# Review of Chain Flail Delimbing-Debarking

W. F. Watson[1]
*Mississippi State University*
*Mississippi State, MS, USA*

A. A. Twaddle
*Forest Research Institute*
*Rotorua, New Zealand*

J. B. Hudson
*University of Aberdeen*
*Aberdeen, Scotland*

## ABSTRACT

Over 200 commercially built chain flail delimber-debarkers are now in operation worldwide. These units, teamed with inwoods chippers, are producing chips acceptable for pulping from many species of hardwoods and softwoods. The flails can remove the bark as well as drum debarkers in the case of southern pine species. The chips produced by these portable operations have been shown to be equal in quality to the chips produced at mill and satellite wood yards. It has been estimated that the flail-chipper system will produce up to 2.9% more clean chips than are obtained with conventional longwood harvesting and handling systems. The flails have been used to remove rot, foliage, and charcoal in specialized applications. The rejects from the flail represent a readily recoverable source of energy material, but this debris must be reduced in size to facilitate handling. Developments for reducing the size of the rejects are ongoing, especially using modified agricultural tub grinders. Chains are a major cost in the operation of the flails. Strategies have been developed which can prolong the life of the chains, and tests are ongoing with improved materials in the manufacturing of the chains. The cost of delimbing and debarking with the portable flails has been estimated to be between $(US)0.60 and $(US)3.30 per green tonne.

**Keywords**: *chain flails, delimbing, debarking.*

## INTRODUCTION

Delimbing is a costly item in any timber harvesting operation, which usually reduces the net amount of biomass recovered. Few operations have been successful in recovering or utilizing the limby portion of the tree. Operational recovery of tops in post-harvest operations have been carried out in several European countries and in the Pacific Northwest region of North America, and many additional concepts have been proposed and some tested [6, 17], but seldom have these efforts proven to be cost effective.

In specialized situations, firms have found that trees can be economically transported to the mill with the tops intact. In Sweden, the tree-section method of harvest has enabled firms to move the tops to centralized tree-section delimbing-debarking drums where they are removed and can be recovered for fuel [14]. In the Southern U.S.A., one firm transports whole slash pine stems with the top intact to its wood yard [35]. This firm uses a modified debarking drum to remove the tops for processing into fuel. As well as recovering fuelwood, this method also recovers additional pulpwood fiber.

In the last decade, an old approach to debarking has been revitalized for both delimbing and debarking which in many cases affords a great opportunity to recover the tops as a fuel source. This approach is the use of chain flails for the delimbing operation. The chain flail delimber-debarker has found a niche in North America by teaming the flail with inwoods chippers to process limby species and trees whose size makes them awkward to transport. Using the flail has been shown to lead to vastly improved utilization in these situations and the flails have been successfully teamed with other hogging units to recover the tops as a fuel.

Flails are mechanically simple machines and therefore have been adapted for implementation in many parts of the world. Studies are being carried out in many locations on the various units and their applications. Thus, a review of the use of chain flails was funded under the Bioenergy Agreement of the International Energy Agency, Task VI Activity 2. This paper will focus on the issues on flail use that were reported in that review.

[1] *The authors are respectively: Professor, Department of Forestry; Researcher; and Professor, Department of Forestry.*

**Table 1.** Specifications for North American flail delimbers-debarkers that are commercially available [26].

| | Flail | | |
|---|---|---|---|
| **Item** | **MacMillian ForestPRO** | **Manitowoc** | **Peterson Pacific** |
| Model | HDFPP-20 | VFDD-1642 | 4800 |
| Drum orientation | Horizontal | Vertical | Horizontal |
| Flail drive | Hydraulic | Hydraulic | Direct |
| Flail speed[a], rpm | 525-625 | 525-625 | 525-625 |
| Chains per drum[a] | 39 | 36 | 38 |
| Feed opening, cm | 53x122 | 122x41 | 58x122 |
| Feed rate[1], m/min | 38 | 38 | 38 |
| Power, kW | 242 | 172 | 134 |
| Place of manufacture | Shreveport, LA | Manitowoc, WI | Pleasant Hill, OR |

[a]These items are variable and can be adjusted to meet conditions.

## COMMERCIAL MANUFACTURERS OF CHAIN FLAILS

Experimentation with chain flail delimber-debarkers took place across the Pacific Northwest region of the U.S.A. in the early 1980's. Several contract loggers manufactured flails in their shops [16, 22], and the Weyerhaeuser Company was carrying out detail testing in their test center [3, 14]. Work was taking placing in the Nordic countries with variations of the same concept [1, 2, 14, 30]. North American firms developed commercial units based on this early experimentation and have currently captured the world market for flail delimber-debarkers, although a New Zealand unit, the Forest King, has recently been produced [8]. The three North American makes of flails available are the ForestPRO, Manitowoc, and Peterson Pacific. Specifications for these makes are contained in Table 1. Two firms have now manufactured integral flail-chipper units. Peterson Pacific is marketing their integral unit as the model 5000 while Chiparvestor is also marketing their integral unit.

