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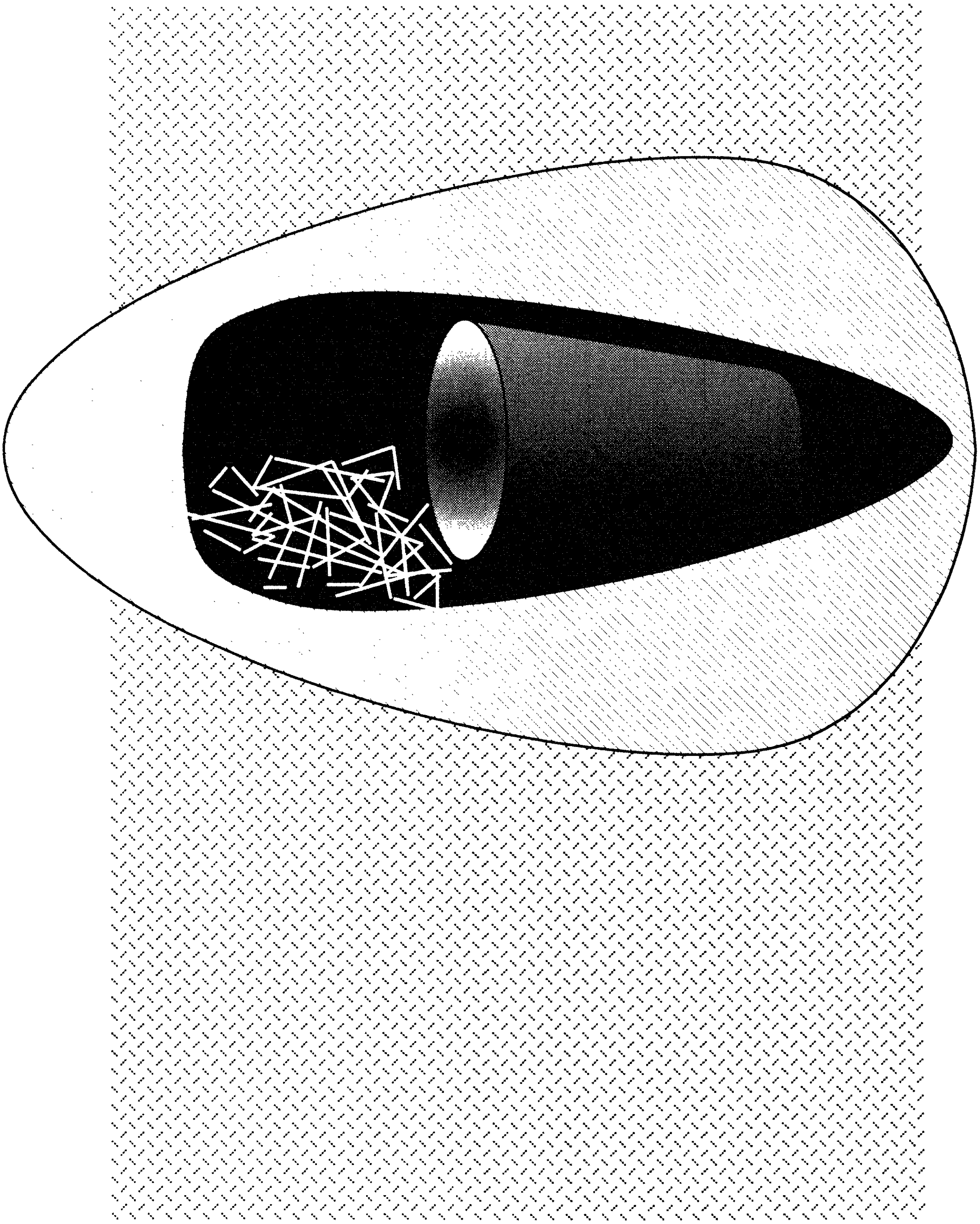
Teardrop Chunker Performance

Joseph B. Sturos



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Describes a new machine designed to reduce small-diameter logs into small chunks or blocks. The chunks can be used to manufacture flakeboard and composite wood products as well as for energy wood. Presents data on the physical character of chunkwood produced; production rates; and torque, power, and energy requirements for two species and two nominal chunk lengths.

KEY WORDS: Chunkwood, energy wood, wood conversion, chipping, wood comminution, flakeboard, composite wood products.

