Manufacturing, open top, chip van was obtained through a very cooperative effort by A. C. Edwards and Crook Ellis of Westvaco's Kraft division in Charleston, South Carolina. Van loads of Whole-Tree-Chips came from the Baker Timber Company, an independent logging contractor. The operation normally operated one Hydroax feller-buncher, two grapple skidders, a delimbing gate and a separator equipped Morbark 22 chipper.



1. Initially, all particles are traveling at the same speed with the air flow.
2. As kinetic energy dissipates, particles leave the chip stream according to their mass.

Figure 4. Chip stream ballistics

THE RESEARCH VAN

In field trials, the modified chip van served two purposes. 1) It was capable of extensive chip mass sampling to determine the characteristics of Whole-Tree-Chips as produced in even age stands of Loblolly pine. 2) The van served as a platform for testing three chip cleaning treatments.

First, floor screens were installed to determine the amount of fines and smaller particles which would settle out of a chip stream during loading. Floor screens were lighter than conventional trailer decking and should allow undesirable material to exit during loading or on the woods road.

Second, a blower was installed to direct a 30 mile per hour air flow against the chip stream at an approximate 50° angle from the van roof. Particles with less ballistic energy would have their trajectory further decayed by the resisting air flow. The result would either reject light particles from the trailer or knock them to the floor. For ease of identification, these treatments will be referred to as Blower trials.

The third treatment was a combination of bounce deflection and a modified vacuum air lift segregation. The overhead duct from treatment one was screened with #16 expanded metal and suction applied. The chip stream was deflected from a overhead screen at an approximate 140° angle, achieving impact separation of the barky chip bond and bark particle size reduction. The partial vacuum removed contaminants from the chip stream as it deflected from the screen.

The deflection apparatus was modified after two trials to increase the deflection screen area (Figure 5). In addition,

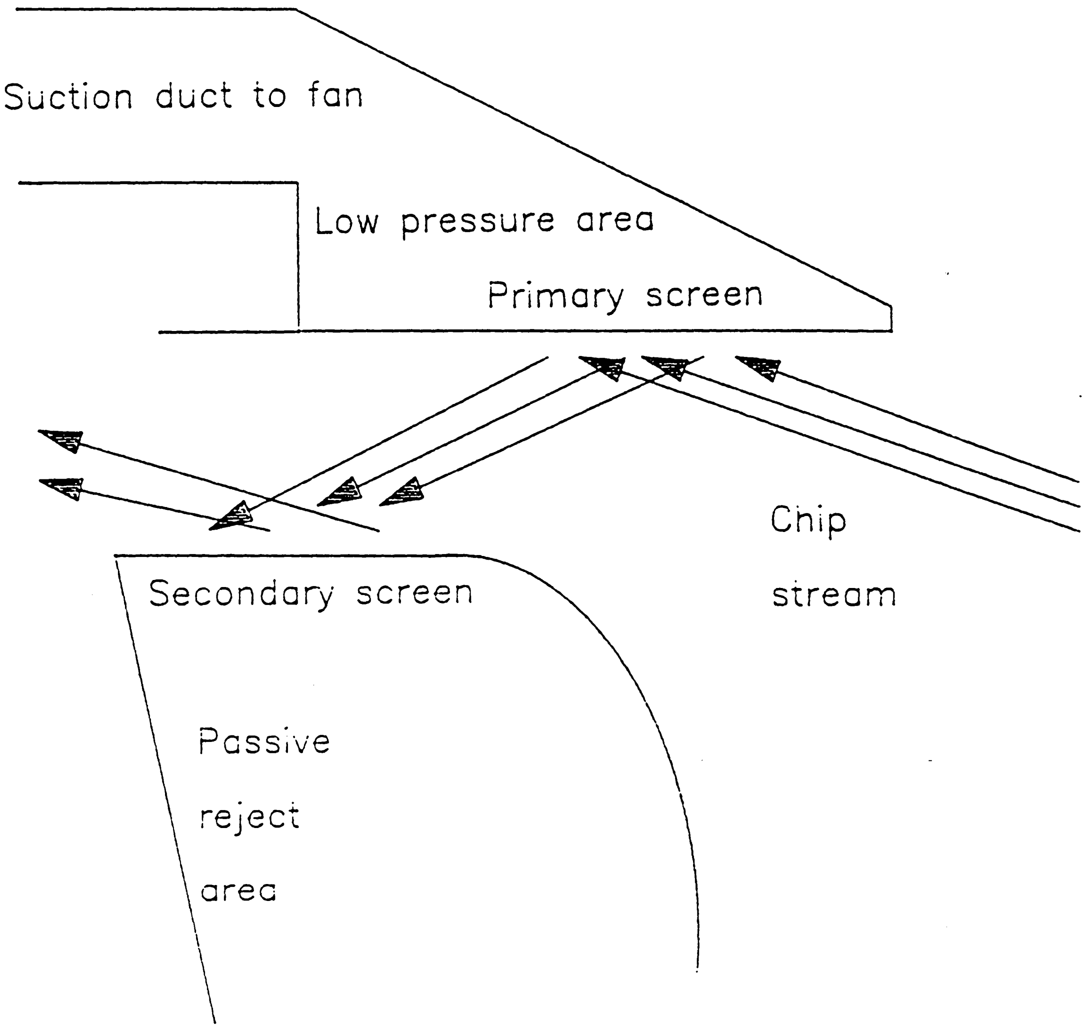


Figure 5. Horn arrangement for double deflection

a passive screen was positioned below and behind the first deflection screen to rebound the chip stream a second time. Framework for mounting the second screen was designed to inhibit chip stream air flow while allowing chips to load via residual momentum. Here after, the unmodified version of the deflection-suction screen will be referred to as Deflection trials while the modified version will be termed Horn trials.

Radial fan and ducting

A Dayton Manufacturing, radial blade industrial blower with a 26 inch diameter wheel comprised the major element of the chip cleaning mechanism. Power was provided by a Cross Engineering hydraulic gear motor displacing 3.3 cubic inches per revolution. Approximately 30 horsepower were available at 1,900 R.P.M. (Appendix A).

Interconnected plenum chambers were constructed for both intake and exhaust sides of the fan housing. Using a series of six airtight doors, air flow from the fan could be routed through either of two ducting systems. The overhead duct ran 32 feet from the blower compartment at the front of the van to a point eight feet forward of the rear doors. At this point a four foot long hood hung through the roof allowing air to be blown or pulled from the area of the van doors. A second duct system, controlled by the two plenums, consisted of two baffled dust bins located on either side of the blower compartment. Dimensions for both compartments were 60 inches long by 103 inches tall and 20 inches wide. Three 20 x 70 inch baffles were alternately arranged for air flow stratification causing debris collection in each of the three chambers. Rearrangement of the two plenum's doors allowed air to be pulled or blown through the bins and under a false floor created by the beam supported screen and plywood decking system described in the next section.

Floor screen & pan sampling system

Floor screens and the pan sampling system were designed to test another hypothesis concerning the manner in which Whole-Tree-Chippers load vans. When a chip stream exits the chipper spout, both air mass and particles are traveling at approximately the same speed. As kinetic energy dissipates, ballistic decay occurs, depositing particles at differing distances along the van's floor according to their mass. It was assumed that fines and grit would travel less than 30 feet from the chipper spout, collecting on the screened portion of the van floor. Screens would in turn pass these particles to the sampling pans enabling analysis of their size, distance gradient.

Screens and sample pans were installed by constructing a false floor support system raised 10 inches over the original height. The 28 feet closest to the rear doors were screened with a combination of No. 16 flat and turned expanded metal sheeting. Flat expanded metal was laid down first with the longitudinal axis of the diamond perforations running parallel to the axis of the van. Next, the turned or raised edge sheeting was overlaid on the flat expanded metal. These sheets were placed with the raised lip facing towards the rear doors to ease chip mass sliding at the mill dump.

Orienting the diamond pattern of the raised edge sheets perpendicular to the trailer axis (and the first layer of flat expanded metal) effectively reduced the approximate 7/8 inch long by 3/8 inch wide aperture in each type of sheet to a maximum octagonal opening 3/8 inch across the flats. The second advantage of this overlay design is the anti-clogging nature effected by the flat expanded metal. Material attempting to enter a hole must first present a surface small enough to penetrate the turned edge sheet opening. Should a pin chip meet this criterion, it then must present a dimensional profile which will allow penetration of the combined sheets. If a chip fails to meet the second criterion, it is held on top of the second sheet and remains poised in the mouth of the first sheet's aperture, allowing it to slide off the screen during dumping. With normal screens, oversized material attempting to penetrate an opening will wedge in the opening, blinding that hole.

Floor screens were supported at a height of ten inches by inverted wooden "T" beams constructed of two structural 2 x 10 inch planks. Beams were bolted, top flange down, to the floor on 30.5 inch centers and extended 35 feet from the rear doors forward. Seven screen frames covered the rear 28 feet of the raised section, while the forward seven feet were covered by 3/4 inch plywood. This arrangement provided three 29 inch wide slots under the screens. The beam flanges acted as glides for metal sampling pans lifting them clear of the van's rather rough floor. Sampling pans were constructed of 16 gauge sheet steel measuring 28.5 inches wide, 36 inches long and 5.5 inches deep. Nine pans were inserted in each subfloor slot, enabling a 7.13 square foot sample to be drawn from each pan in 27 separate locations under the screens.

Bucket sampling system

The second sample segment came from a series of eight buckets suspended from four each six inch, wide flange "I"

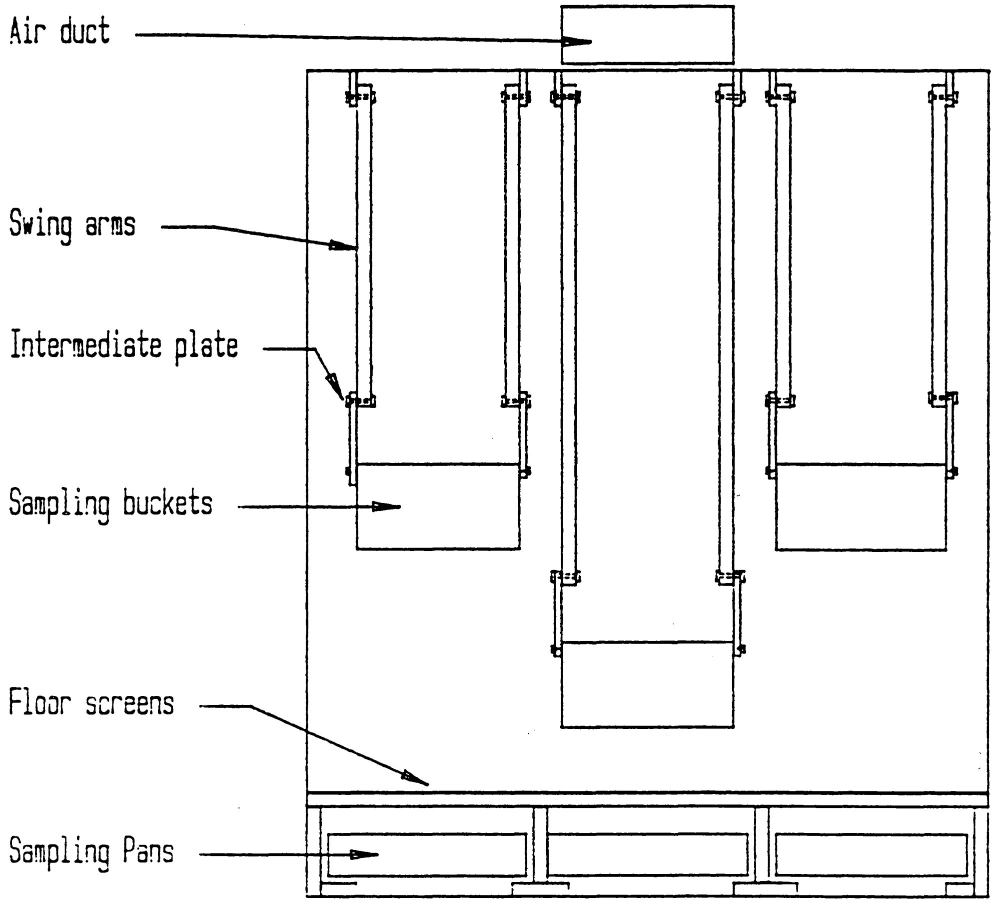


Figure 6. Transverse trailer section at 22 feet

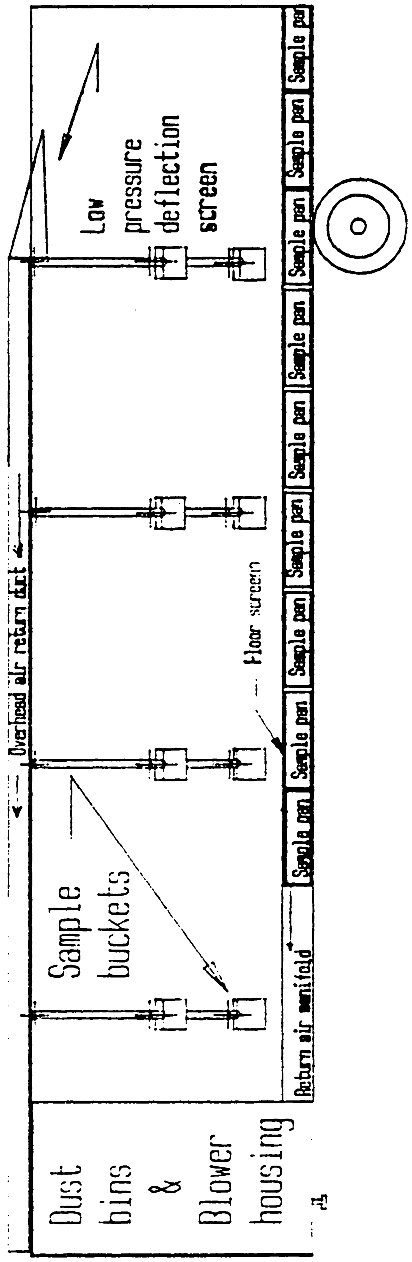


Figure 7. Longitudinal cross section

beams. Each of the 93 inch beams were bolted across the top lips of the van's side walls on eight foot centers from the rear doors forward. Each of the four beam positions were equipped with pivots for three lateral sampling bucket locations. Buckets were suspended from the beam mounted pivots by 2 x 4 inch steel box beam swing arms (Figures 5. & 6.).