## ISSUES IN THE USE OF FLAILS

### Bark Content of Chips

Chain flails can only gain acceptance when the chips produced by the chain flail systems are of comparable quality with those chips produced in the woodrooms at pulp mills. The flail unit is responsible for debarking; thus, the debarking quality of the flail must be compared to the quality of debarking of the pulp mill's drum debarker. A maximum acceptable bark content in most pulp mills is 1 percent.

Early tests of the flail units demonstrated that 1 percent bark content could be maintained in chips produced in flail systems. However, the flails had to be run at very high speeds to maintain this low bark content. The high drum speeds resulted in rapid chain wear and prohibitive debarking costs. Experiments with other chains have identified brands which can better withstand the higher flail speeds and thus reduce the debarking cost.

A summary of studies reporting bark content attained with chain flail units is given in Tables 2 and 3. In general, it can be seen that bark contents of 1 percent can be attained year around on softwood species. Bark contents of under 3 percent are attainable when processing delimbed hardwoods as was observed by Favreau [7].

In recent years, many operators have begun to use 2 chains in each opening on the flail drum to improve debarking during the winter months. Table 3 gives results of tests that demonstrate that this practice can significantly decrease bark content in the chips. It will be shown later that doubling chains on the drum can actually increase the life of the chains; thus, the decrease in bark content can be achieved with little additional cost.

**Other Quality Factors of Chips as Related to Flails**

Some quality factors of the chips produced from flail delimbed-debarked wood are in no way a function of the flail unit. However, the ability of the flail-chipper system to produce an acceptable quality chip for some manufacturing process is the pre-eminent factor affecting acceptance of the flail technology.

Grace, Yu, and Stuart [10] carried out a controlled study which addressed changes in the size distribution of chips that could be attributed to the flail. A wood yard which chipped undebarked stems was used in the study. In half of the tests no debarking was carried out on tree-length stems; in the remaining tests the same type stems were flail delimbed prior to chipping. The results of this study are shown in Table 4. Difference in seasons of the year when the no debarking and flail debarking test took place could have confounded the results, but a significant increase in fines was observed in two of the four species groups for the flail debarked stems. However, the shortleaf pine had a significant decrease in fines. Thus, it was not possible to say that the flail was causing the production of more fines.

Table 5 gives the average percent of overs, pins, and fines of chips produced at 50 wood rooms at pulp mills and 23 satellite wood yards [31]. All of these samples came from mills using drum debarkers. Fines were defined as passing through a 2 mm thickness screen and through a 5 mm round hole in this study. In most studies given in Table 2, the fines screens had 3 mm round holes. Thus, a direct comparison of the results in Tables 2 and 5 cannot be made. However, an additional study was installed [36] so that a direct comparison could be made with Twaddle's results. Nine flail-chipper operations processing pine stems and with chippers set up to produce 22 mm chips were sampled in May of 1990. The wood yard operations in Twaddle's study with the same setup and which were also processing pine were extracted for comparison. Table 6 reports these comparisons. Note that the inwoods flail-chipper operations produced significantly fewer fines and pins but significantly more overs than did the wood yard operations.

**Fiber Loss With the Use of Flails**

A major concern with the use of flails is the amount of fiber that is lost with the use of flails. The debris that piles up at the flail reject outfeed obviously contains wood fiber useable as pulp. Raymond [18] summarized fiber loss studies from various sources. His report is summarized in Table 7. These results, too, are not conclusive.

Stokes and Watson [26] projected differences in chips recovered by three types of handling systems for slash pine. This study estimated total clean chip yield for whole-tree drum debarking and delimbing to be 2.1 percent less than with a chain flail inwoods chipping system. When compared to a conventional tree length-drum debarking system, the chain flails produced 2.9 percent more clean chips. These results demonstrate that flail systems produce at least as many clean chips as conventional handling systems even though all of the pulpable fiber in the tree is not recovered.

**Chain Flails Processing Frozen Wood**

Several years of experience has now been gained on the use of flails to process frozen timber. Sauder and Sinclair [20] and Sauder [21] reported on trials using a Peterson Pacific flail to delimb spruce, pine, and aspen in Alberta, Canada. These studies showed the chain flails to be effective if the flail chains were well maintained. Bark content of the chip samples ranged from 0.5 percent to 1.4 percent. The chipper in the study was worn, and it was difficult to determine if chipper problems incurred were related to the cold temperature or the chipper condition.

Valley Forest Products in New Brunswick, Canada, reported on their first year's experience with a ForestPRO flail unit processing full hardwood stems [33, 34]. The average bark content observed in their operations was 3.4 percent before screening. This firm felt the quality of the chips produced from flails were acceptable.