North Central Forest Experiment Station
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Teardrop Chunker Performance[1]

Joseph B. Sturos

Chunkwood is a concept that originated in a USDA Forest Service research program in the mid-1970's. The original program objective was to improve forest utilization by reducing small-diameter trees and forest residues into 2- to 3-inch-long chunks of wood that can be used to manufacture flakeboard and other composite wood products. More recently, chunkwood has gained the attention of the international energy community as an alternative fuel particle. Chunkwood can be loosely defined as all forms of wood mechanically severed from whole trees or forest residues. The chunks range from 2 to 12 inches long in the fiber direction and can have any cross section, including round pieces the full diameter of the tree or log.

Researchers at the Forestry Sciences Laboratory in Houghton, Michigan, have continued to explore chunking alternatives to enhance utilization of logging residues and small-diameter trees from thinnings and poor-quality stands. They have invented and patented three different chunking machines—the Helical Head Comminuting Shear (Arola and Sturos 1982, Barwise *et al.* 1977), the Involuted Disc Slicer (Arola *et al.* 1982, Barwise *et al.* 1984), and most recently the Multi-Product Wood Processor (Kangas *et al.* 1986) (fig. 1). The Multi-Product Wood Processor or "Teardrop Chunker" is a small machine designed to chunk trees less than 7 inches in diameter. The Teardrop Chunker produces a unique form of chunkwood. Compared to the Helical Head Chipper and the Involuted Disc Slicer, which produce fractured, broken chunks of wood (fig. 2), the Teardrop Chunker produces solid wood chunks that are primarily short, round log sections (fig. 3). As with the Involuted Disc Slicer, the length of the chunk (parallel to the fiber direction) is adjustable.

A limited study was conducted to determine output, power, and energy characteristics of the Teardrop Chunker. This paper reports those findings.

MACHINE DESCRIPTION

The experimental Teardrop Chunker consists of four main parts: a rotating cutting drum, a feed mechanism, a flywheel, and a hydraulic power supply (fig. 4). The drum has two teardrop-shaped openings 180 degrees apart with sharpened edges that repeatedly slice off the end of a log as it is propelled into the openings by the feed rollers (fig. 5). The drum rotates vertically, which allows the chunks to drop out of the bottom by gravity. Chunk length is controlled by changing the rotational speeds of both the cutter drum and infeed rollers. The drum is 14-1/2 inches high, 16 inches in diameter, and 1/4 inch thick. The teardrop hole openings are 18 inches long; they are 7 inches wide at the large end and taper down to 3/4 inch wide at the small end. The cutting edge is a single bevel formed by removing the inside edge of the teardrop opening in the drum.

To assist in the cutting action, a 17-inch-diameter, 2-inch-thick flywheel is used. The drum, flywheel, and a hydraulic motor are all tied to a common drive shaft by means of individual chain and sprocket arrangements. Because of the sprocket ratios used, the common drive shaft and hydraulic motor rotate 2.25 times faster than the cutter drum, and the flywheel rotates 6.75 times faster than the cutter drum.

The feed mechanism consists of four rollers (two above the log and two below) that grip and propel the log into the rotating cutter openings. Each feed roller tapers from 8 inches in diameter on the ends to 6 inches in diameter in the middle.

Joseph B. Sturos, Mechanical Engineering Technician, North Central Forest Experiment Station, Houghton, MI.