Eight sets of swing arms were constructed, four sets with 34 inches between pivot points and four sets having 61 inch centered pivots. Buckets were attached to each set of swing arms using 1/4 inch thick steel plates four inches wide and one foot long. Plates were drilled on nine inch centers, with one end attached to the swing arms and the other attached to the sample bucket's sides with hardened 1/2 inch bolts. Eight chip sampling buckets were constructed of 1/4 inch plate. Interior dimensions were two feet long, one foot wide and one foot deep.

Thus equipped, each sample bucket hung from two swing arms and two interim plates which gave three articulating joints. In the cocked or ready position, buckets hung upside down from the van roof. As the chip pile accumulated during loading, each bucket was released in turn. As the bucket fell, its swing arms and interim plates lead the inverted bucket through the first 45 degrees of arc. As the swing arms approached the second arc segment, bucket motion converted from a vertical fall to horizontal sweep. The interim plates kept the bucket's pivot point to the rear of the swing arm's lower pivot. This prevented the bucket from presenting its bottom side to the chip mass on impact and also imparted a rapid revolving motion to the bucket, giving a scoop action as it struck the chip pile.

Samples taken with this setup are from highly localized areas of the load. Although only eight sample buckets were used, the combination of 12 pivot points with two swing arm lengths gave 24 possible sampling locations.

DATA COLLECTION

Eight trials were conducted within a thirty mile radius of Monck's Corner, South Carolina. Trials began on October 31, 1986, with five trials in a single eighteen-year-old stand of Loblolly pine. The sixth trial took place December 6, 1986, in a sixteen-year-old stand. The final two trials were conducted April 28 and May 1, 1987, in a twenty-five-year-old stand.

Trials one and four were Passive or untreated loads with no mechanical treatment applied. Numbers two and three were Blower trials, where a high speed air stream intersected the chip stream as it entered the van. Trials five and six were Deflection runs where the chip stream was deflected off the overhead suction hood. Trials seven and eight employed a modified Deflection hood and were referred to as Horn runs (Table 16.).

Operations at the landing required two men. After the sample buckets were positioned and cocked, one man observed the chip pile as it accumulated within the van. When buildup was sufficient, he signaled the other and each bucket was released in turn. After loading, the van was moved a short distance and the 27 sample pans were removed from under the floor screens. Pan contents were bagged, sealed and marked by location. Sample pans were then replaced and the van driven to Westvaco's chip dump in Charleston. During the 20 to 35 mile trip, chip settling or compaction occurred through out the load. This gave maximum bulk density to bucket samples buried in the chip load. At the mill, the van was emptied using Westvaco's hydraulic truck dump.

Table 16. Trial organization

Trial #	Treatment	Date
1	Passive	10/31/86
2	Blower	11/03/86
3	Blower	11/05/86
4	Passive	11/06/86
5	Deflection	11/07/86
6	Deflection	12/06/86
7	Horn	4/28/87
8	Horn	5/01/87

Chips flowed freely around and under the sample buckets allowing them to maintain their load. The truck again pulled from traffic and chip samples were struck level with the bucket top and capped. Once the van had returned to the Monck's Corner staging area, dust bin, pan and bucket samples were removed, bagged and weighed. Trial time ranged from two to three days depending on manpower and type of trial.

DATA ANALYSIS

Laboratory screening equipment and operation

Whole-Tree-Chip size classification was accomplished with the aid of six screens mounted in a All American Tool and Manufacturing Company, vertical throw vibrator. Screen frame movement was limited to 0.150 inch vertical travel at a rate of 11 cycles per second. These settings avoided harmonic dampening which occurred at higher frequencies and kept chips from bouncing out of the frames.

The largest four screens were handmade using 16 gauge sheet steel. Holes were laid out on a diamond grid and located by a center punch. Pilot holes were then drilled in a size appropriate for the draw bolt of a two piece punch and die set. In all cases the punch was drawn through from on the same side of the sheet. This practice provided a smooth rounded edge on what was to be the top side of the screen. Uniform hole size was insured through constant draw pressure as applied by a 1/2 inch drive pneumatic wrench operating at 50 psi.. After punch operations, all holes were hand broached on the flashing side with the aid of a 3/8 inch bearing scraper. The above operation produced a smooth radius hole with no edge on either side capable of cutting into chip fiber and trapping a chip in the hole. Hole diameters were three to four thousands oversize, but within plus or minus 0.001 inch in uniformity (Table 17.). In operation, each two cubic foot bucket sample was screened in five to six pound increments to prevent screen overload. Each load was agitated until material had substantially ceased migration between levels. Screen frames were removed and thoroughly cleaned between each sample. Size classes were grouped and weighed to develop class distributions.

Table 17. Screen specifications

Screen Size	Percent Opening	Maximum Variation	Screen Type
1-1/8"	60 %	+ .003"	punched hole
7/8"	52 %	+ .008"	punched hole
5/8"	47 %	+ .003"	punched hole
3/8"	44 %	+ .004"	punched hole
1/4"	90 %	- .030"	wire screen
1/8"	85 %	- .015"	wire screen

Bark content determination

After screening, one pound samples were drawn from each size class by scooping an appropriate amount from the center of each bag. These were hand sorted into three piles: clean chips, chips with attached bark, and free bark. Because of the gate delimbing operation and the use of a disk mounted debris separator, foliage constituted less than one tenth of one percent for any size class. After initial segregation, all weights were recorded to the nearest 1/10 gram using a Metler electronic balance. Chips with attached bark were separated from the bark and both factions were again weighed.

Analyses were based on weighted average percentages from each size class within each trial. Bucket samples were screened into six classes and one pound samples from each bucket/size class were hand sorted. Weights for "Clean Chips," "Barky Chips" (chips with attached bark), "Attached Bark" (bark separated from barky chips), "Free Bark" and "Total Bark" were recorded and the percent of sample calculated. Percentages were then multiplied by each bucket's size class weight; the resulting weights were summed across all buckets. When converted to percentages these figures represent any given load characteristic. From this point percentages for the entire load were calculated two ways. First, a content of interest for any particular size class was calculated as its load weight divided by the total weight of that size class for the load. These figures are referred to as size class percentages. A second method simulated paper mill screening activities by accumulating weight for size classes larger than the one of interest. For example, if bark content for the load sized 3/8" and larger is desired, bark weights for all size classes 3/8" and larger were summed and divided by the sum of the bucket sample weights larger than 3/8". These figures are referred to as cumulative percentages and simulate the practice of "load scalping" to remove the smaller more contaminated segment.

Statistical analysis

Because Deflection and Horn trials caused chips to pile first in the center of the van, some buckets in the fourth row did not always fill unless large loads were taken. In addition, Horn installation required the removal of the sample bucket closest to the rear doors. This situation caused an unequal number of observations for all factor level combinations and necessitated the use of an unbalanced statistical design. The analysis of variance (Anova) for a randomized block design was used to test the hypothesis that there was no difference between treatment means. F tests for both treatment and blocks were conducted using alpha = .05. Having computed an Anova, pairwise comparisons using Duncan's Multiple Range Test (MRT) allowed further comparisons between individual trials. The MRT is preferred in this design as it has a very high probability of declaring a difference between means when there actually is a difference. This minimizes the possibility of a Type 1 error and provides a check on Anova procedures.

Ash and silicates content

Ash content is used as an approximate measure of the mineral salts and other inorganic matter. Methodology is described by publication number T 211 om-85 available from the Technical Association of the Pulp and Paper Industry (TAPPI). Oven dry 25 gram samples were placed in a covered crucible and ignited in a muffle furnace at 575 (+ or - 25) degrees centigrade. The resulting ash weight was recorded to the nearest 1/100th of a gram.

The Wet ash method (T 245 om-83) wet-ashes bone dry samples in heated nitric and sulfuric acids. Insoluble residues are neutralized and then filtered through ashless paper. Filter paper and contents are then incinerated using a procedure similar to T 211 om-85. Material remaining after this process is considered essentially pure silicon dioxide.

Moisture content

Materials from the first Passive trial was kiln dried, but this method proved cumbersome due to kiln scheduling. Subsequent moisture content analyses were taken using a microwave oven and a technique developed by G. Wengert (1985). The microwave must be equipped with a carousel and samples must be placed on the outside of the tray to provide uniform exposure. A medium low power setting was used and samples were exposed for 10 minutes before weighing. A second exposure of five minutes was used to insure the sample was oven-dry.

RESULTS AND DISCUSSION

As the name implies, field trials are influenced by factors not controlled by the research team. These influences should be understood before presenting a formal discussion of research results.

External conditions which most influenced results include chipper condition and tree size, measured as average stem weight. Internal constraints of time, manpower and equipment availability limited the amount of data available to compensate for outside interference.

As the study was conducted within a commercial operation, it was desirable to minimize interference with normal contractor operations. Consequently, researchers were unable to control knife changes, disk speed, anvil clearance, or collect support information on tree weights and bark thickness. While more time would have helped data collection, trial environment paralleled those to be expected in practical application. Table 18. lists the major stand and equipment conditions which prevailed during each test.

External conditions not only influenced trial results, but also influenced design of the van and its systems. Test sites were 350 miles from shop facilities at Virginia Tech. Due to long travel distances, it was necessary to have the unit pre-assembled for rapid deployment on arrival. Multiple test features had to be included in the assembly so conversion from one mode of operation to another could be accomplished with only hand tools. In the final analysis, both the floor screen and air power system would have been more efficient if design and installation were free of these constraints.

Table 18. General trial conditions.

Trial no.	Date	Treatment	Chipper condition	Trees /ton	Comments
1	10/31/86	Passive	Good	5.13	
2	11/3	Blower	Good	5.44	
3	11/4	Blower	Good	4.63	
4	11/6	Passive	Good	5.07	
5	11/7	Deflect/ suction	Dull knives	6.40	Smallest trees
6	12/6	Deflect/ suction	1/2 speed	5.50	Engine trouble
7	4/28	Horn	Very dull knives	5.16	
8	5/1/87	Horn	Very dull knives	5.14	Increased air flow

THE FIRST FOUR TRIALS - PASSIVE VERSUS BLOWER

Trials #1 thru #5 were conducted in the same stand. Chipper maintenance was at its best during Trials #1-4. Daily knife changes produced good quality chips. Test loads were no later than fourth after a knife change, assuring fewer fines and a higher percentage of large chips.

Trials #1 and #4 were Passive trials while #2 and #3 were blower treatments attempting to remove bark and grit with a 30 mile per-hour air stream intersecting the chip stream at an approximate 120^{o} angle. Paired analysis failed to detect any significant difference between Passive and Blower treatments for total bark, barky chips, or attached bark content. Analysis of variance indicated differences between blocks which led to comparisons between trials rather than treatments. Duncan's MRT procedure paired individual trials without regard to treatment, ranking #1 & 2 as different from #3 & 4. These results were reiterated in analysis of clean chip content and barky chip percentages.

Two explanations for this cross treatment ranking can offered. First, the blower was not able to move enough air to compete with the eighty to ninety mile per hour chip stream. The overhead air stream operating at approximately one third that rate, was simply over-powered by the chipper. Second, and perhaps most important, was the extraneous variability introduced by tree size. Trials #3 and #4 were conducted using larger and therefore heavier stems. Table 19 lists Cumulative total bark percentages for the first four loads. Figure 8 shows the relation between stem weight and total bark.

Table 19. Cumulative total bark percentages
(Trials #1 - 4)

Trial#	All*	>1/8"	>3/8"	>5/8"	>7/8"	>1-1/8"
T#1	6.83%	7.03%	5.40%	3.21%	2.16%	1.99%
T#2	7.53%	7.75%	5.94%	4.11%	2.17%	3.48%
T#3	5.25%	5.41%	3.96%	2.39%	1.38%	1.42%
T#4	5.45%	5.58%	4.08%	2.48%	1.98%	1.97%

* Percentages are weighted averages for the total load, including fines.

DEFLECTION TRIALS #5 & 6

Trial #5 was conducted in the same stand as the previous four while six occurred five weeks later in a different stand. Five and six were deflection trials which reduced bark three ways. (1) The chips stream was deflected from a overhead screen which allowed fines to pass. (2) Screen impact also caused the more brittle mature bark to fracture into smaller particles. (3) A suction fan pulling air from the back side of the screen facilitated the removal of grit, fines and abraded bark particles from the chip stream.

Several problems were encountered with these trials which may have distorted their results. Average tree size for Trial #5 was the smallest encountered during testing. Mean stem weight for Trial #5 was 21% lighter than that of the first four trials. Smaller stems have higher ratios of bark to clear wood than large stems, and the bark tends to be juvenile, thinner and more resilient.

Lack of chipper control also contributed to bias. Twelve production loads were chipped prior to Trial five's test van and knife condition was poor. For Trial #6, the chipper suffered from power loss and could only run 50% of design speed. This caused chip size distribution to shift towards larger chips with more attached bark.

Another problem with Trials #5 and #6 could not be confirmed until after Trial #7. It then became apparent that dust bins designed to collect chip stream debris were too small. Sometime during the first half of the loading process, bins would fill to the point where air exiting the blower could not escape. This caused back pressure against the fan which in turn lowered suction efficiency. As long as static pressure remained low, the chipper air stream was likely supercharging the fan allowing it to move more air. As flows became blocked, pressures equalized on both sides of the fan and the cleaning action deteriorated. In addition, the intake/deflection screen was positioned too far from the chip spout which allowed material to spread out over a frontal area 30% larger than the screen. This left a considerable portion of the load untreated.

Some interesting data were gathered despite problems. Trial five's cumulative percentages for total bark, chips with attached bark and the weight of attached bark were lower than expected. Only the larger trees of Trial #3 consistently showed better results.

Figure 7, comparing total bark with stem weight, shows a definite pattern. Trials #1 through #4 had total bark percentages which correlated directly with their stem weights. Trial #5, on the other hand, demonstrated an average total bark percentage more in line with 390 pound stem weights than its 312 pound average. Both total bark and barky chip percentages were used to test the hypothesis that Trial #5 reduced these contaminants to a level more consistent with much larger sized trees.