**Using Flails for the Removal of Rot, Foliage, or Charcoal**

Chain flails were envisioned as a tool for removing rot as early as the 1970's. The U.S. Forest Service [32] developed a prototype for removing rot but commercialization never took place. Pat Kuzmer has indicated that a Manitowoc flail is operationally removing rot in a fixed operation in Russia. Sauder and Sinclair [20] indicated that chain flails should be useful in removing rot from red cedar as well as charred bark and wood from trees damaged by fire. They reported on tests conducted on the Peterson

**Table 2.** Production, bark content, percent pins, and fines of production studies of chain flails and inwoods chippers.

| Reference | Location | Flail | Chipper | Time of Year | Species | Productivity | Bark | Pins | Fines |
|---|---|---|---|---|---|---|---|---|---|
| 1. Sauder, 1989 [21] Sauder and Sinclair, 1989 [20] | Alberta, Can. | Peterson Pacific 4800 | Morbark 22RXL | February & March 1989 | Spruce-Pine-Fir | 10.8 BDt/Hr | 1.18 | | |
| | | | | | Black Spruce | 10.4 BDt/Hr | 1.12 | | |
| | | | | | Pine Pulpwood | 9.5 BDt/Hr | 1.32 | | |
| | | | | | Aspen | 13.7 BDt/Hr | 4.00 | | |
| 2. Scott Maritimes, 1989 [20] Raymond, 1990 [19] | Nova Scotia, Can. | Peterson Pacific 5000 | Morbark 23 | May to August 1989 | Hardwood and Softwood | 27.8 gmt/PMH | 1.10 | -2.60- | |
| 3. Valley Forest Products, 1989 [33] | New Brunswick, Can. | ForestPRO 23 | Morbark 23 | January to March 1989 | Hardwood | 35 gmt/PMH | 2.2 | | |
| | | | | March to May 1989 | Hardwood and Birch | 42 gmt/PMH | 3.96 | | |
| 4. Grace, Yu, and Stuart; 1989 [10] | Virginia, USA | Peterson Pacific 4800 | Woodyard Chipper | April 1989 | Delimbed loblolly pine | | 1.3 | | |
| | | | | | Delimbed Virginia pine | | 0.2 | | |
| 5. Carte, Watson, Stokes; 1989 [4] | Georgia, USA | Peterson Pacific 4800 | Morbark | December 1986 | Loblolly pine | | 1.55 | 10.04 | 2.79 |
| Stokes, Watson, Twaddle, Carte; 1989 [29] | South Carolina, USA | Peterson Pacific 4800 | Morbark | January 1987 | Slash pine | 34.0 gmt/PMH | 3.38 | 5.28 | 1.99 |
| | | | | | Loblolly pine | 34.4 gmt/PMH | 2.80 | 5.90 | 1.71 |
| | Arkansas, USA | Weyco I | Morbark 22 | October 1987 | Loblolly pine | 25.4 gmt/PMH | 1.05 | 2.14 | 1.47 |
| | Oklahoma, USA | Weyco I | Morbark 23 | January 1988 | Loblolly pine | 26.6 gmt/PMH | 1.04 | 2.97 | 1.78 |
| | | | | | | | 3.53 | 2.01 | 1.38 |
| | Oklahoma, USA | Weyco II | Trelan 23 | January 1988 | Loblolly pine | | 5.47 | 1.90 | 1.28 |
| | Texas, USA | ForestPRO | Morbark 23 | April 1988 | Slash pine | | 0.83 | 2.35 | 1.00 |
| | Oklahoma, USA | Manitowoc | Trelan 23 | April 1988 | Loblolly pine | | 1.94 | 1.24 | 0.59 |
| | Oklahoma, USA | Weyco II | Trelan 23 | April 1988 | Loblolly pine | | 1.45 | 1.93 | 1.53 |
| | Oklahoma, USA | Weyco I | Morbark 23 | April 1988 | Loblolly pine | | 2.38 | 2.35 | 1.45 |
| | Arkansas, USA | ForestPRO | Morbark 23 | August 1988 | Loblolly pine | 41.6 gmt/PMH | 1.92 | 1.90 | 0.84 |
| | Oklahoma, USA | Manitowoc | Trelan 23 | October 1988 | Loblolly pine | | 1.47 | 1.69 | 1.20 |
| | Oklahoma, USA | Weyco II | Trelan 23 | October 1988 | Loblolly pine | | 2.77 | 1.65 | 1.30 |
| | Oklahoma, USA | Weyco I | Morbark 23 | October 1988 | Loblolly pine | | 1.42 | 2.30 | 1.50 |
| | Florida, USA | Manitowoc | Blue Ox | November 1988 | Delimbed oaks | | 2.34 | 1.31 | 0.97 |
| | | | | | Delimbed Tupelo gums | | 2.28 | 0.51 | 0.66 |
| | | | | | Delimbed sweetgums | | 2.55 | 1.18 | 0.81 |