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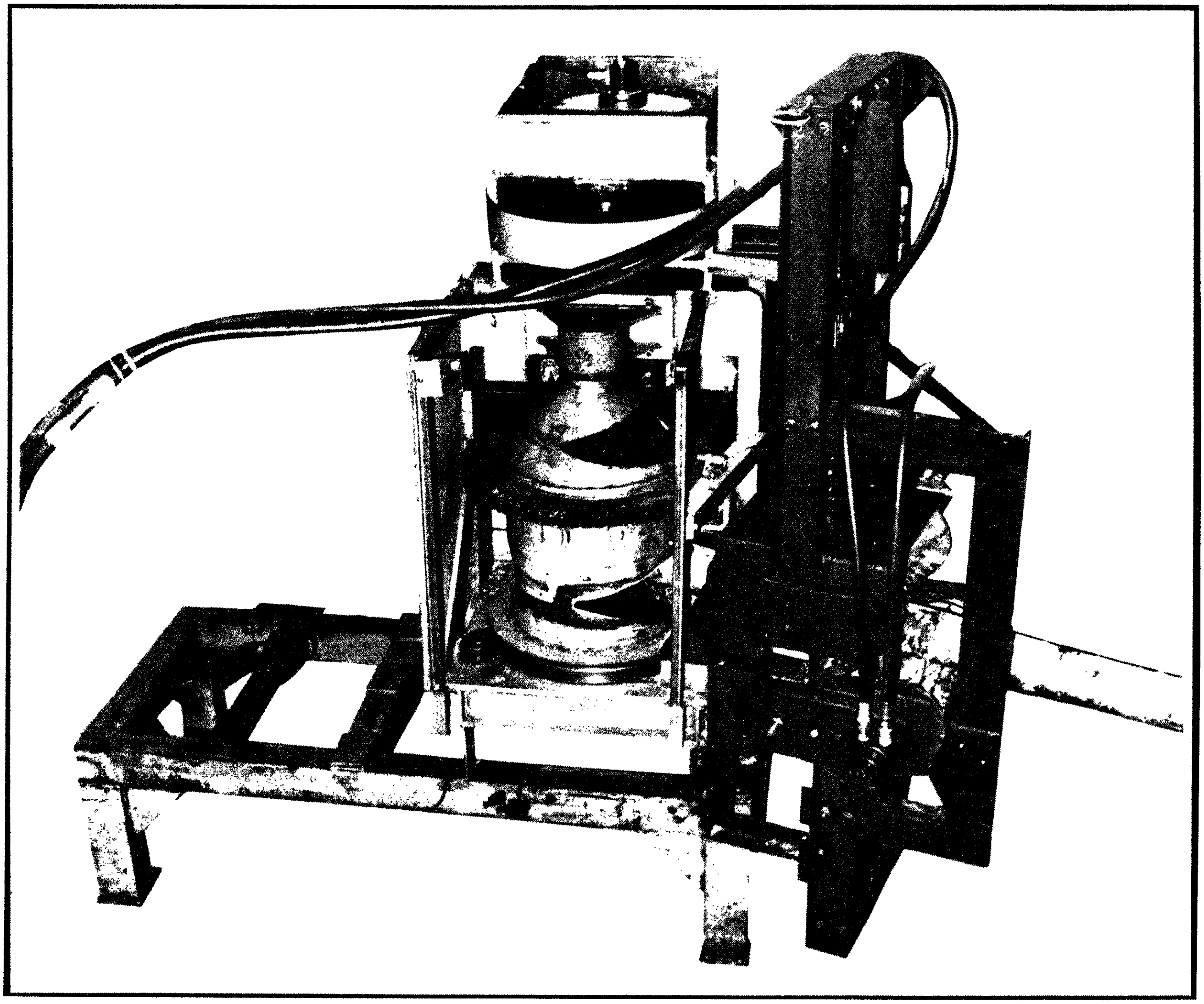

Figure 1.—*The Multi-Product Wood Processor or "Teardrop Chunker."*

PROCEDURES

The machine was tested using two species of wood and two nominal chunk lengths. The species tested were aspen, a low-density hardwood, and sugar maple, a high-density hardwood. The two chunk lengths chosen were short, from 3 to 4 inches long in the fiber direction (our unofficial standard), and long, the maximum length of chunk the machine would produce.

A small number of trial runs were made to determine a suitable combination of cutter and feed roller speeds. The cutter and feed settings selected were as follows:

	Short chunks	Long chunks
Cutter speed (rpm)	147	118
Feed roller speed (rpm)	175	254

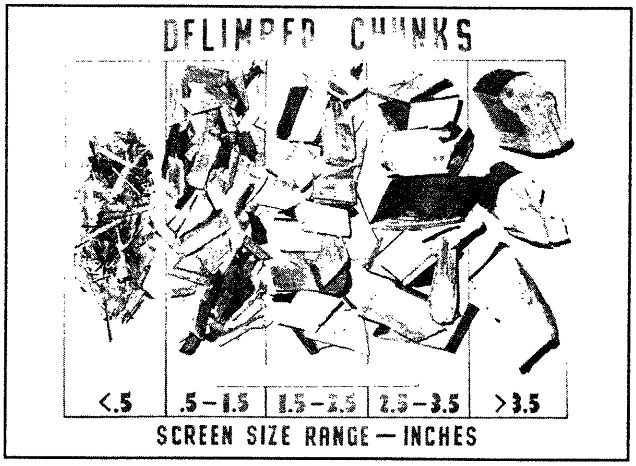

Figure 2.—*Typical particles produced by the Involuted Disc Slicer using delimbed sugar maple logs. (Volumes shown are approximate proportions.)*