Table 20. Cumulative barky chip percentages
(Trials #1 - 5)

Trial	All*	>=1/8"	>=3/8"	>=5/8"	>=7/8"	>=1-1/8"
T#1	3.68%	3.79%	4.39%	5.30%	6.81%	9.50%
T#2	3.21%	3.31%	3.97%	5.82%	6.87%	9.51%
T#3	2.47%	2.55%	3.03%	3.68%	3.86%	4.48%
T#4	3.43%	3.51%	4.13%	4.75%	6.64%	6.83%
T#5	2.98%	3.08%	3.60%	4.39%	4.09%	6.12%

* Percentages are weighted averages for the total load, including fines.

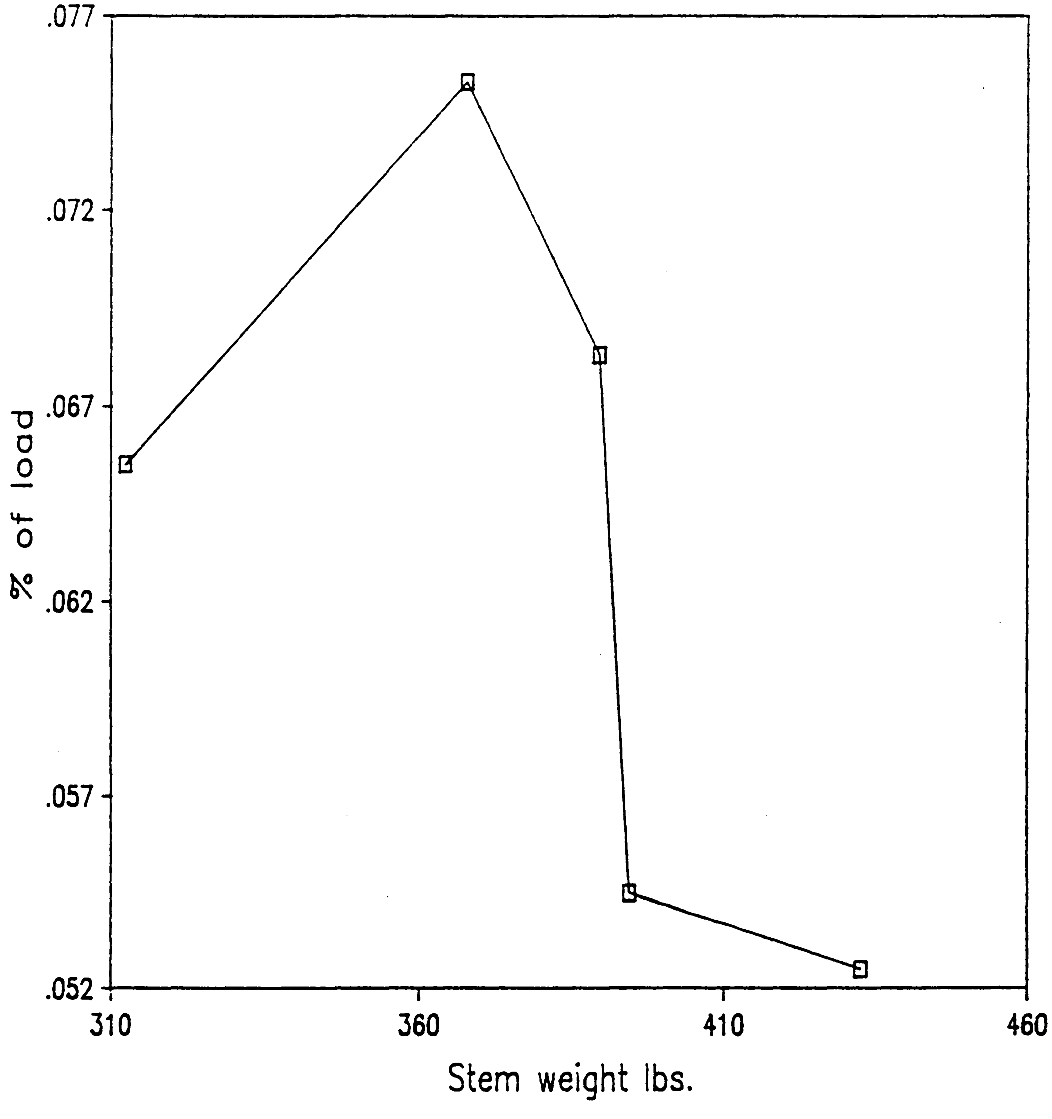


Figure 8. Relation between stem weight and total bark for Trials #1 - 5.

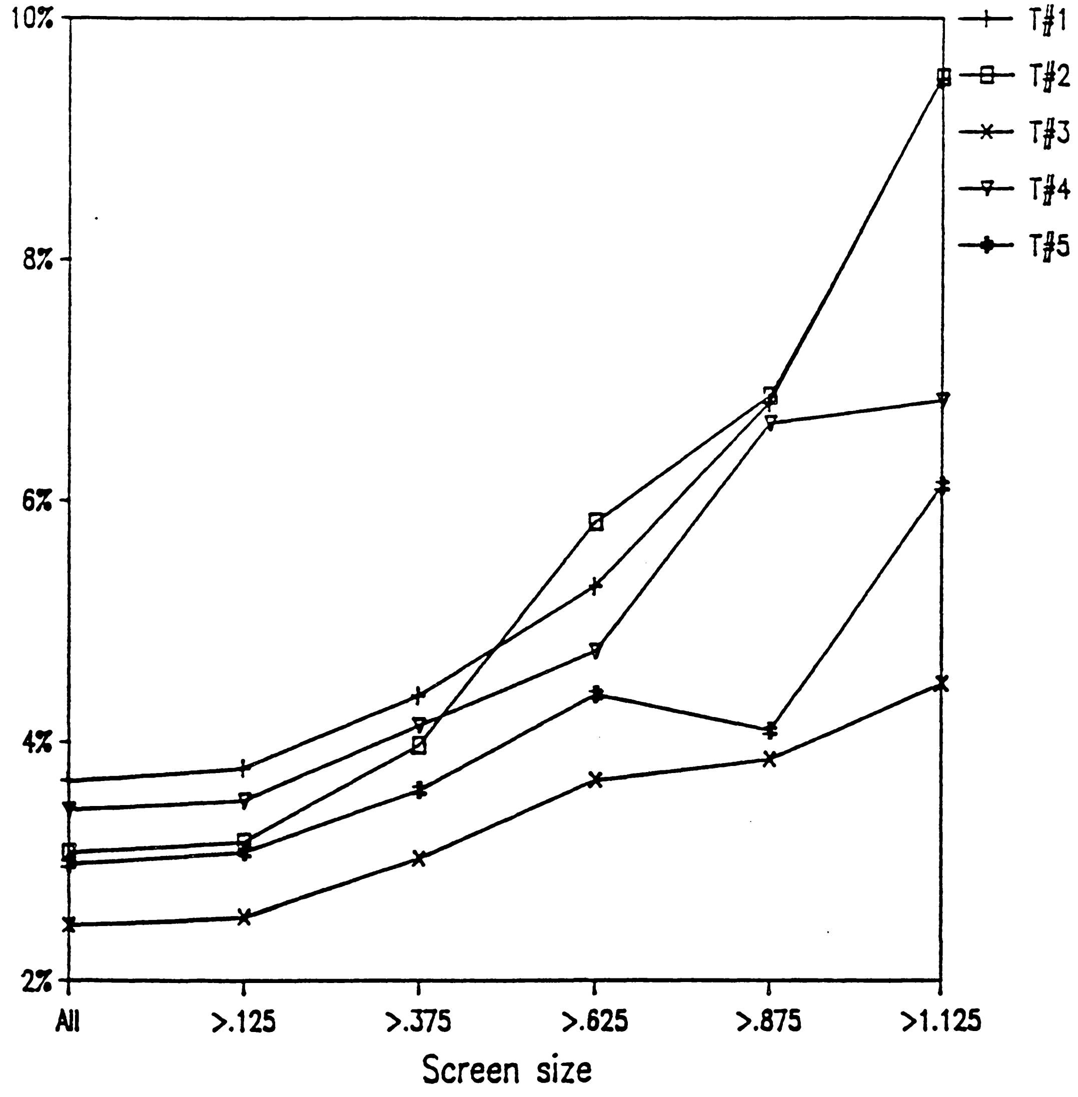


Figure 9. Cumulative barky chip percentages - Trials #1 - 5

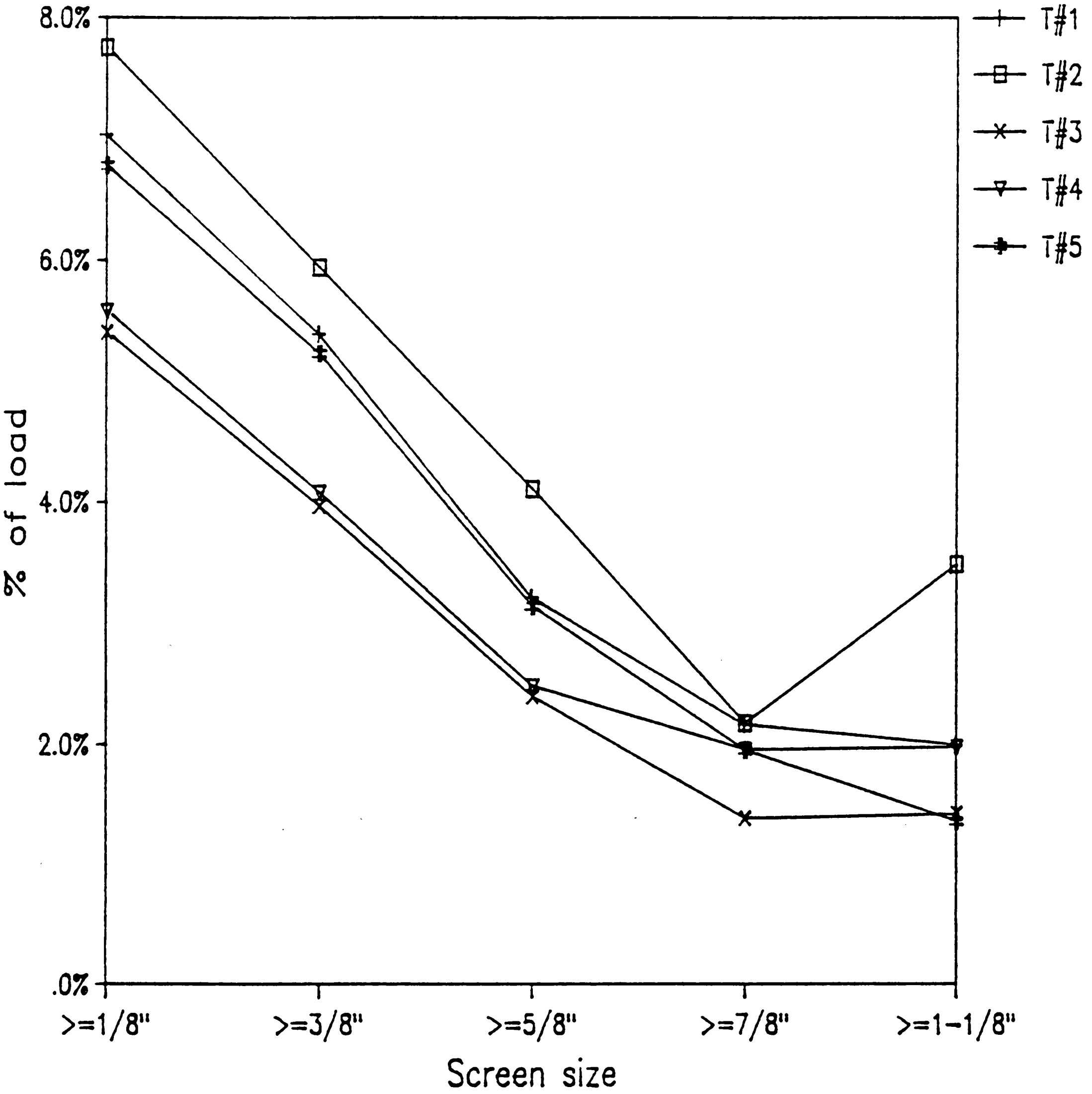


Figure 10. Cumulative total bark percentages - Deflection vs. Passive and Blower trials (T#5 vs. T#1-4)

Cumulative total bark and attached bark percentages were analyzed using Duncan's MRT and Anova procedures. Duncan's Least Significant Difference test gave the following ranks (in ascending order) for cumulative barky chip percentages.

$T^{\#}3$ $T^{\#}5$ $T^{\#}4$ $T^{\#}2$ $T^{\#}1$

Analysis of variance rejected the null hypothesis of equality between all five samples, but failed to reject when Trials #3, #4 and #5 were compared. The conclusion is that deflection was successful in reducing barky chips to a level comparable with the trials conducted in larger stems.

When total bark was analyzed, Duncan's MRT rated sample means in the following manner:

$T^{\#}3$ $T^{\#}4$ $T^{\#}5$ $T^{\#}1$ $T^{\#}2$

In total bark content, Trial #2 contained significantly more bark than all others while five was comparable only with four and one. Anova gave similar results when Trials #3, #4, #5 and #1 were analyzed rejecting the hypothesis that Trial #3 and #5 were of the same population. The results indicate that despite inferior stem size, deflection was successful in bark reduction for the larger chip size classes. The treatment's inability to make a more significant reduction in over all bark content is attributed to bin capacity problems.

HORN TRIALS #7 & #8

Trials #7 and #8 were conducted in early spring, the height of apical meristematic activity. Consequently, barky chip or attached bark comparisons between Horn and Passive trials would serve no purpose. Comparisons for seven and eight are made with samples taken from trucks in the chipper queue immediately preceding and following the test van. These samples were scooped from the chip pile at the rear of the van.