## Table 2 Continued

| Reference | Location | Flail | Chipper | Time of Year | Species | Productivity | Bark | Pins | Fines |
|---|---|---|---|---|---|---|---|---|---|
| 6. Schuh, Basser, Kellogg; 1987 [22] | Oregon, USA | Gibson | Morbark 23 | Summer 1986 | Douglas-fir | 13.9 BDT/SMH | 0.5 | | |
| | Washington, USA | Mischel Bigfoot | Sumner | Summer 1986 | Douglas-fir | 5.6 BDT/SMH | 0.7 | | |
| | | Peterson Pacific Prototype | Morbark 22 | Summer 1986 | Delimbed Douglas-fir Western Hemlock | 12.9 BDT/SMH | 1.5 | | |
| 7. Hudson, 1990 [12] | Southern France | Manitowoc | Morbark 22 | | Mixed hardwoods | 15.0 GMT/PMH | 1.0 | | |
| 8. Stokes, 1989 [28] | Alabama, USA | Peterson Pacific | Morbark 27 | July 1989 | Sycamore | 31.8 GMT/PMH | 2.1 | | |
| 9. Favreau, 1991 [7] | Quebec, Canada | Peterson Pacific | DDC 5000 | November 1991 | Maple | | 4.5 | | |
| | | | | December 1991 | Maple | 7 vans/shift | 2.6 | | |
| 10. Franklin, 1991 [9] | Omataroa, NZ | Forest King | Morbark 20 | Summer 1991 | Radiata pine | 55.2 GMT/PMH | 1.0 | 1.4 | 0.4 |
| | | | | | | 53.4 GMT/PMH | 0.5 | 1.6 | 0.5 |
| | | | | | | 60.0 GMT/PMH | 0.7 | 1.8 | 0.8 |
| | | | | | | 13.5 GMT/PMH | 1.9 | 1.6 | 0.4 |

Symbols Used: BDT = Bone dry metric tonnes
GMT = Green metric tonnes
PMH = Productive machine hour
SMH = Scheduled machine hour

**Table 3.** Chip quality results of 1989 chain wear trials [4].

| Month/Year | Flail | Chain | Chain Configuration | Chipper | % Bark | % Pins | % Fines | % Overs Length | % Overs Width |
|---|---|---|---|---|---|---|---|---|---|
| July 1989 | Manitowoc | Beacon 7 | Single/7 link | Chiparvester | 0.31 | 0.86 | 0.38 | 13.80 | 6.16 |
| July 1989 | Manitowoc | Beacon 7 | Single/7 link | Chiparvester | 0.76 | 1.59 | 0.83 | 3.69 | 5.71 |
| July 1989 | Manitowoc | Beacon 7 | Double/7 link | Chiparvester | 0.48 | 1.69 | 0.65 | 7.79 | 7.42 |
| July 1989 | Manitowoc | Super Campbell | Single/9 link | Chiparvester | 0.47 | 1.27 | 0.47 | 2.84 | 5.36 |
| July 1989 | Manitowoc | Trawlex | Double/7 link | Chiparvester | 1.36 | 0.52 | 0.27 | 3.05 | 9.71 |
| July 1989 | Manitowoc | A 8 A Alloy | Single/9 link | Chiparvester | 1.30 | 1.49 | 0.59 | 1.85 | 6.17 |
| July 1989 | Manitowoc | Canadian Chain | Single/8 link | Chiparvester | 0.88 | 0.66 | 0.32 | 3.84 | 7.19 |
| July 1989 | Peterson | Super Campbell | Single/9 link | Chiparvester | 3.08 | 1.74 | 1.46 | 2.29 | 2.89 |
| July 1989 | Peterson | Campbell Alloy | Single/9 link | Chiparvester | 3.05 | 1.28 | 1.21 | 2.68 | 3.81 |
| July 1989 | ForestPRO | Beacon 7 | Double/7 link | Trelan | 0.36 | 0.59 | 0.31 | 6.30 | 7.76 |
| July 1989 | Manitowoc | Super Campbell | Single/9 link | Chiparvester | 0.79 | 0.88 | 0.56 | 3.13 | 5.86 |

**Table 4.** Chip size distribution on a percentage basis for delimbed stems [10].

| Chip Size | Treatment | Percentage of Sample | | | |
|---|---|---|---|---|---|
| | | Loblolly | Shortleaf | Virginia | Yard Run |
| Oversize | No debarking | 10.3** | 13.2 | 12.5 | 14.0* |
| | Flail | 7.2 | 11.9 | 14.2 | 14.1 |
| 1/2 to 1" | No debarking | 47.6* | 54.1 | 53.8 | 53.3 |
| | Flail | 41.9 | 53.0 | 53.8 | 53.2 |
| 1/8 to 1/2" | No debarking | 36.5* | 27.8* | 29.4 | 28.7 |
| | Flail | 41.8 | 31.0 | 27.6 | 27.4 |
| Fines | No debarking | 5.6** | 4.9** | 4.3 | 3.9** |
| | Flail | 9.1 | 4.4 | 4.3 | 5.3 |

*Difference in the no debarking and flail trials are significant at the 0.1 to 0.05 level.