The test logs were green, 8 feet long, delimbed, straight, and free of large knots. Their average diameters ranged from 3.2 to 5.4 inches. Each test log was weighed and measured for both small and large end diameters and length. From these data we calculated initial log volumes (using the truncated cone approximation), average log diameter, and average log density. The logs were fed into the machine large end first. To eliminate the problem of uncontrolled cutting that occurs after the end of the log leaves the feed mechanism, the feed was stopped before the end of the log passed through. Therefore, about 2 feet of the log was not chunked for each test. The weight of this residual piece was subtracted from the initial log weight to determine the net weight chunked. The net volume of log chunked was calculated by dividing the net weight chunked by the average log density.

For each test log we determined the average length of the chunks produced. The log was marked with five different colored bands located 16 inches apart. Five chunks, one from each colored band, were collected and analyzed for average length. The chunks had irregularly shaped ends so we measured both the minimum and maximum length and then determined the mean.

Because of the exploratory nature of the study, we did not randomize the testing. The short chunk tests were conducted first. The species were alternated between consecutive tests.

After the testing was completed, we weighed the total output for each of the four different chunk types in 4.6-cubic foot batches (30-gallon garbage can) and calculated the mean bulk densities. We also took material samples of each chunk type and analyzed them for particle size distribution and moisture content.

The four chunk types produced—aspen and sugar maple, short and long—were characterized by screening for size and analyzing each size fraction for average particle weight. Samples of each chunk type were manually classified using a plywood board with a series of round holes. The holes ranged from 1/2 inch to 3-1/2 inches in diameter in 1-inch increments. Each sample was sorted into groups based on the smallest hole size that would pass the piece.

To further define machine performance, we analyzed chunk length, productivity, torque, power, and energy factors. A two-way analysis of variance (ANOVA) was made to determine what effect the independent variables, species and nominal chunk length, had on average chunk length, rate of production, peak torque, average torque, average horsepower, and average energy. The data were combined where there were no significant differences at the 0.01 level and plotted against average log diameter. Linear regression equations were developed for those plots where the linear correlation coefficients were statistically significant at the 0.01 level.

INSTRUMENTATION

A recording oscillograph (Consolidated Electrodynamics Corporation Model 5-124A[2]) was used to record drive shaft cutting torque, integrated drive shaft cutting torque, and cutting drum rotation signals. The drive shaft cutting torque was measured using a four-active arm Wheatstone bridge

[2] *The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others that may be suitable.*