On the other hand, total bark comparisons between Horn and Passive trials did have some significance across seasons. Any bias in total bark resulting from seasonal differences should occur as a result of chipper knives knocking loose bark off the stem and rejecting it through the separator. This danger was reduced by the poor condition of the chipper's disk seal. The test machine was being used to clean out culls and unmerchantable stems from a logging operation. Consequently it suffered from lack of attention during Trials #7 and #8. Knife changes occurred every two days, and as mentioned, the disk seal had long since ceased to be effective. Statistically, there was evidence that Passive samples #7 and #8 were comparable with results from Trials #1-5 (Table 21). Anova comparison failed to reject the hypothesis that there were no differences between treatment means, indicating that seasonal differences in total bark content were minimal. Bark may have separated from the stem more easily, but still wound up in the van.

Trial #5 indicated deflection was capable of bark particle size reduction and an effort was made to improve the design prior to Trials #7 and #8. The new Horn design had a larger low pressure screen area and second passive screen positioned to provide a secondary deflection of the chip stream. This double bounce action helped compensate for the chipper's tendency to supercharge the test van's blower. Material which could not enter the main suction area had another opportunity to exit at the passive screen before being carried into the van.

During deflection trials it was suspected that chip loading had continued beyond dust bin collection capacity. Bins remained unmodified for seven, however, loading was discontinued at approximately one-half capacity. The only loading problem experienced was a failure to keep the chip stream centered as load weight depressed the trailer suspension.

Horn trials rendered lower cumulative bark contents than the first four trials despite Trial seven's chip stream targeting problem. The only suspicious results were bark counts retained on the five eights and seven eights inch screens in Trial #7. Bucket samples for the trial were fairly uniform except for bucket four right, located in the front right hand corner of the test van. Not only was this bucket's five eights inch size class larger than any other bucket, but it contained ten percent more bark. Circumstances suggest sampling error due to the chip stream being directed towards that bucket's location by the Horn, resulting in a concentration of 5/8" and larger particles. However, that class represented only twenty percent of the total load, and weighted average bark contents remained low.

Table 21. Cumulative bark and clean chip percentages
(Trials #1 - 4 vs. Horn trials & Passive samples)

Cumulative percent total bark

Trial	All	>=1/8"	>=3/8"	>=5/8"	>=7/8"	>=1-1/8"
T#1	6.83%	7.03%	5.40%	3.21%	2.16%	1.99%
T#2	7.53%	7.75%	5.94%	4.11%	2.17%	3.48%
T#3	5.25%	5.41%	3.96%	2.39%	1.38%	1.42%
T#4	5.45%	5.58%	4.08%	2.48%	1.95%	1.97%
T#7	4.65%	4.83%	3.75%	3.06%	1.52%	.81%
P#7*	5.55%	5.82%	4.63%	2.85%	.92%	1.95%
T#8	4.13%	4.25%	3.44%	1.95%	1.42%	1.09%
P#8*	5.60%	6.00%	5.10%	2.70%	1.30%	2.10%

Cumulative percent clean chips

Trial	All	>=1/8"	>=3/8"	>=5/8"	>=7/8"	>=1-1/8"
T#1	87.45%	90.01%	91.17%	92.49%	92.26%	89.89%
T#2	87.20%	89.75%	90.96%	91.37%	92.32%	89.68%
T#3	89.89%	92.53%	93.58%	94.59%	95.49%	95.02%
T#4	89.41%	91.50%	92.49%	93.66%	92.68%	92.46%
T#7	91.11%	94.78%	95.85%	96.57%	97.89%	98.57%
P#7*	90.18%	94.58%	94.30%	95.22%	95.73%	89.35%
T#8	92.97%	95.69%	96.47%	98.00%	98.53%	98.89%
P#8*	88.00%	94.50%	94.10%	96.40%	97.00%	96.40%

*Denotes Passive load sample data.

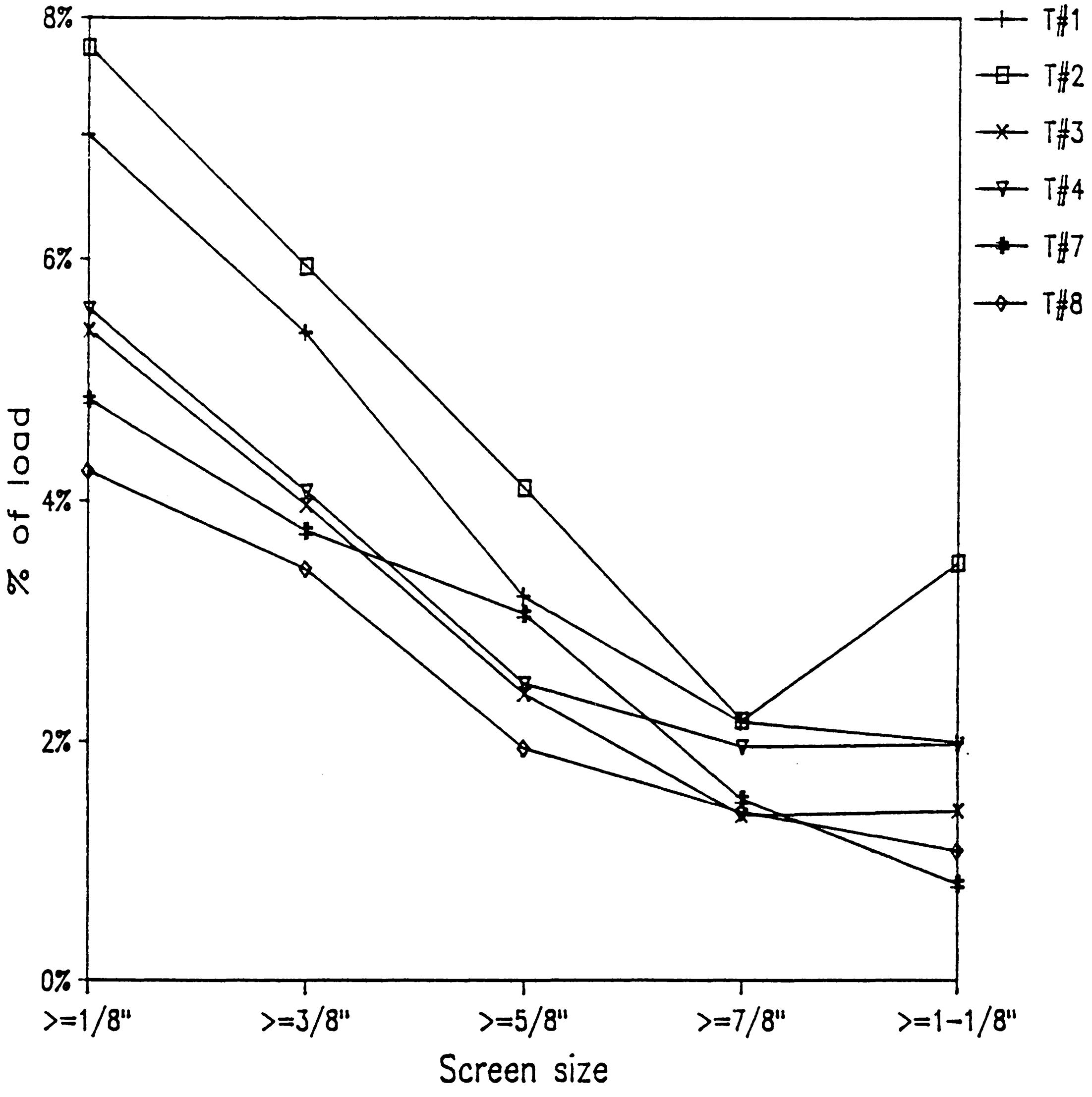


Figure 11. Cumulative total bark percentages - Horn trials vs. Passive and Blower trials (T#7,8 vs. T#1-4)

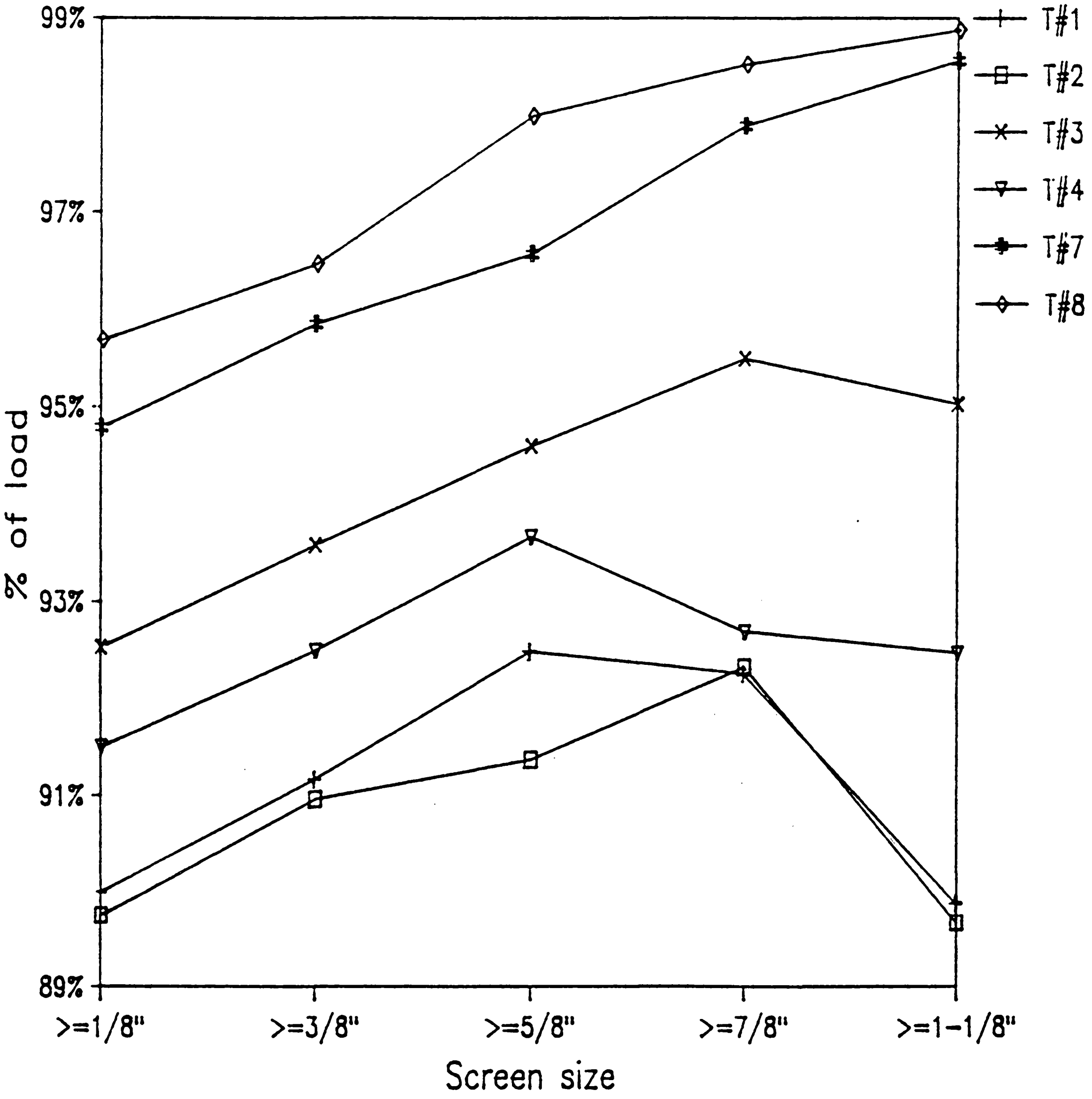


Figure 12. Cumulative clean chip percentages - Horn vs. Passive and Blower (T#7,8 vs. T#1-4)

Duncan's MRT failed to differentiate between Trials #7 and #3, but found significant differences between the mean bark content of eight and all other trials. Trial #7 and #8 were again significantly different when clean chips were analyzed. Analysis of variance comparisons between Horn treatments and the two best previous runs (T$^{\#}$3 & 4), heavily rejected the null hypothesis of equality between population parameters. Despite significant results, comparisons between seasonally separated treatments, or trials with varying levels of equipment maintenance, are not definitive. Therefore, comparisons between Horn trials and Passive samples taken from other loads were indicated.

$$T^{\#}8 \qquad \underline{T^{\#}7 \qquad T^{\#}3 \qquad T^{\#}4} \qquad \underline{T^{\#}5 \qquad T^{\#}1} \qquad T^{\#}2$$

Two Passive samples taken April 28, 1987 along with Trial #7, and two more with Trial #8 on May first. Scooping these samples from the back end of other trailers resulted in erratic contaminant distributions. However, comparisons between sample means were not badly effected. Trial #8 differed from Trial #7 in that dust bin baffles were cut down to one third their original area and the two outside pan slots were left vacant. This improved air flow for the suction system and vastly improved efficiency. Trial #8 results were by far the best with fewer contaminants and higher clean chip counts as seen in Tables 22.

As the following graphs show, Trial #7 did somewhat better than its paired Passive sample while #8 out performed all others. For total load in the 1/4" and larger size class, Trial #8 showed a six percent improvement over its paired Passive sample, while reducing total bark to less than four percent. Clean chips in the same categories improved over two percent.