**Difference in the no debarking and flail trials are significant at the 0.05 to 0.01 level.

Pacific flail, processing two loads of fire-killed stems. In these tests, bark in the processed chips was reduced to 2 to 3 percent, but that charcoal was still present at unacceptable levels. They indicated that varying flail speeds and feed rates might possibly make it feasible to use flails in these situations.

In some cases, removal of foliage is important to minimize the depletion of nutrients from the site. Foliage removal with flails in Denmark was briefly discussed by Suadicani [30]. The Danish Institute of Technology has used rubber flails for foliage removal. Baadsgaard-Jensen [2] discussed operations where flails were employed in Sweden and Finland for removal of foliage prior to chipping, again with the objective of leaving the nutrient-rich foliage on the site. Jonsson [12] reported on developmental work with the flail concept for light foliage removal prior to felling and forwarding for ecological reasons.

Scott Paper Company of Mobile, Alabama U.S.A., considered a different situation where foliage removal was desirable [25]. Scott had established test plantations of sycamore as a fuel source for their wood-fired boilers. As this company became more and more dependent on hardwoods for their pulp mill, the sycamore plantations became more attractive for the pulping process. The only portion of the sycamore stem that was a problem in the pulping operation was the leaves. Also, the small stems grown in the short rotation situation could only be feasibly harvested with the use of chippers. Thus, a Peterson 4800 flail was tested for removal of small

**Table 5.** Distribution of contents of chip samples from 73 chip manufacturing facilities in the Southern U.S.A. [31].

| | Percent of Sample | |
|---|---|---|
| | Softwood | Hardwood |
| **Bark** | 0.8 | 1.5 |
| **Overs** | 19.3 | 23.2 |
| **Accepts** | 75.4 | 73.8 |
| **Pins** | 3.6 | 1.9 |
| **Fines** | 1.7 | 1.1 |

**Table 6.** Comparison of dimensions of chips produced from pine stems at a wood yard with chips produced with flail delimbers-debarkers and inwoods chippers.

| | Wood Yard Chips | In-Woods Chips | F | Significance |
|---|---|---|---|---|
| **Number of samples** | 45 | 51 | | |
| **% Overs** | 19.23 | 25.48 | 9.77 | .05 |
| **% Accepts** | 75.25 | 72.03 | 3.11 | NS |
| **% Pins** | 3.72 | 1.66 | 50.58 | .01 |
| **% Fines** | 1.80 | 0.82 | 39.57 | .01 |

limbs and foliage prior to chipping in July 1989. The test was carried out in a five-year-old sycamore plantation which had been regenerated by coppice methods. The flail speeds were reduced so that foliage removal and minimal delimbing was carried out. Adequate defoliation was achieved, but the production of the operation was hampered by the small piece size (average diameter of 5.3 cm). To be made cost efficient, the stands should be grown an additional two years or more to improve the productivity.

**Opportunities for Recovering Flail Debris for Energy**

Stokes and Watson [27] reported that for every 5.6 tonnes of chips produced with a flail-chipper system in slash pines, 1 tonne of residues are processed through the reject spout of the flail. In studies of the flail-chipper system processing thinnings from loblolly pine plantations ratios of only 1.7 tonnes of chips per 1 tonne of chipper rejects have been observed.

The material at the outfeed of the chipper reject represents a sunk cost for felling and transporting the material to the chipper. The burden of these costs must be borne by the clean chips. The price paid for this material at a wood-burning facility in the Southern U.S.A. is approximately $(US)12.00 per green tonne. The cost of transporting the material to a wood-burning facility 125 kilometers would be $(US)7.50 per green tonne. Thus, under current economics, a system which could convert the residue and move the potential fuel into a chip van for $(US)4.50 per green tonne or less would be economically viable.

The Hermann Brothers in the State of Washington, U.S.A., has an ongoing flail-chipper operation carried out this recovery of potential energy material [16]. The Hermann operation consisted of shop-built components for flailing and processing of the flail rejects. The processing of the rejects was carried out with a unit called a shredder. The shredder used a drum chipper to reduce the rejects of the flail to a desired size for hogfuel. A knuckleboom hydraulic loader feeds the rejects and presorted undersized stems into the shredder. Hopper doors were installed over the chipper to prevent material from being thrown out during the shredding process.

**Table 7.** Percent of wood fiber lost in several debarking systems [19].

| Debarking Method | Range in Fiber Lost: Maximum | Range in Fiber Lost: Minimum |
|---|---|---|
| | — — — percent | — — — |
| Ring debarkers | 3.3 | 0.0 |
| Drum debarkers | 6.6 | 0.1 |
| Flails | 4.8 | 3.0 |

**Table 8.** The expected life of Campbell Beacon 7 chain in a Manitowoc flail processing loblolly pine thinnings, one chain per slot.