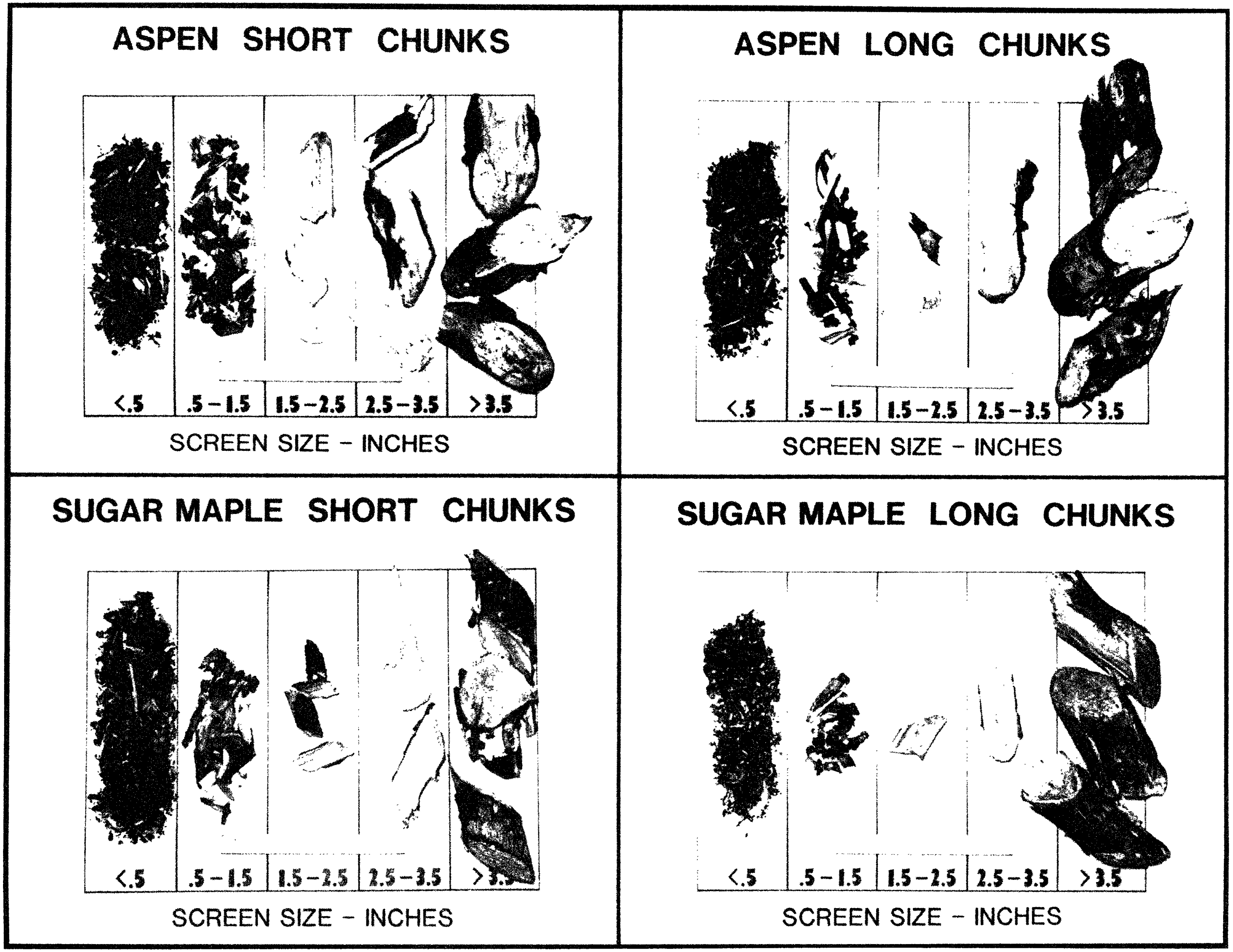

Figure 3.--*Typical particles produced by the Teardrop Chunker using two species, aspen and sugar maple, and two chunk lengths, short and long. (Volumes shown are approximate proportions.)*