Table 22. Contaminant distributions for trials 7 & 8

Cumulative load percentages

T #7 4/28/87	All	>1/8"	>1/4"	>3/8"	>5/8"	>7/8"	>1-1/8"
Passive van	100%	95.35%	86.86%	69.63%	34.42%	10.94%	3.03%
Test van	100%	96.12%	83.90%	65.56%	28.33%	8.57%	2.03%
T #8 5/1/87							
Passive van	100%	93.09%	82.06%	66.18%	29.02%	8.98%	2.81%
Test van	100%	97.16%	88.09%	74.64%	36.02%	12.65%	3.35%

Cumulative total bark percentages

T #7 4/28/87	All	>1/8"	>1/4"	>3/8"	>5/8"	>7/8"	>1-1/8"
Passive van	5.6%	5.82%	5.00%	4.63%	2.85%	.92%	1.95%
Test van	4.6%	4.83%	4.21%	3.75%	3.06%	1.52%	.81%
T #8 5/1/87							
Passive van	5.6%	5.98%	5.45%	5.10%	2.74%	1.29%	2.10%
Test van	4.1%	4.25%	3.75%	3.44%	1.95%	1.42%	1.09%

Cumulative clean chip percentages

T #7 4/28/87	All	>1/8"	>1/4"	>3/8"	>5/8"	>7/8"	>1-1/8"
Passive van	90.2%	94.58%	94.06%	94.30%	95.22%	95.73%	89.35%
Test van	91.1%	94.80%	95.40%	95.85%	96.57%	97.89%	98.56%
T #8 5/1/87							
Passive van	88.0%	94.54%	93.80%	94.10%	96.42%	96.97%	96.44%
Test van	93.0%	95.70%	96.18%	96.47%	98.00%	98.53%	98.89%

Cumulative barky chip percentages

T #7 4/28/87	All	>1/8"	>1/4"	>3/8"	>5/8"	>7/8"	>1-1/8"
Passive van	1.08%	1.14%	1.25%	1.44%	2.56%	3.87%	9.22%
Test van	.49%	.51%	.53%	.57%	.49%	.74%	.71%
T #8 5/1/87							
Passive van	.82%	.88%	.99%	1.10%	1.10%	2.11%	1.75%
Test van	.08%	.08%	.09%	.11%	.06%	.07%	.04%

Cumulative attached bark percentages

T #7 4/28/8	All	>1/8"	>1/4"	>3/8"	>5/8"	>7/8"	>1-1/8"
Passive van	.26%	.28%	.30%	.37%	.62%	.52%	.53%
Test van	.12%	.13%	.14%	.16%	.11%	.14%	.08%
T #8 5/1/87							
Passive van	.21%	.22%	.25%	.30%	.26%	.37%	.29%
Test van	.02%	.02%	.02%	.02%	.01%	.02%	.02%

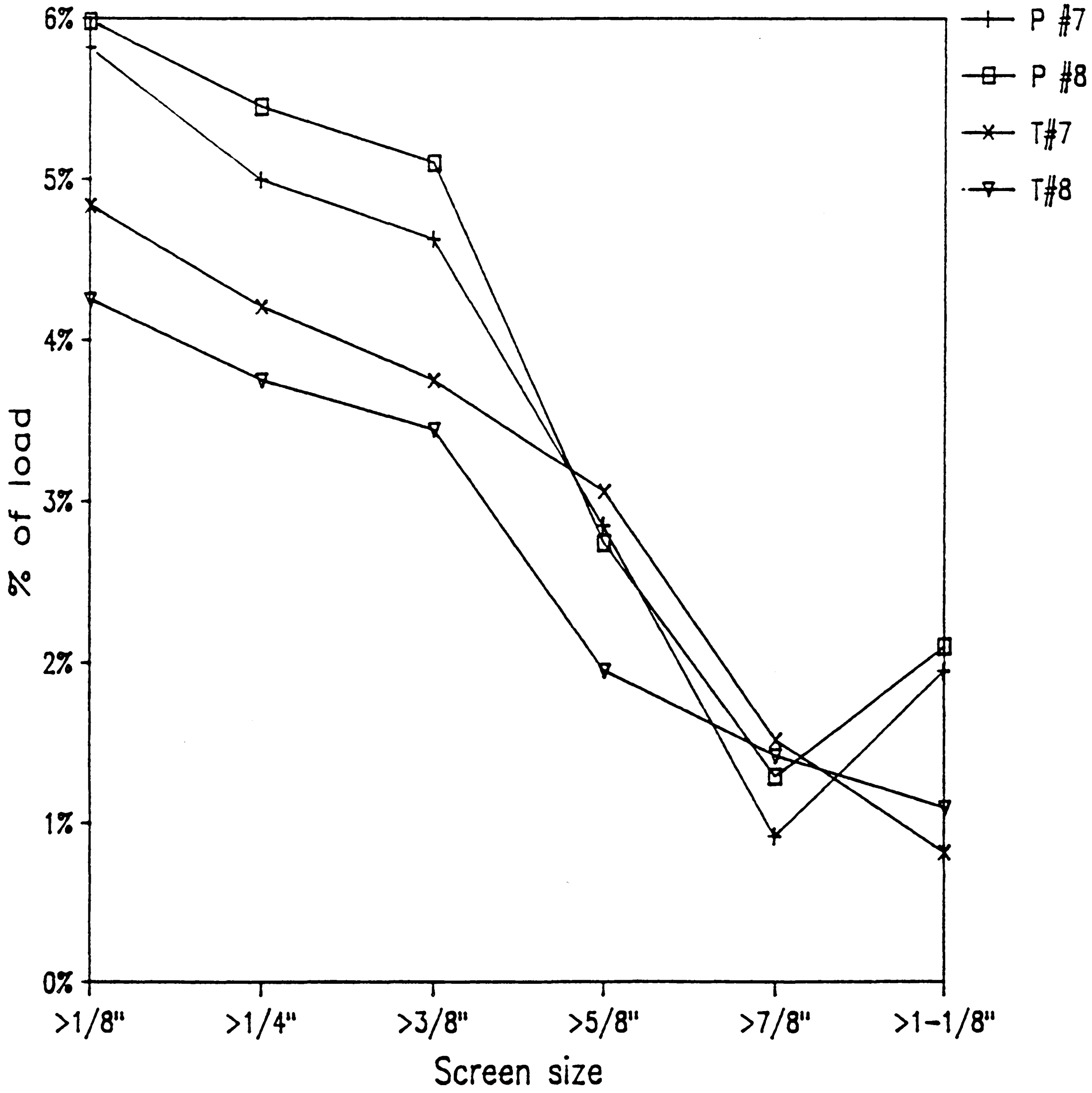


Figure 13. Cumulative total bark percentages - Horn trials vs. Passive samples

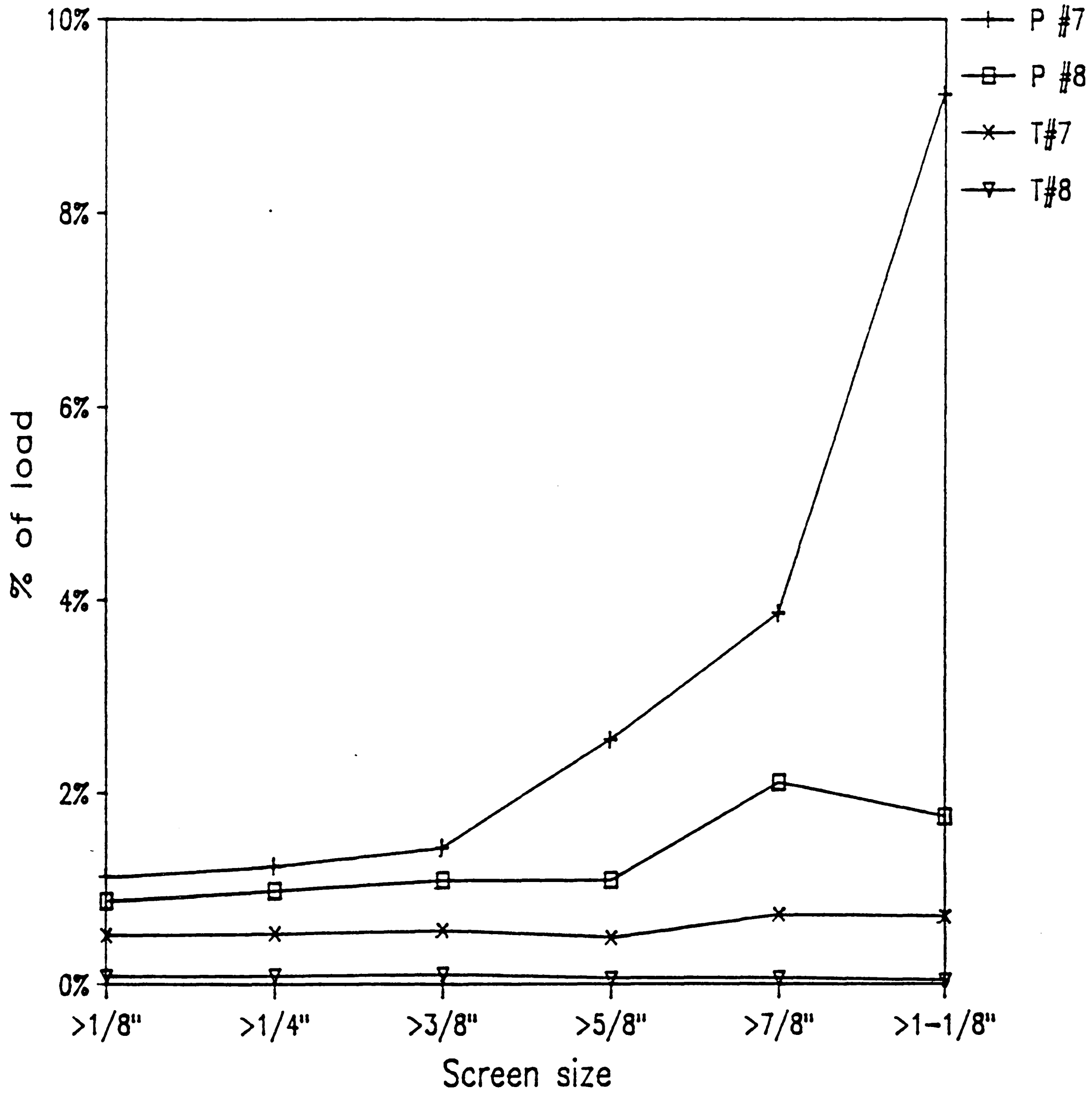


Figure 14. Cumulative barky chips - Horn trials vs. Passive samples

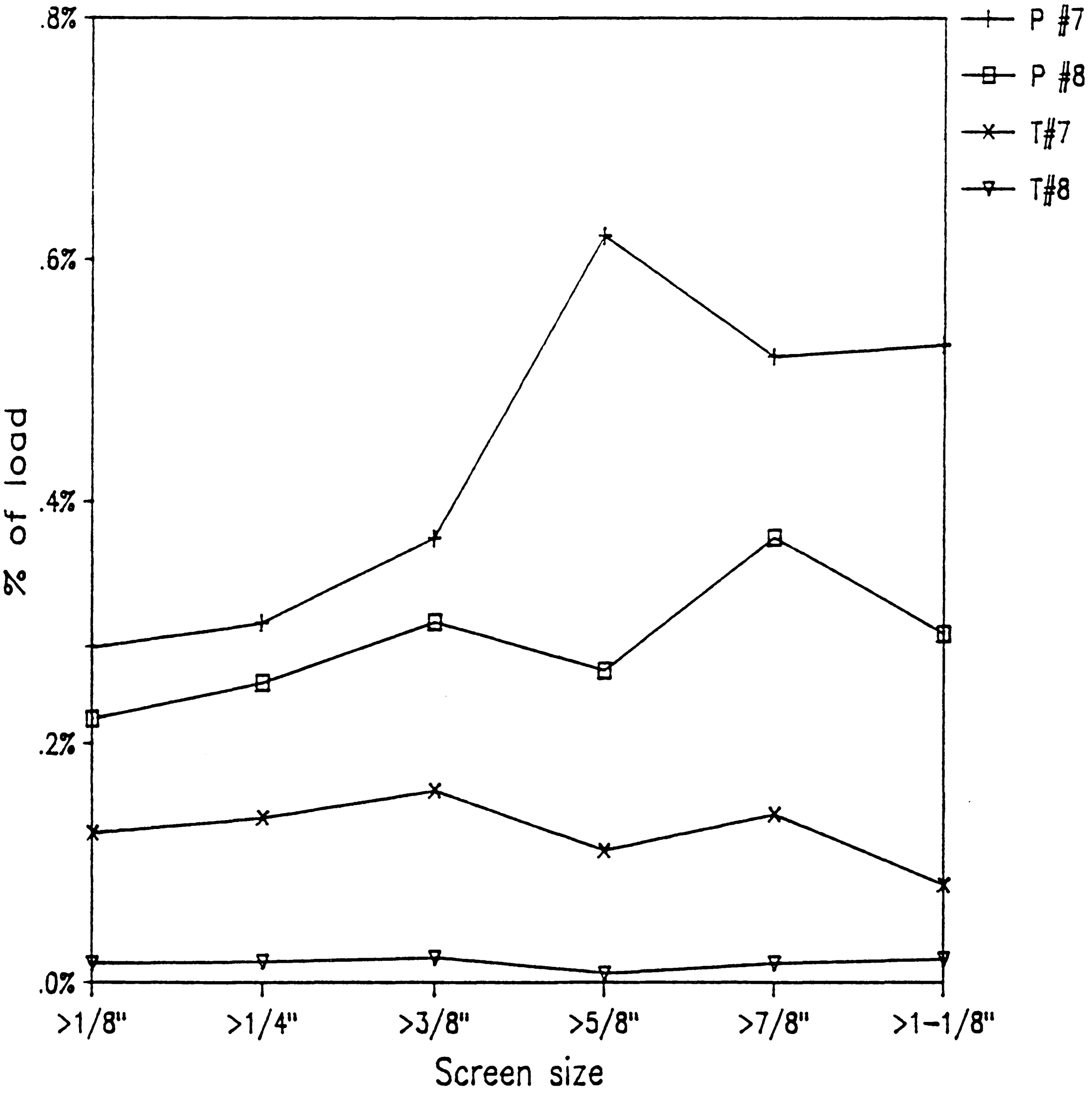


Figure 15. Cumulative attached bark percentage - Horn vs. Passive samples

In Passive #7 and 8, dissimilarities between larger size classes were probably due to small sample sizes and sampling procedure. Where chips are stored in sloped piles, larger chips tend to slide down the sides while smaller chips remain towards the top. This natural segregation was difficult to avoid when samples were pulled from a pile formed in the van rather than being captured from the chip stream. In Trial #8, Passive cumulative load percentage increased six points from the >1-1/8" class to 7/8" class, while treatment load gained nine percent. Treatment total bark gained only half of one percent despite the disproportionate size class increase.

Randomized Block Anova tests between treatments and Passive samples rejected equality or the null hypothesis in all cases. Duncan's MRT consistently paired Treatment #7 and Passive #8 while sometimes failing to differentiate between Treatment #7 and Passive #7. This ranking occurred when all four samples were run separately and disappeared when treatment #8 was dropped as significantly different.