| | Front Drum Link Number[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| **Chain Number[b]** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| | green tons | | | | | | |
| 1 | | | 3920 | 3857 | 2056 | 2075 | 5933 |
| 2 | 4299 | 2595 | 1857 | 1555 | 1108 | 1106 | 2197 |
| 3 | 2756 | 2030 | 1225 | 1239 | 1094 | 392 | 729 |
| 4 | 2694 | 1568 | 949 | 981 | 502 | 392 | 729 |
| 5 | 2899 | 1201 | 778 | 723 | 511 | 392 | 729 |
| 6 | | 2101 | 1190 | 862 | 682 | 500 | 994 |

| | Rear Drum Link Number[a] | | | | | |
|---|---|---|---|---|---|---|
| **Chain Number[b]** | **2** | **3** | **4** | **5** | **6** | **7** |
| | green tons | | | | | |
| 1 | | | | 4492 | 4005 | |
| 2 | | | 3226 | 2415 | 2340 | 5512 |
| 3 | | | 2567 | 1278 | 1272 | 2354 |
| 4 | 6193 | 2237 | 1398 | 974 | 614 | 1542 |
| 5 | 5512 | 4253 | 1120 | 899 | 559 | 1486 |
| 6 | 5340 | 3145 | 1564 | 1127 | 852 | 1864 |

[a]Link 1 is nearest the drum; link 7 is furthest from the drum.

[b]Chain 1 is at the top of the drum; chain 6 is at the bottom location on the drum.

**Table 9.** The expected life of Campbell Beacon 7 chain in a Manitowoc flail processing loblolly pine thinning, two chains per slot.

| | **Front Drum Link Number**[a] | | | | | |
|---|---|---|---|---|---|---|
| **Chain Number**[b] | **2** | **3** | **4** | **5** | **6** | **7** |
| | — — — — | — — — | green tons | — — — | — — — | — — — — |
| 1 | 8407 | 4748 | 4147 | 3510 | 3399 | 5433 |
| 2 | 6893 | 3858 | 3390 | 2917 | 1874 | 3386 |
| 3 | 4320 | 3053 | 2513 | 1590 | 881 | 1289 |
| 4 | 3446 | 2496 | 2132 | 1151 | 648 | 1045 |
| 5 | 3053 | 2244 | 1850 | 1020 | 702 | 881 |
| 6 | 4154 | 2676 | 2149 | 1678 | 1225 | 2112 |

| | **Rear Drum Link Number**[a] | | | | | |
|---|---|---|---|---|---|---|
| **Chain Number**[b] | **2** | **3** | **4** | **5** | **6** | **7** |
| | — — — — | — — — | green tons | — — — | — — — | — — — — |
| 1 | 5173 | | 8322 | 7362 | 6497 | 1190 |
| 2 | | 9720 | 6190 | 3427 | 2216 | 3367 |
| 3 | | 1024 | 4210 | 2759 | 1227 | 1744 |
| 4 | 1068 | 4492 | 2938 | 1826 | 895 | 1671 |
| 5 | 9720 | 4731 | 2863 | 1830 | 1085 | 1553 |
| 6 | | 9182 | 5911 | 4175 | 3336 | 4557 |

[a]Link 1 is nearest the drum; link 7 is furthest from the drum.

[b]Chain 1 is at the top of the drum; chain 6 is at the bottom location on the drum.

A major concern with the shredder was that links lost from the chains on the flail could end up in the shredder. To prevent this from happening, a permanent magnet was installed to intercept chain fragments in the flail residue.

The Hermann Brothers' shredder was found to process the material at a cost of $(US)7.00 to $(US)8.50 per green tonne. This prototype unit had an initial cost of $(US)350,000 and was found to have considerable reserve capacity. Thus, a unit of smaller production capacity and of lesser cost would be desirable to process the flail residue.

Investigations into the commercial market for hogs have shown that their initial cost to be of the same magnitude or larger than the Hermann prototype. Also, hogs are usually installed in fixed locations and truly portable units are not available.

Field demonstrations have been carried out on the use of beefed-up agricultural tub grinders to process the flail residue. The grinders are open-top rotating tub units with flail hammers that reduce the particle size of inputted material. The hammers continue to reduce the size of the material until it can pass through a screen at the bottom of the tub. Lane Equipment Company of Charlottesville, Virginia, U.S.A., is marketing tub grinders which have been equipped with larger hammers than are customarily used in the agricultural applications. These units have successfully been demonstrated with the Weyerhaeuser Company in Arkansas and Oklahoma and have shown that they can handle the commutation of limbs, tops, and bark to desirable sizes. A contractor for Weyerhaeuser in DeQueen, Arkansas, is recovering piles of flail rejects and processing the material through an RSI (Recycling Systems, Inc. of Wynn, Michigan) tub grinder.

A major problem with the grinders is that the hogged material is conveyed from the grinders, therefore open top vans are necessary for loading this material. Lane and RSI are working on the development of grinders which can blow the hogged material into covered chip vans.

The tub grinders have an advantage over chipper or shredder units in that stray metal particles will cause little or no damage to the units. Another major advantage is that complete beefed-up units with blowers are projected to cost less than $(US)100,000.