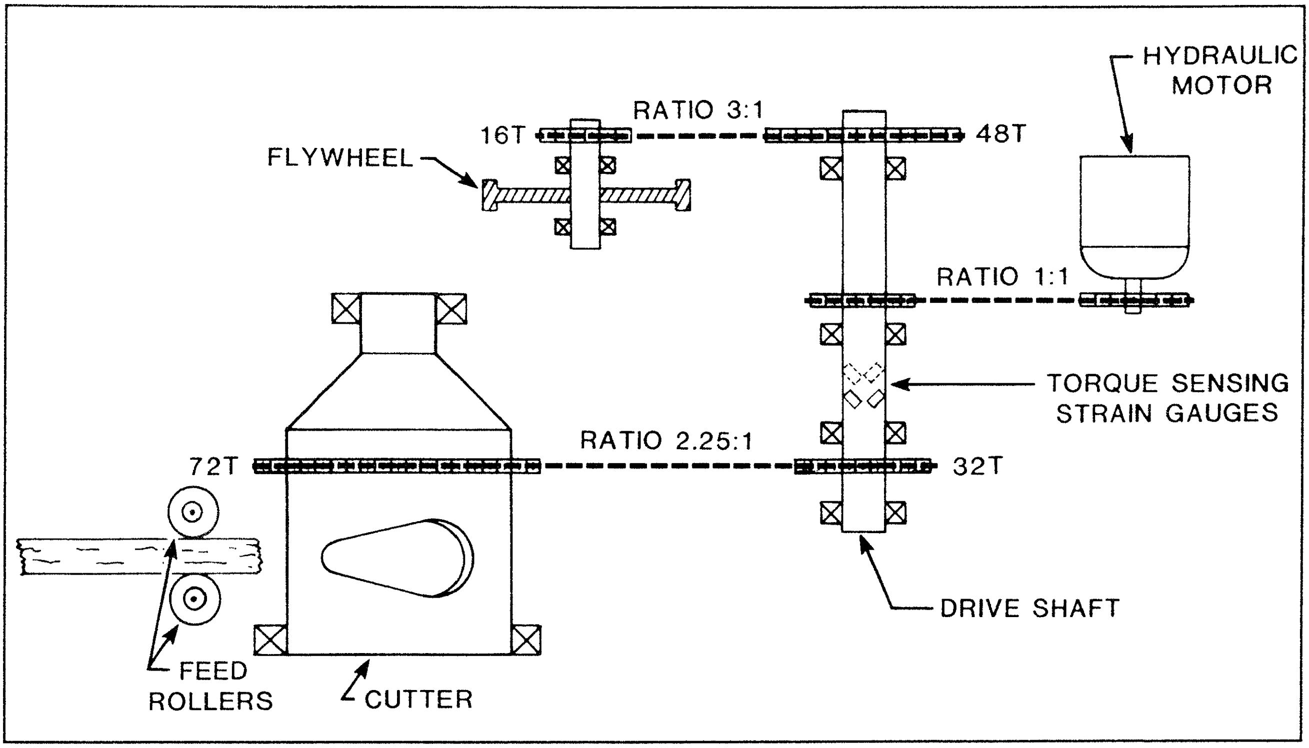

Figure 4.—*Schematic of Teardrop Chunker drive train.*

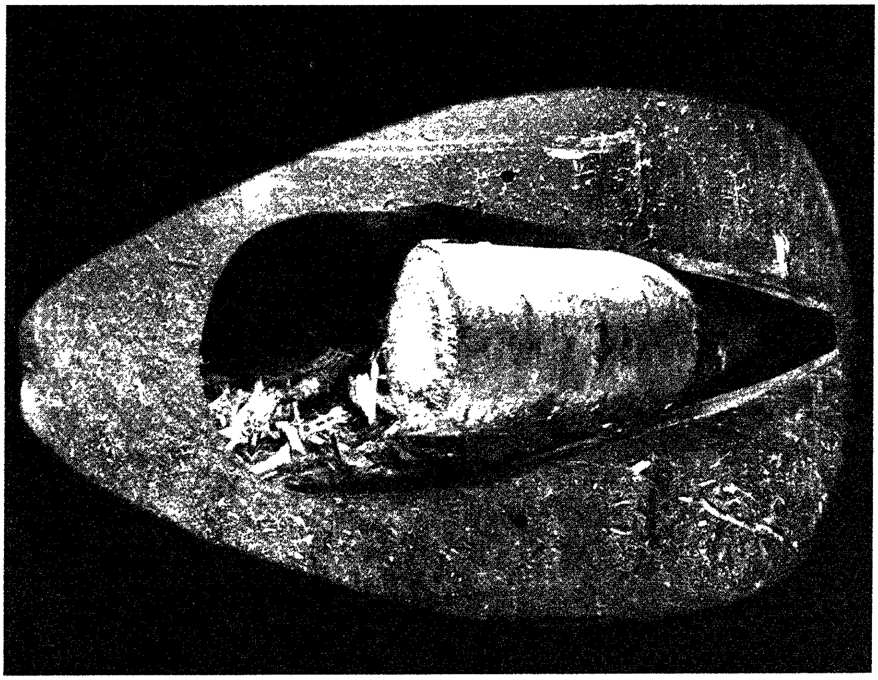

Figure 5.—*Teardrop-shaped cutter opening on the Teardrop Chunker.*

circuit. The bridge circuit consisted of four strain gauges mounted circumferentially around the shaft with the gauge elements oriented 45 degrees to the shaft center line. The gauged shaft was statically calibrated for torque by locking the center section of the shaft in a special fixture and twisting the gauged section by means of a lever arm and hydraulic cylinder mounted in place of the corresponding drive sprocket and chain. A load cell was placed in series with the hydraulic cylinder to measure the force applied.

Cutter drum rotation was sensed by an electromagnetic pickup that produced one pulse per drum revolution. The average cutter drum revolutions per minute (rpm) were calculated by dividing the number of revolutions made during the cutting by the time taken. Average drive shaft rpm was calculated by multiplying the drum rpm by 2.25, the sprocket ratio.