POWERED SYSTEMS

Horn trial results indicate double deflection and vacuum screening is a potentially effective method for upgrading Whole-Tree-Chips. The prototype system had the following effects:

1) Oversize "cards" were broken up by the deflection screens increasing chip load in the 5/8" size class.
2) Impact with the deflection screens loosened attached bark and reduced the size of free bark particles.
3) The active and passive screen combination used in Horn trials removed one third of the fines delivered by the chip stream.

4) The percentage of clean, acceptable chips in the van was increased by as much as five percent.

Further refinement of the systems could result in additional improvement.

As installed, the suction deflection screen was not able to accommodate the entire air stream supplied by the chipper. None the less, it still managed to extract one-third of fines delivered by the chip stream. Experimental results indicate that if all air were stripped from the chip stream, lighter particles, relying on air velocity to maintain ballistic integrity, would be removed with excess air. This would prevent fines from settling in the chip mass and adhering to wet green chips. Acceptable material would rebound from the screens and load under residual kinetic energy.

Trials #5 through #8 all had active debris collection systems. If these trials had not benefited from power segregation, some percentage of the material would have remained in the load as either bark or fines. It is was evident that Deflection and Horn trials reduced chip concentrations in the 7/8" and 1-1/8" size classes. These larger chips are normally fissured, when bounced from the deflection screen they are reduced in size by splitting along the cracks. The reduction does not effect pulping but does reduce over size rejects. In a similar fashion, brittle mature bark is reduced for easier screen rejection rather than carried over into some larger chip category. Material collected by active systems was not hand segregated for useable fiber and bark, this differentiation being impossible with existing resources.

Of the 12.2 tons loaded in Trial #5, 350 pounds of debris were collected by the dust bins. Trial six's load weight totaled 18.9 tons, but only 19 additional pounds of material were collected by the dust bins. After much speculation about the chipper's poor mechanical condition it was reasoned that collection capacity was probably the culprit. An attempt was made to verify this suspicion in Trial #7, but personnel problems negated Horn efficiency. The original chipper operator had quit his job and each individual truck driver was loading his own truck. Fortunately, the same driver was available for both Trials #7 and #8, a circumstance which allowed seven to serve as a training trial. For Trial #8, dust bin baffles were reduced in size and the outside pan slots were left clear, relieving blower back pressure. The chip spout was also jammed against the primary deflection screen making it impossible for chips to miss the Horn's critical entry point. Load weight was 6.6 tons and 432 pounds were retained by the dust bins. On a percent of load basis this represented more than a two fold increase in efficiency.

Table 23. Active system contaminant collection

	Deflection		Horn	
Trial #	5	6	7	8
Dust bins lbs.	350.7	369.30	99.65	432.10
% of load	1.4%	.98%	.58%	3.30%
Passive screen lbs.			158.40	222.90
Total % of load			1.51%	4.95%

Table 24. Average dust bin size class distribution (Trials #5, 7, and 8)

Size class	Faction %
1/4"	1.51%
1/8"	25.71%
1/16"	40.62%
Fines	32.16%

FLOOR SCREEN SAMPLING

The twenty-seven sample pans arranged in three rows covered the rear 27 feet of the test van. Material dropping through the floor screens was contained by location for later analysis to determine load characteristics. When pan samples were screened by size classes, those farthest from the chip spout contained low concentrations of fines and higher percentages of 1/8" pin chips. These figures were reversed for pans in the first row, directly under the chip spout.

During the first five trials, floor screen pans were emptied and weighed immediately after each loading operation. As Deflection and Horn trials became more efficient it was discovered that only small amounts of material were collected during the loading operation. The major reason less trash fell through was due to the way deflection spread chips on the van floor. In normal loading chips accumulate in the van from front to rear. When deflected, chips tended to pile in the middle of the van blinding the screen. This prevented light material settling out of the chip stream from penetrating the floor screens. Comparisons between trials were, therefore, limited to weights removed during the dumping process. These weights were more substantial than samples taken immediately after loading. Chips would tumble as they cascaded from the van and bring more small particles in contact with exposed portions of the screen. Results were influenced by a combination of load weight and contaminant content.

The four heaviest loads were Trials #1 thru #4. In these loads floor screens were able to remove more than 200 pounds of material, a figure representing the maximum effectiveness for that installation. Load #4 removed the least debris, but, had fairly large trees which may have influenced its performance. Load #5 was six tons lighter than the first four loads but also had the smallest trees which produced more small material for removal during the dumping process. Load #6 removed very little material for its weight but also had the largest chips and least fines (1.61%). Dull blades in loads #7 and #8 caused high fines contents, but were the lightest loads. These smaller loads reduced screen rejects as can be seen in Figure 15.

The failure of Trial #6 and #3 to rank in accordance with increasing fines percent removed is probably due to bucket sampling error. Variances for these data are more than sufficient to accommodate these figures.

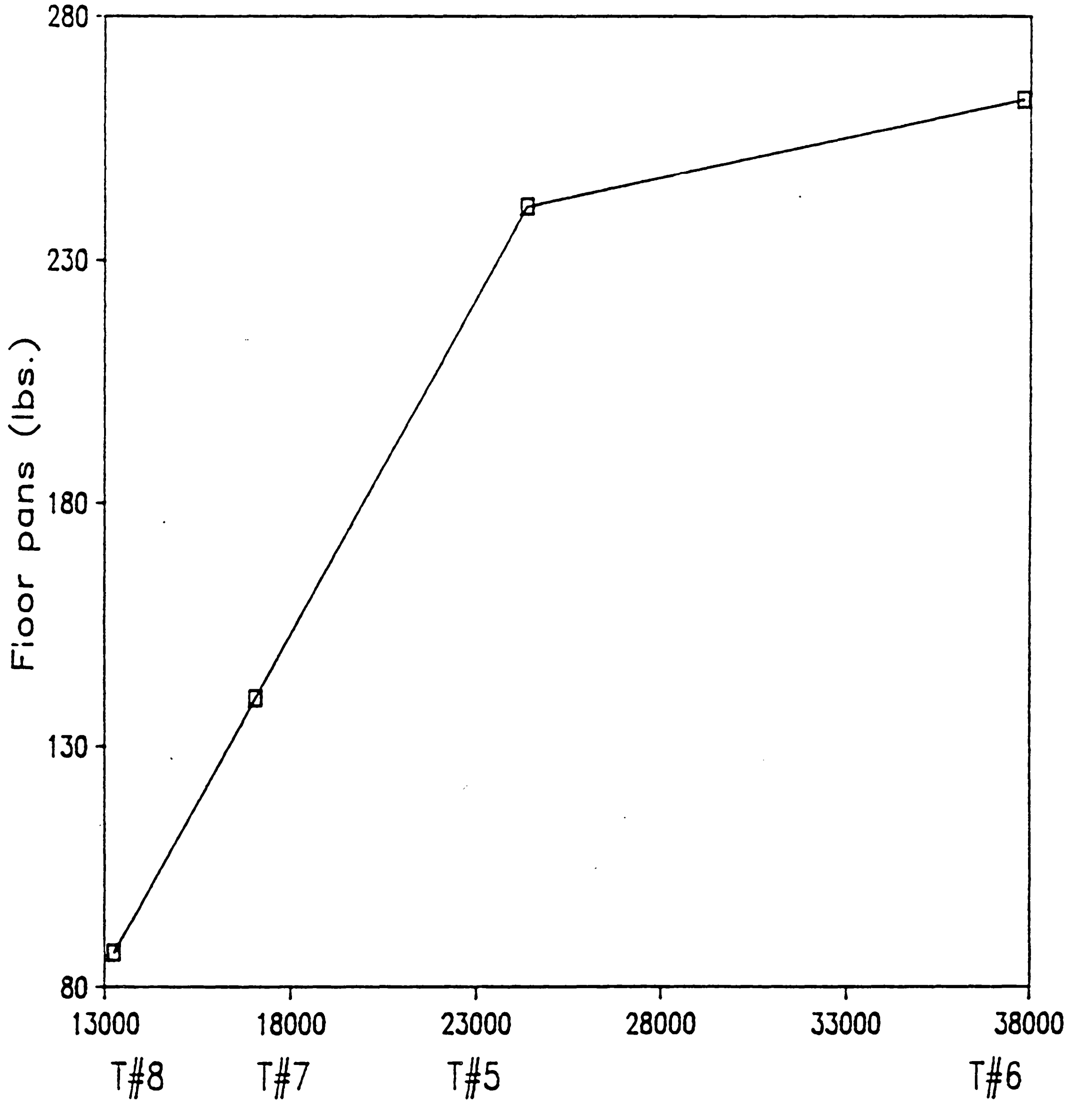


Figure 16. Floor screen weight vs. load weight

Table 25. Relation between load weight, fines content and Floor Screen efficiency

Duncan's MRT (Mean pan weights in ascending order)-	$T^{\#}8$	$T^{\#}6$	$T^{\#}7$	$T^{\#}2$	$T^{\#}4$	$T^{\#}3$	$T^{\#}1$	$T^{\#}5$
Load weight -	13240	37800	17040	37520	37100	39780	37800	24360
Fines % in sample buckets -	2.8%	1.6%	3.5%	2.3%	1.7%	2.4%	2.0%	2.5%
Fines % removed by floor screens -	22.3%	43.1%	23.2%	25.4%	26.5%	22.1%	29.5%	39.4%
Load % removed by floor screens -	.66%	.695%	.82%	.58%	.45%	.53%	.60%	.99%
Notes -		1				2		3

1. Slow chipper disk speeds created larger chips with more attached bark and fewer fines as a percent of load.
2. Trial #3 had the largest trees, producing the lowest bark content and second lowest fines content.
3. Trial #5 had the smallest trees of any load and duller knives. This resulted in a high fines content despite the suction screen, but also the highest floor screen fines removal rate.

Floor screen effectiveness

Because of their small hole size, floor screens became blinded early in the loading process. Screens were intended to allow fines and pins to pass during loading. Additional trials would be required to determine if blinding could be reduced by increasing hole size or altering shape. Floor screens did serve two functions. They allowed chip stream dust particles to settle in the sample pans according to their ballistic qualities, and they preformed a screening operation at the chip dump. It was initially felt that more material would penetrate the screens during the loading process however, larger particles quickly blinded the screen. Sampling pans under floor screens were emptied after loading and resulting weight/position relation noted. Generally speaking, pans farther from the loading area contained less weight but larger particles, while pans closer to the doors held more weight and finer particles. Very little additional material penetrated the floor screens during movement from woods to mill. This indicated that screen floors in chip vans would result in little material being lost on public highways in route to the mill.

Tumbling action imparted to chips exiting the van at the chip dump resulted in maximum screening efficiency. Comparisons between before and after dump weights showed approximately 75% of screen yields were achieved during dumping. These results indicate two possible applications of the process. If active screening were the primary objective, screen effectiveness could have been improved by positioning at the chip dump rather than in the van floor. On full van loads, only 50% or less of the chip mass ever contacted the screens. Less than half of this material was able to travel more than ten feet of the screen surface (Figure 17.). Positioning screens so that all material came in contact with a run of at least 20 feet would result in two to three times the efficiency. As installed, floor screens removed one third of a load's fines.

The second possibility considers several factors. First, in the average 40 foot van, installed weight of floor screens totaled approximately 100 pounds per four by seven foot section. This yields a total floor covering weight of 1,071 pounds for 300 square feet. A 1-3/8-inch-thick oak floor (34.4 cubic feet) with a specific gravity of 0.7 and a moisture content of 18% (.07 x 62.4(1+(18/100)) x 34.4) would weigh 1,773 pounds. This would result in a empty weight reduction of roughly 700 pounds.

The third point is that material which penetrated the 3/8" opening was much smaller than expected. Increasing average opening to 1/2" would allowed more material to pass during loading and transportation. Chips would eventually cover all portions of the screen, but, lighter material settling near the rear doors would have a opportunity to exit. A larger screen spacing would also reduce total deck or screen weight, allowing up to 1,000 pounds more useable material to be loaded before legal weight limits were exceeded. The combination of reduced floor weight and fines content could increase total usable chip capacity by as much as one ton or four percent.

The fourth and last consideration mitigates against installation at the chip dump. Extra screens are expensive and may prove to be a redundant effort if the screen house can effectively remove this same load segment. In addition, waste material extracted at the mill is paid for at pulp chip prices and requires further handling.

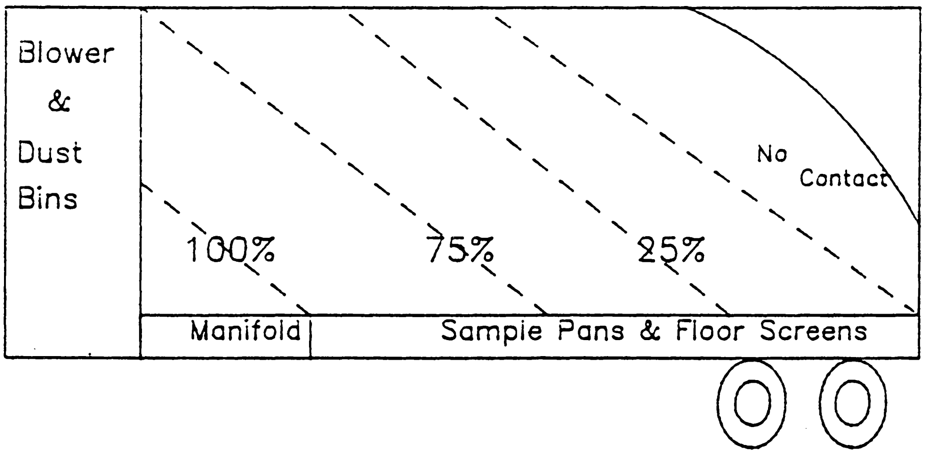


Figure 17. Relationship between load position and floor screen contact area.

REJECT MATERIAL CHARACTERISTICS

It was noted earlier that drum debarking resulted in useable fiber loss. Up to 30% of material falling through drum slots could be considered wasted product. When small stems are retained in drums long enough for complete debarking, reject material may run 14% by weight even though actual bark content measures only 10%. This means four percent of input material is wrongly rejected. Both Horn and Floor screen systems have a similar phenomena associated with their cleaning actions.