The future is certainly optimistic for the recovery of the flail residue as an energy source. Any increase in fossil fuel prices will make current commutation technology for the residue feasible. Likewise, the use of tub grinders holds great promise for reducing the cost of this processing in operational situations. Perhaps some manufacturer will design a tub grinder unit especially for processing this material when a market for such a unit is firmly established.

**Chain Wear**

Stokes and Watson [28] reported that chain cost constituted 20 percent of the total operating cost of the three commercial versions of flail delimber-debarkers. The magnitude of this cost indicates that advances in chain management and technology afford a great opportunity for improving the acceptance of this technology.

Chains used in flail delimber-debarkers were designed for use in other applications. The chains are made up and marketed by the chain manufacturers in rolls. The chains on the rolls are then cut to the length of chain required for the flail. Most of the brands of chains in current use require 7 to 9 links to make the proper length of chain for the flail. Thus, 1/8 to 1/10 of the chain purchased is destroyed when the chains are cut to the designed length. This is another situation in which expanded usage of the flail units will lead to some chain manufacturers building a product designed especially for the flail delimber-debarker market.

Carte [5] has gathered data on chain wear to aid in chain management decisions. His basic finding is that the outer three links on each chain receive the greatest wear. Carte studied several brands of chain and has developed tables of expected life of the chain on a Manitowoc flail unit processing loblolly pine thinnings. Tables 8 and 9 give these expected lives for Campbell Beacon 7 chain in two common applications, a single chain per slot and 2 chains in each slot. The tables report the expected number of tons that can be processed before the working area of the chain wears to the diameter at which it will fail.

Since the Manitowoc has flail drums mounted in a vertical position, the most chain wear occurs on the bottom chains. Also note that doubling the chains decreases the wear on the individual chains. (Doubling the chains is common to improve debarking during difficult periods, and some operators vow to use double chains year round.) The links nearest the drum receive so little wear that the failure of these links in an operation will never occur. Prudent operators have learned to reverse the chains and place the worn ends nearest the drum during chain maintenance.

In 1991, Baughman conducted an intensive study to determine the types and brands of chains that were the most cost effective for the contractors chipping for the Weyerhaeuser Company in Arkansas and Oklahoma. He tested all types of chain that were available from domestic manufactures and several types produced overseas. Baughman's work lead to the Weyerhaeuser contractors almost exclusively adopting a Peerless 9 link chain that has been heat treated by an outside vendor. The chain is known as Wellingford Treated Peerless chain. This chain has been found to give excellent service at a reasonable cost. Stone Container in Ontonagon, Michigan, is using flail-woodland chipper operations to harvest the previously unmerchantable aspen stands in their holdings. They have contractors using the integral units as well as the separate flail units teamed with a chipper. Jackson, a forester with Stone, is working with the contractors on methods of controlling costs and improving chip quality.

Jackson has recently enlisted the support of several chain and flail manufacturers in gaining a better understanding of action of the chains as delimbing and debarking is carried out. His methods involved the use of high speed video of the action of the chains during the flailing process. Jackson's basic observations were:

1. The 6 links of the chain nearest the drum remained rigid during the flailing action in both the 8 and 9 link chains.

2. The greatest abrasive action that is occurring with the chains is not from the chains making contact with the drum but from the chains hitting other chains.

3. The outer links of short link chains tend to recover better after contacting the wood than do the longer links.

4. Presenting the stems to the flail at an angle slightly off the perpendicular to the drum tended to improve debarking and reduced the amount of chain against chain contact.

These video tapes are now being used by the participating cooperators to develop better chain designs, and to possibly redesign the flails themselves [11, 38].

**Table 10.** Production and cost estimates for chain flails delimbing and debarking.

| Citation | Brand of Flail | Species | Productivity | Cost |
|---|---|---|---|---|
| Grace, Yu, and Stuart, 1989 [10] | Peterson Pacific | Delimbed pine | 265 gt/Day | $(US)1.25/gt |
| Lambert, Howard, and Hermann, 1985 [16] | Hermann Prototype | Western Hemlock<br>Douglas-fir<br>Red Cedar | 35 gt/PMH | $(US)0.58/gt |
| Jonsson, 1989 [14] | Weyerhaeuser Stationary Prototype | Loblolly pine | 600 ft$^3$/Shift | $(US)6.30/gt |
| Sauder and Sinclair, 1989 [20] | Peterson Pacific | Spruce-Pine | 221 m$^3$/Shift | $(Can)4.60/m$^3$ |
| | | Black Spruce | 150 m$^3$/Shift | 5.40/m$^3$ |
| | | Lodgepole Pine | 86 m$^3$/Shift | 6.19/m$^3$ |
| Stokes and Watson (1989a) [26] | ForestPRO | Loblolly | 41.6 gt/PMH | $(US)1.92/gt |
| | Manitowoc | Delimbed hardwood | 47.9 gt/PMH | 1.77/gt |
| | Manitowoc | Loblolly | 26.0 gt/PMH | 3.27/gt |
| | Peterson Pacific | Loblolly | 34.4 gt/PMH | 2.21/gt |
| | Peterson Pacific | Slash | 32.2 gt/PMH | 2.36/gt |
| Watson et.al. (1991) [37] | Manitowoc | Clearcut Loblolly | | $(US)2.81 |
| | ForestPRO | Thinning Loblolly | | 2.67 |