For each test, we determined peak cutter drive shaft torque, average cutter drive shaft torque, average power, and average energy transmitted to the cutter. Average cutter drive shaft torque was determined by electronically integrating the instantaneous torque signal and then dividing the integral by the cutting time. Average power transmitted to the cutter was calculated using the average torque and the average drive shaft rpm. Average energy was calculated by dividing the average power by the production rate.

TEST RESULTS

Of the 32 logs chunked, 20 (10 aspen and 10 sugar maple) were made into short chunks, and 12 (8 aspen and 4 sugar maple) were made into long chunks. The average diameter of the aspen logs ranged from 3.3 to 5.4 inches; the average diameter of the sugar maple logs ranged from 3.3 to 4.5 inches. Although the machine successfully cut a 4.5-inch-average diameter (4.8-inch-maximum diameter) sugar maple log while set to produce short chunks, it stalled on a 4.5-inch-average diameter (4.9-inch-maximum diameter) sugar maple log while set to produce long chunks.

The Teardrop Chunker produced mainly large chunks of wood, which were primarily solid, unfractured, short sections of log (fig. 3). At least 75 percent of the weight of each sample was composed of particles larger than 3-1/2 inches in diameter (table 1). An intermediate amount (from 6 to 21 percent by weight) of smaller chunks passed through a 3-1/2-inch round hole but not through a 1-1/2-inch round hole. A small amount (from 4 to 7 percent by weight) of particles and fines, primarily bark and surface fiber torn off by the feed rolls, passed through a 1-1/2-inch round hole.

Table 1.--*Screen retention fractions and particle weight statistics*

Screen size range (inches)	Percent of total weight[1]	Mean particle weight[1]	Range
		--- *Grams* ---	
	Aspen short chunks		
<0.5	3	-	-
0.5-1.5	4	0.7	0-17
1.5-2.5	2	14.1	2-63
2.5-3.5	17	113.0	25-288
>3.5	75	261.5	52-485
	Aspen long chunks		
<0.5	4	-	-
0.5-1.5	3	0.7	0-11
1.5-2.5	1	10.5	1-35
2.5-3.5	7	105.4	29-330
>3.5	85	432.8	84-633
	Sugar maple short chunks		
<0.5	4	-	-
0.5-1.5	3	0.9	0-14
1.5-2.5	1	11.1	3-26
2.5-3.5	5	223.5	76-370
>3.5	88	441.9	45-675
	Sugar maple long chunks		
<0.5	3	-	-
0.5-1.5	1	0.7	0-4
1.5-2.5	0	20.0	7-33
2.5-3.5	21	369.2	74-693
>3.5	75	723.6	542-953

[1]Oven-dry weights.

Both the short and long chunks of aspen had a bulk density of 23.7 pounds/cubic foot (lb/cu ft) at an average moisture content of 52 percent (wet-weight basis). The bulk density for sugar maple ranged from 27.5 lb/cu ft for short chunks to 29.3 lb/cu ft for long chunks at an average moisture content of 37 percent.

The average chunk length produced for the various log diameters chunked ranged from 2.8 to 4.9 inches for short chunks and from 4.5 to 7.2 inches for long chunks (fig. 6). The two species were combined because the two-way ANOVA indicated that there was no significant difference between species data at the 0.01 level. Linear regression equations were developed because both the short and long chunk groups had significant negative linear correlation coefficients at the 0.01 level (table 2).

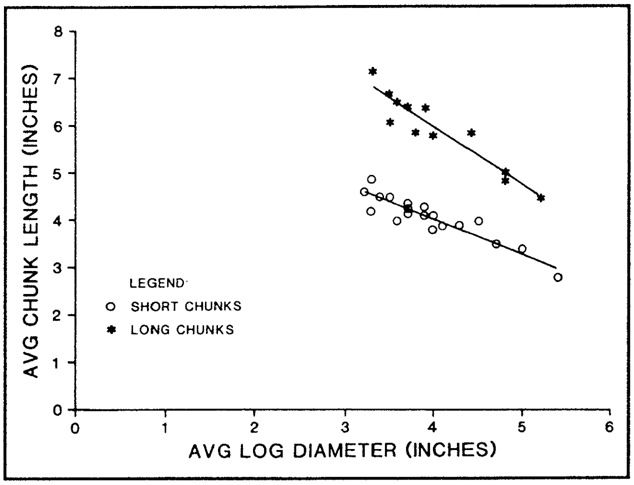

Figure 6.—*Test data and the linear regression lines for average chunk lengths produced for short and long chunk production settings.*

The average rate of production ranged from 6.9 to 10.9 cubic feet/minute (cu ft/min) for short chunks and from 7.8 to 13.4 cu ft/min for long chunks (fig. 7). Again, the aspen and sugar maple data were combined because the ANOVA test indicated that there was no significant difference between them. The linear correlation coefficients indicate a significant positive linear correlation between production rate and log diameter (table 2).