It can be seen, in Table 27, that Horn action collected less than one percent of the load's useable fiber while floor screens removed only 1/100th of a percent. The small amounts of fiber collected by both systems was in the form of pin chips, one-quarter inch or less, in maximum cross sectional dimension. Material of this size is either lost or problematic in most pulping processes. Should improved designs become available, more than twice the contaminants could be removed before fiber waste approached that of drum debarking systems.

Table 26. Summary of material rejected by cleaning systems

	Screen size	% of load	% rejected	% bark	1/4" Pins as % of load	 rej. mtl.
Horn	>.250"	18.3%	.80%	18.0%	.65%	13.19%
	>.125"	12.4%	2.10%	20.0%		
	Fines	3.9%	2.05%	32.0%		
Floor screens	>.250"	18.3%	.02%	5.8%	.01%	1.78%
	>.125"	12.4%	.21%	9.1%		
	Fines	3.9%	.59%	16.0%		

Dispersion of silica, mineral salts and other inorganics

Both incineration and acid reduction tests were used to determine the amount of silica or inorganic material contributed by each load faction. Initially, thirteen parallel samples were treated with both the incineration and acid methods to determine the relationship between the two methods. Because bark contains more inorganic compounds, the following trend resulted. Acid reduced bark samples lost one-third to one-half more weight than incinerated bark samples. When chips were tested, acid reduced samples lost one-half to two-thirds more weight than incinerated samples.

In all, fifty-four separate samples were tested. A representative picture of how silica is distributed through size classes between bark and fiber is shown in Table 26. As can be seen, 42% of the silica is concentrated in size class factions that pass a 3/8" screen. This load segment represents between 20 to 30% of the load depending on chipper condition.

Table 27. Ash content by size class and faction for Trial #1 (Load weight 37,800 lbs.)

	Ash weight in pounds			
Screen size	Chips & fines	Bark	Total	% of total load
>1-1/8"	3.51	.29	3.80	.01%
> 7/8"	13.31	1.07	14.38	.04%
> 5/8"	24.36	4.19	28.55	.08%
> 3/8"	39.62	11.56	51.18	.13%
> 1/8"	45.34	14.40	59.76	.15%
> 1/16"	4.31	*	4.31	.01%
Fines	12.39	*	12.39	.03%
Total	142.84	31.64	174.34	.46%

*Unsorted, included with pins and fines.

CHIP SAMPLES ANALYZED BY THE MILL vs. VIRGINIA TECH. SAMPLES

Disparities were apparent between sampling analyzed by the paper mill and samples taken from the test van for analysis at Virginia Tech. Mill sample results consistently showed lower bark counts. It is theorized that because samples were taken from the chip handling system, some segregation or bark reduction had been induced by the system. Another possibility is that mill analysis does not quantify this faction because of the difficulty. Whatever the case, not all bark factions were counted. Table 28 shows mill bark counts resulted in estimates of total bark ranging from one to two percent less than those obtained by hand sorting over forty pounds of samples for each load.

Table 28. Comparison between chip analyses preformed by the Mill and analyses at Virginia Tech.

Mill analyses of the first four tests

Trial#	Saw Dust	1/8 to 1/4"	1/4 to 1-1/4"	8 mm	Over 1-1/4"	Bark	M. C.	Sand
T#1	3.30%	6.70%	87.60%	1.30%	1.10%	4.30%	51.20%	.16%
T#2	3.00%	6.50%	85.80%	3.30%	1.40%	4.80%	52.20%	.40%
T#3	4.40%	8.60%	86.00%	6.00%	.40%	4.90%	52.80%	.33%
T#4	3.80%	7.40%	86.60%	8.00%	1.40%	4.70%	53.20%	.12%
Avg.*	3.63%	7.30%	86.50%	1.50%	1.07%	4.67%	52.35%	.25%
Mill Avg.	5.30%	8.20%	83.10%	1.50%	2.10%	5.00%		

Samples analyzed at Va. Tech.

Trial#	Fines	1/8 to 1/4"	1/4 to 1-1/8"	Over 1-1/8"	Bark	M. C.	Sand
T#1	3.57%	13.48%	81.56%	1.39%	6.50%	51.44%	.46%
T#2	3.23%	9.21%	86.30%	1.26%	6.31%	50.10%	.45%
T#3	2.58%	7.96%	87.65%	1.82%	5.01%	56.97%	.36%
T#4	2.08%	6.80%	89.46%	1.67%	5.31%	50.01%	.35%
Avg.*	2.86%	9.36%	86.24%	1.53%	5.78%	52.13%	.41%

* Average for Trials # 1 - 4.

SUMMARY AND CONCLUSIONS

Deflection systems

Because of varying trial conditions and continuing modifications to the treatment apparatus, trials within treatments were not directly comparable. The effect of overall variability was to create eight statistically separate treatments. This is reflected in Trials #1 - 4 where tree size caused cross ranking between treatment and untreated or passive loads. In this instance, the size variable proved more powerful than treatment. In Trials #7 - 8, dust bin air flow capacity and spout distance from the primary deflection screen made a marked difference in treatment performance. Similar problems existed for all trials. Regardless of the difficulties, some conclusions may be drawn. Table 29. uses Duncan's MRT to demonstrate the relative ranking of trials for three chip quality categories.

Both passive and blower powered deflection screens showed promise in field trials. Further research on the deflection angle, screen size and type is needed to maximize efficiency. The variable which made the most difference in these trials was chipper spout distance from the primary screen. A close setting takes advantage of the chip's maximum velocity, transmits the greatest shock to bark/chip bonds, and separates bark particles, causing them to detach and or decrease in size. Proximity also allows smaller screen areas as the chip stream is not given time to spread.

Table 29. Chip quality summary as ranked by Duncan's New Multiple Range Test

	Trial number						
Clean chips	8	7	3	4	5	1	2
Total bark	8	7	3	4	5	1	2
Barky chips	8	7	3	5	4	2	1

ANTI-CLOGGING SCREENS

Expanded metal screens as used in the van floor have proven to be non-clogging, inexpensive, durable, and light weight. They were very effective in removing fines and eighth inch pin chips. Longer screen runs are required to achieve maximum effectiveness.

More testing is required to determine the effects of larger screen openings. Only then could the benefits of additional product and higher quality be realized from weight savings, and cleaning action during loading and transportation.

SEGREGATION OF PIN CHIPS FROM BARK

Because conventional mill screening does not remove pin chips, there is a need for further investigation of screen motion and hole type as they apply to wood chips. One system suggested by this study would first use a vertical throw, square hole screen in eighth and quarter inch sizes. Material passed by this process can be re-screened with round hole screens of the same size using a horizontal motion. This should recover a large percentage of pin chips while allowing cube shaped bark particles to drop through.

MILL SAMPLING

If contractor cleaned Whole-Tree-Chips are to be used in paper making, high volume chip sampling would be desirable for two reasons. First, the contractor must be monetarily compensated for chip cleaning efforts. Otherwise his attitude will be that material rejected by cleaning operations is simply lost product. The second concern is the tardiness of information received from a sampling lab. By the time this data becomes available, many variables in the fiber supply line may have changed.

New computer aided spectral analysis techniques are currently being developed by the engineering department at Virginia Tech. News releases have characterized the process as high speed with applications in chemical and wood product industries. Efforts such as these need to be researched and supported with specific application of chip/bark differentiation in mind.

CHIPPER DESIGN

Fines generated by the trial chipper ranged from a high of four percent to a low of around two. One possible approach to reduce fines would be to revise chipper air management. The back side of a disk chipper is fitted with paddles which both throw and blow chips through the output chute. This resembles a radial blade blower in both design and function. The major difference is that air taken into the system must come from the input side of the disk. This side is loaded with fine particles generated by the cutting action of the blades. If air were allowed to enter from the back side of the disk housing it might be possible to reduce contaminated air drawn from the input side. Should this prove insufficient, the possibility of pressurizing the back side of the disk housing may deliver the desired results. A possible side benefit may result in reduced knife pocket packing. In this situation fines are forced into the blade mounting area, causing progressively larger chips as knives are forced from their installed positions.

While disk chippers predominate in the South, the potential for drum chippers to create a physical difference between contaminants and desirable factions has not been well documented. It has been noted that drums produce more fines, more strips, and are difficult to service during knife changes. Their major redeeming feature seems to be lower horse power requirements. Given current equipment concentrations, it is more feasible to experiment with minor changes in disk chippers. Another possible avenue of exploration is to simply make larger chips. Bark fractures in a different manner than useable fiber, and can be reduced in size by deflection. Attached bark percentages can also be reduced by deflection. What will be required is a shift in chip size distributions towards larger chips. Increasing nominal chip size from 5/8 inch to 7/8 inch should increase usable fiber retained on screens larger than 3/8 of an inch. More reject material could be removed in the screen house or vacuum deflection system without significantly affecting pulping qualities.

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APPENDIX A.

HYDRAULIC AND AIR FLOW CLACULATIONS

Hydraulic

The Dayton Manufacturing, 26 inch, radial blade blower required 25 horse power at 1,900 revolutions per minute for maximum air movement efficiency. Power was supplied by a Cross Manufacturing hydraulic motor, which drove the blower through two "A" size v-belts with a 1:1 pulley reduction.

Given: System Pressure = 2,000 P.S.I.
Motor Displacement = 3.3 Cu. In.
Motor Speed = 1,900 R.P.M.
Then: Gallons/minute = (R.P.M. x Cu. In.)/231
$\underline{27.14} = (1{,}900 \times 3.3)/231$
Horse Power = P.S.I. x G.P.M. x 0.000583
$\underline{31.65} = 2{,}000 \times 27.14 \times 0.000583$

Air Volume and Speed Calculations

Flow of Air in Pipes. - The following formulas are used:

$$v = ((25{,}000 \times d \times p)/L)^{1/2}$$

$$p = (L \times v^2)/(25{,}000 \times d)$$

in which v = velocity of air in feet per second;
p = loss of pressure due to flow through pipes in ounces per square inch;
d = inside diameter of pipe in inches;
L = length of pipe in feet.

Quantity of Air Discharged Through Pipes.

$$cfs = v/a$$

Where cfs = cubic feet of air per second;

a = the area of the pipe in square feet;

Conversion of static pressure (SP) as expressed by inches of water to air pressure as expressed in pounds per square inch (psi).

Where: 62.31 lbs. = weight of 1 ft^3 of water at 70^oF;

27.73 in^3. = volume of 1 lb. of water (1728/62.31).

Therefore a 1 in^2. column of water 27.73 inches tall exerts a pressure equivalent to one pound per square inch.

Considering the total air movement system, overhead duct work had the smallest cross sectional area and constituted the limiting factor for air flow calculations. Ducting measured 8 x 20 inches. The resultant 160 square inches is equivalent to a pipe 14.27 inches in diameter.

$14.27 \text{ in.} = (160/3.1416)^{1/2} \times 2$

In calculating air volume and velocity it will be assumed that during operation, static pressures ranged from 6 to 13 inches of water. Variation resulted from dust bin clogging as they approached capacity and as hydraulic efficiency deteriorated with heat buildup. The manufacture's cfm rating for blower speeds of 1,860 rpm will be used as this figure represents an average speed during operation.

For 6" Static Pressure, blower cfm rating equals 8,110 and velocity of air through the duct is equal to volume divided by cross sectional area:

Inlet/Outlet Velocity = 8110 / 1.11 = <u>7,306 ft./ min,</u>

and velocity per second = 7,306 / 60 = <u>121.777 ft./sec.</u>

Pressure and velocity losses are calculated using formulas for flow of air in pipes. Pressure loss in ounces per square inch equal,

$(36 \times 121.777^2)/(25{,}000 \times 14.27) = \underline{1.496\ oz./in^2.}$

Substituting into the velocity function, air speed in feet per second is equal to,

$((25{,}000 \times 14.27 \times 1.496)/36)^{1/2} = \underline{121.771\ ft./sec.}$

This figure is modified by a coefficient of discharge to compensate for plenum and exit duct inefficiencies. A reasonable estimate is .75 yielding a new inlet/exit speed

of .75 x 121.771 = 91.33 ft./sec;

or (91.33 x 60 sec. x 60 min.)/ 5280 ft. = 62.3 mph.

The volume of air passing through the 1.11 ft^2. duct at this speed is the product of velocity times cross sectional area.

Cubic feet per second = 91.33 x 1.11 = 101.38 cfs,

or 6,082 cubic feet per minute.

Similar calculations for 13 inches of static pressure at a 3,841 cubic feet per minute blower rating, yields inlet/exit speeds of 2,880.75 cubic feet per minute. Air speed at this volume equals 29.5 miles per hour.

APPENDIX B

A COMPARISON OF TWO HARVESTING/SITE PREPARATION TECHNIQUES IN THEIR EFFECTS ON SITE NUTRIENT BUDGETS

This presentation supports Whole-Tree-Chipping as a means of ameliorating the detrimental effects of mechanical site preparation on nutrients available for establishment and subsequent rotations of loblolly pine (*Pinus taeda* L.). Direct comparisons will be drawn between Whole-Tree-Chipping (W-T-C) and a Bolewood harvest followed by a drum chop and "cool" burn for slash reduction. Data for the comparisons model come from three studies conducted in the Virginia/ North Carolina Piedmont region. Decision criteria will be the net effect on site nutrient availability during the next rotation.

W-T-C harvesting operations are characterized by the removal of stems 5 cm in diameter and larger. In an even-aged plantation this would be equated with approximately 90% of the above-ground biomass, and reduce the weight of residues approximately 50% over conventional boltwood harvests (Boyle and Ek, 1972) which would increase yield approximately 108% (Ford, et. al., 1976). In situations where efficient harvesting techniques are practiced, the site may be machine planted without further site preparation.

Direct effects of harvesting equipment on site; age; mineral soil mixing with L, F, and H layers are approximately equal for the two systems (Boyle and Ek 1972). Following a conventional harvest, drum chopping further mixes the original litter and humus layers with slash, increasing organic decomposition rates (Fox, 1984). Fire is classified as either cool for slash reduction, or hot for debris reduction cautions that the use of hot fires can volatilize 200 to 300 Kg./ha of nitrogen (N) from the O1 and O2 layers. Additionally, potassium (P), phosphorus (K), calcium (Ca), and magnesium (Mg) are transformed into a soluble form.