Symbols used: gt = green tonnes
PMH = Productive Machine Hour

**Productivity and Costs of Chain Flail Operations**

It is desirable that a flail unit match the productivity of the chipper it is teamed with. Such a match should lead to an optimal cost for the operations. Sauder and Sinclair [18] demonstrated that species differences dramatically impact the ability of the flail to keep up with the chipper. They reported productivity of 221 $m^3$ per shift on a mixture of spruce and pine in the furnish while only 86 $m^3$ per shift when a pure furnish of lodgepole pine was being processed (see Table 10).

The flails that are now commercially available represent a limited capability in the capacity to vary flail speeds and feed rates. In some situations, more powerful flails might be necessary to process species with more limbs or with limbs which are more difficult to remove.

Table 10 gives a summary of the cost of operating and of the productivity of chain flail units in a variety of situations. The cost per tonne varied from \$(US) 0.60 to \$(US) 5.30. The cost of processing is species-specific and can be a function of minimal specifications on chip quality. It is possible to achieve lower bark content by increasing flail speed and decreasing feed rate through the unit. Increasing flail speed increases chain wear and decreasing feed rate lowers productivity. Either of the changes will increase the cost unit of production.

A cost comparison between woodlands chipping after flail debarking and wood yard chipping was conducted on both thinning and clearcut operations in loblolly pine plantations in the Southern U.S.A. [37]. The comparison was made at the chip pile at the pulp mill. It was found that woodlands chipping was cost competitive for thinnings, but was more costly when processing the larger stems from clearcuts.

## SUMMARY

Chain flails as delimbing-debarking tools seemed to have become firmly established worldwide. Other uses of flails show promise also. Chain flails are operationally removing stem rot in Russia and have been tested on removal of charcoal on fire-damaged trees in Canada. Tests have also been carried out on using chain flails to remove foliage in Sweden and Denmark.

The North American manufactured flail units are currently dominating the market. Manufacturers from other countries will perhaps become a more competitive force in the market in the future. The North American flail teamed with a North American disc chipper has been found to be an effective system for producing pulp-quality chips. Flail units and inwoods chippers are operationally producing chips with less than 1 percent bark in pine species and less than 3 percent bark in hardwoods.

The key to the manufacture of pulp-quality chips with the flail-chipper team has been to maintain the chains on the flail and proper maintenance of the knives, anvils, and bedknife on the chipper. Maintenance on the flail involves replacing chains when three or more links are lost from a chain.

Recovery of the reject material for an energy source is very simple with two of the North American brands of flails. The ManitoWoc and ForestPRO brands have inclined outfeeds for the rejects which make recovery of the rejects for further processing a simple task. Recovery of the rejects from the Peterson Pacific units would require additional conveyor units.

The further processing of the flail rejects is necessary if they are to be used for an energy source. The limbs in the rejects make it impossible to attain full loads of the rejects in the unprocessed form. Also, the limbs would make it difficult to unload vans filled with the unprocessed rejects.

Experimentation has begun with finding units to further process the rejects. The Hermann Brothers' prototype used a drum chipper to reduce the rejects to a smaller size. This unit was sensitive to metal in the furnish and was very costly to operate. The initial cost of the Hermann prototype is similar to the cost of commercially available hogs. Recent demonstrations with beefed-up agricultural tub grinders show promise that this type unit will be suitable to handle the processing of the rejects. The tub grinders must still be perfected to include blowers to facilitate loading of vans.

The recovery of the reject materials from flails as an energy source is hampered now by economics. If either the cost of fossil fuels rises or if technology reduces the cost of processing the rejects, then the recovery of rejects from flails for energy will certainly expand.

One major concern with the recovery of the rejects as an energy source is that such intensive utilization will severely deplete nutrients from the site. Work in removing the nutrient-rich foliage prior to harvest or during extraction has been examined in Sweden, Denmark, and Finland. These efforts are aimed at leaving the foliage on the site while recovering the wood and bark. If the recovery of the flail rejects becomes viable, then it might be necessary to remove the foliage to prevent nutrient drain in many locations. The work that has been carried out in Sweden, Denmark, and Finland indicate a flail of some description might also be appropriate for this task.

The flail units that are in operation have been found to be cost competitive with alternative methods of bark removal and delimbing, often because of savings that are occurred in other parts of the operation. For example, flails have been found to be very useful in handling thinned stems in the Southern U.S.A. because it was very costly to haul tree length thinned stems. The cost of the flail has been found to range from $(US)0.60 to $(US)6.30 per tonne of chips processed. Chain costs are a significant part of this cost and show the greatest opportunity for further research and development.

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## *MANUSCRIPT REVIEWERS* *VOLUME 4 1992-93*