Two data sets were used to construct the nutrient distribution model (Table 1). Discrepancies between these data sets may be justified in several ways. Geochemical, biogeochemical, and biochemical cycles contribute in varying degrees to the movement of different nutrients. For example, biochemical cycling drives 60% of P through the system, while K depends on biogeochemical cycling for 66% of its movement (Switzer and Nelson 1972). This influences nutrient distribution among needles, bole, and forest floor on a seasonal basis. Microsite variations between study sites also contribute to the discrepancy. Figures used in Table 2 were averages of those reported in the two studies, with percentage of nutrients in bolewood calculated from tables given by Jorgensen, and others (1975). These particular figures were used because they were the only ones available which specifically distinguished between root and aerial nutrient concentrations.

Study sites were located within 2° latitude of each other and soils were categorized as "Udults, low in organic matter content, temperate, warm and moist (Red-Yellow Podzolic soils)" (Brady, 1974). Biochemical nutrient cycling is very efficient in this environment, losing only 1 Kg/ha/yr of N and even less K (Pritchett, 1979; Fox, 1984). Under such conditions, nutrients and finely divided organic particles in the soil are relatively scarce, and sudden additions of soluble nutrients quickly fill the available cation exchange sites, leaving the remainder in the soil solution exposed to leaching (Burger, 1979). The situation is further exacerbated by post-harvest conditions which leave few living root systems to take advantage of the high nutrient availability. This was illustrated by Fox (1984) with wide movements of C:N ratios for the chop and burn treatment. From an initial site ratio of 29:1, N increased over the following nine months to a level which reduced C:N ratio to 22:1. Given a half-life estimate of seven years for N (Pritchett, 1979), concentrations rose approximately 38% or were made available at a rate at least nine times faster than in a forest floor. By comparison, the single pass shear-and-disc treatment (judged closest in effect on forest floor to W-T-C), had little mixing effect on the soil and experienced sequential C:N ratios of 23:1 and 21:1 over the same period.

Discussion

The comparison model gave a slight edge to bole harvesting immediately after harvest (table 3). It is suspected that if enough data were available for a meaningful comparison, the differences would not test significant via Duncan's multiple range test. This simplified representation necessarily excludes a large number of factors which will influence the nutrient budget. Precise estimates were either unavailable or were at wide variance. This section will deal with these variables in a non-quantitative manner.

Exclusion of the geochemical cycle's influence favors chop and burn over W-T-C by not accounting for higher rates of nutrient losses caused by leaching and ground-water runoff associated with bare soil exposure. In addition, Fox's (1984) data were taken from a site with a slope of 17°, which would have inflated nutrient flush rates of highly mobile nutrients from the burned site.

Volatilization rates were not available for P and K, which favor chop and burn by excluding these rates from calculations. The N volatilization figure of 100 Kg/ha is less than total N for slash alone, not including N present in L, F, and H layers. The lack of data for P and K affected by volatilization is offset by the arbitrary assumption that 50% of each nutrient is mobilized or transformed to an easily soluble form by the fire. Biochemically dependent, P transfers seasonally between needles and woody mass. Harvesting just after the first needle flush is complete may understate the amount of P mobilized by a slash reduction fire. On the other hand, since it is biogeochemical, K may be overstated if it is assumed that litter layer storage is relatively unaffected by a cool fire.

Failure to quantify the moisture-temperature relation, along with the resulting elevated microbial activity, favors chop and burn again by not accounting for nitrification which would have been higher in the burned area. This again has the effect of loading the site with more nutrients than can be used in the near future.

The estimated 95% biomass removal for W-T-C harvesting compares favorably with Ford's and others (1976) reported 108% increase in fiber removal when considered in light of a N distribution of 44.7% in the bole (Jorgenson et al. 1975). Nitrogen concentrations are linearly correlated with dry matter weight in stressed systems (Fox, 1984).

Nitrogen levels reported in the literature for above-ground portions of loblolly pines grown in the North Carolina Piedmont varied from 174 Kg/ha to 384 Kg/ha. The higher figure was reported in a species survey by Freedman and others (1981) and attributed to Switzer and Nelson (1973). However, the Switzer and Nelson (1972) study used in this assessment reported the lowest figure found.

Studies conducted on the basis of literature surveys are often reduced to accounting techniques based on mean data results from research not designed to test specific relationships. Resorting to CPA tactics ignores outside influences resulting in conclusions which are good for little except raising more questions. A well-designed experiment is more desirable for directing future efforts.

Conclusions

Progressively higher levels of mechanical site preparation have the effect of mobilizing larger quantities of nutrients in the first few years of the next rotation. Net effect is excellent growth response in young stands followed by nutrient deficiency at mid-rotation as soil reserves are rapidly depleted (Fox, 1984).

Techniques, such as whole-tree-chip harvesting, which minimize disturbance of the litter and lower strata do not exhibit such spectacular young growth but are better able to maintain nutrient storage levels. This allows a rotation to maintain growth rates until the forest is recycling adequate amounts of nitrogen (Pritchett, 1979). Net result is an equivalent yield by rotation age but with less damage to total site N levels (Fox, 1984).

Table 1. Distribution of tree nutrients in 20 year-old loblolly pine plantation in the North Carolina Piedmont.

Location	N	P	K	Ca	Mg	SOURCE
	-----------------	-----------------	Kg/ha	-----------------	-----------------	
AERIAL PART OF TREE	174	20	99	91	24	1
	257	31	165	187	47	2
% IN BARK & STEMWOOD	44.7%	48%	53.9%	-	-	2
L, F & H LAYERS	124	9.1	16	80	15.4	1
	307	30	28	-	-	2
TOTAL ROOT	64	17	61	-	-	2
MINERAL SOIL	1,753	371	404	-	-	2

Source code:

1 - Switzer & Nelson. 1972

2 - Jorgensen, Wells & Metz. 1975

Table 2. Nutrient distribution model of a 20 year old loblolly pine plantation in the North Carolina Piedmont.

Location	N	P	K	Ca	Mg
			Kg/ha		
Avg aerial content	215	25.5	132	139	35.5
% in bark & stemwood	44.7%	48%	53.9%	-	-
L, F & H layers	215.5	60.5	22	-	-
Mineral soil	1,753	371	404	-	-
Site total	2,183.5	457	558	-	-

Note - Figures in this table are averages of those reported in Table 1.

Table 3. Nutrient balance sheet comparing Bolewood harvest and subsequent chop and burn site preparation with whole-tre chipping in a 20 year old loblolly pine plantation in th North Carolina Piedmont.

Location	N	P	K	Ca	Mg
	Kg/ha				
Avg aerial content	215	25.5	132	139	35.5
Bark and stemwood	96.1	12.2	71.2	-	-
Slash and 8 cm tops	118.9	13.3	60.8	-	-
L, F & H layers	215.5	60.5	22	-	-
Fire effects:[1]					
Volatilized	100	-	-	-	-
Mobilized	0	36.9	41.4	-	-
Total removed chop & burn[2]	196	49.1	112.6	-	-
Total removed W-T-C harv.[3]	204.2	24.2	125.4	-	-
Difference for chop & burn	8.2	<-24.9>	12.8	-	- .

1 - Assumes only 50% of nutrients in slash and L, F & H layers are converted to soluble form by fire action.

2 - Totals are for bole removal plus nutrients either volatilized or made readily soluble for leaching during first season. No addition is made for increased rates of organic decomposit and subsequent leaching.

3 - Total removal for whole-tree harvesting is calculated as 95% of the available aerial portion of the tree rather than the mo conservative 50% of slash and tops plus bole and bark figure suggested by Boyle (1976).

APPENDIX C.

BENEFITS OF IN WOODS WHOLE-TREE-CHIPPING

Volume Estimation

When the total fiber supply problem for a given paper mill is viewed using "least cost" as the criterion variable, economies are constrained by two factors. Both the equipment currently in place and knowledge gained from its use define the boundaries of management options. Research and development seeks to improve processes and remove limiting parameters by systematically moving toward "least cost" solutions.

Whole-Tree-Chipping lowers costs in any given stand by recovering more material than bolewood harvesting. Maximization of harvesting efficency in pulpwood logging requires trees of minimum diameter class. Trees with diameters at breast height (dbh) of ten inches or larger are sawlogs, while stems in the five to ten inch class end up as pulp. Volume calculations for these diameter classes do not include limbs and tops or other stand components in the four inch and smaller range.

Ford, Stuart and Walbridge (1976) addressed this problem in their study of "Appalachian hardwood chipping overrun estimators". They found that eighty percent of the stems in typical stands are under five inches dbh and contribute over thirty percent to total harvest weight. Additionally, conventional volume estimates applied to these stems underestimated their contribution to total harvest weight by one to three-hundred percent. The reason for this anomaly is the volume in limbs and tops. Before Whole-Tree-Chipping these portions were not harvested and their contributions were not considered.

Nelson's study (1971) adds evidence to the overrun phenomenon. Working in Red Oak (Quercus coccinea) a six man chipping crew harvested 2,512 tons in 45 hours. Approximately 28 cords per man day were taken from only 18 of the 40 acres conventional estimation thought necessary.

Given the overrun possibilities of Whole-Tree-Chipping, what are the limitations? A Finnish study of mill costs for harvesting, transportation, screening and cleaning serves to compare expenses in a high energy cost environment. Vesikallio (1977) found chipping of unproductive hardwood forests to be competitive with conventional pulpwood sources if clear cutting was the method of harvest. On the other hand, chip operations in logging residues were not found to be competitive. From these, and many studies in this country, it could be concluded that in woods chipping is at least competitive as a fiber source.

Whole-Tree-Chipping in the United States may be subject to a different set of constraints than Tree Length or Short Wood systems. Most Whole-Tree-Chip material comes from unmanaged or overstocked stands. Additional sources are hardwood logging residues or chipped limbs and tops from the decks of hardwood saw logging operations.

Whole-Tree-Chip systems are not as dependant on input material quality for profitability. Graves, Bowyer and Bradley (1977) conducted a study comparing two sorting methods operating with a chipper. They found ..."sorting proved economically feasible with log values as low as $26.10 per cord, depending on stand conditions, sorting method and equipment used." Another aspect of the study found chip mix quality to be little effected until more than 20% is removed as sawlogs. Results, then, were dependant on the number of sawlogs available for chipping.

Whole-Tree-Chips can require fewer operations and load easier at the landing. In pine stands where trees are specifically designated for mill chips, stems are delimbed then bucked or taken full length to the mill. This material is debarked in fixed installations which require uniform dimensions. Harkin and Crawford (1972) estimate that beside material lost in delimbing, reject material from mill operations may contain up to 30% wood fiber as chunks or splinters. If a method could be developed for cleaning the chipped product of stems, limbs and tops on the landing, almost all material would be available as furnish.

Implications for pulping and silviculture

When Whole-Tree-Chipping Southern Yellow Pine, the furnish source is normally the lowest valued material available. Common practice is to clear cut overstocked stands and conversion sites. Material recovered in these operations is mostly small trees which results in a high percentage of juvenile wood in relation to bole wood.

Contrary to popular belief, several researchers have demonstrated that wood from juvenile sources can be used in the production of acceptable pulp. In 1957, Sproull, (et al.) concluded that good quality pulp can be made from each section of the tree. Alestalo and Yrjo (1966) ascertained that pulps from unmerchantable tops were of comparable strength to pulps from good stemwood, and that branchwood pulps were similar to pulps from lower quality stemwood.

More specifically, the shorter fiber lengths in juvenile wood have demonstrated acceptable Kraft pulping characteristics along with some other interesting benefits. Zarges, Neuman and Crist (1980) tested Populus clones grown under short-rotation intensive culture. They found that not only did they require less refining, but..."Handsheets from the clones grown for five or seven years had strength properties similar (or even superior) to those from mature aspen."

Augmenting the above are findings by Bonduelle (1977). Working with two hybrid Populus clones in planting densities of three, six and nine-thousand trees per hectare (1,214 to 3,642 trees per acre), trees from each density / clone treatment were chipped at two and five years of age. Fiber yield increased eight to twelve percent for both clones as spacing decreased. No difference in pulping properties were recorded for either clone at any density. Furthermore, most of the wood and bark properties were within the range of values elsewhere reported for hybrid poplars (FAO 1979, Zarges et. al. 1980). However, wood fiber length was shorter because of juvenile wood origin. Bonduelle recommended chipping of trees in the six to eight year range for longer fibers and lower bark content.

Studies which define fiber and bark aging relationships for coastal plain Loblolly pine (Pinus taeda L.) are not readily available. Such a study would be useful to define design parameters for a debarking mechanisms operating in specified bark to bole wood ranges. Optimal age solutions for bark to bole wood relations could dictate debarking equipment design. For example, ring and drum debarkers each have their own specialty. Ring technology is cost effective in removing thicker bark from larger trees, while drums more easily remove thinner bark sheaths from younger trees.

In stead of stem cleaning equipment, several studies have investigated mixing Whole-Tree-Chips with chips from debarked logs. Corson (1977) worked with green chips from Radiata pine thinnings. He found acceptable hand sheet strengths in mechanical pulp at bark levels of less than ten percent. Although nine year old trees required more energy than mature wood, he concluded that if bark were reduced 70%, thinnings could be mixed in a 1:2 ratio with mature chips for satisfactory ground wood furnish.

Another variable which can mitigate in favor of Whole-Tree-Chipping is site preparation. Fox (1984) found that the least mechanically disturbed sites were less prone to nutrient flushing. Normal debris reduction rates spread nutrient release more evenly over the stand establishment cycle, maintaining growth until natural leaf fall and precipitation restores nutrient balances. The lack of large slash piles and cull trees on chipping sites can also facilitate planting operations. Such sites are relatively free of fuel and do not require burning, thus seedling mortality is reduced by virtue of lower site temperatures.

A process for obtaining clean chips from limbs and tops would not only solve the problem of using green chips, but should effect silvicultural or woodlands management decisions. The ability to chip ten-year-old material would allow planting densities that achieve full stocking levels between ten and fifteen years of age. Fiber yields would be equivalent to twenty-five or thirty-year-old stands. Those paper mills which manage their own woodlands would have an opportunity to rearrange their silvicultural compartments to accommodate a new optimum selection of timber variables. An other option might be to simply reduce the share of corporate assets invested in timber land.