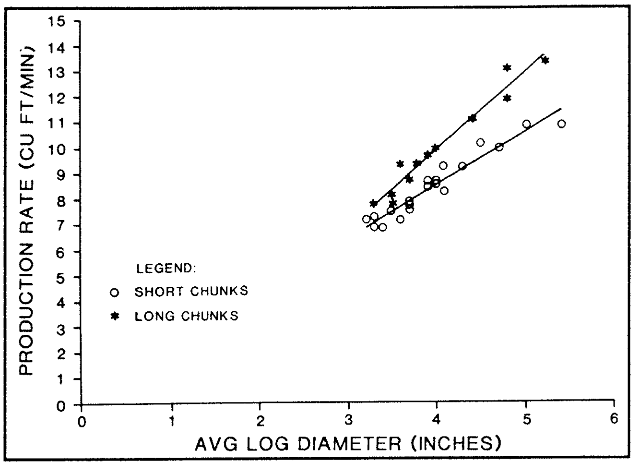

Figure 7.—*Test data and the linear regression lines for production rates developed producing short and long chunks.*

The average torque and peak torque developed in the cutter drive shaft are shown plotted in figure 8. Here, the data for the two nominal chunk lengths were combined because there was no statistical difference between them. Average torque of the cutter drive shaft ranged from 154 to 409 foot-pounds (ft-lb) for aspen and from 281 to 583 ft-lb for sugar maple. Peak torque ranged from 869 to 2,020 ft-lb for aspen and from 1,928 to 3,156 ft-lb for sugar maple. (Note: A peak torque of 3,400 ft-lb was recorded when the cutter stuck while attempting to cut the 4.5-inch sugar maple mentioned above.) The linear correlation coefficients show significant positive linear correlations between torque and log diameter (table 2).

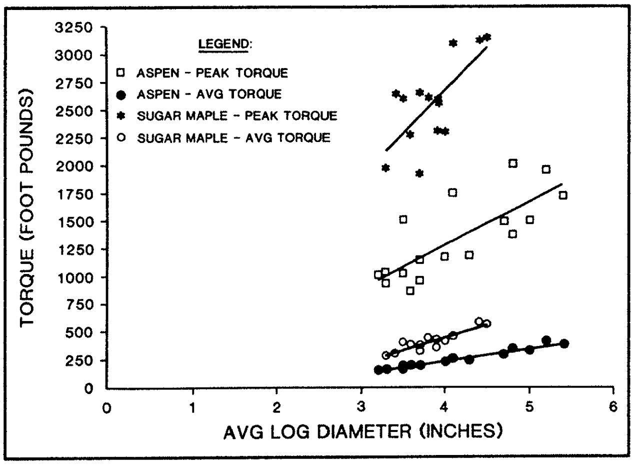

Figure 8.—*Test data and the linear regression lines for aspen and sugar maple peak and average torque.*

Table 2.--*Teardrop chunker performance*

	Regression equation	Linear correlation coefficient R	Significant at 0.01 level
Chunk length			
Short chunks	Length (inches) = 6.95 - 0.73 x avg. diameter (inches)	- 0.91	Yes
Long chunks	Length (inches) = 10.88 - 1.22 x avg. diameter (inches)	- 0.94	Yes
Productivity			
Short chunks	Production (cu ft/min) = 0.16 + 2.10 x avg. diameter (inches)	0.96	Yes
Long chunks	Production (cu ft/min) = -2.46 + 3.09 x avg. diameter (inches)	0.98	Yes
Peak torque			
Aspen	Peak torque (ft-lb) = -294.15 + 394.96 x avg. diameter (inches)	0.77	Yes
Sugar maple	Peak torque (ft-lb) = -434.75 + 780.46 x avg. diameter (inches)	0.69	Yes
Average torque			
Aspen	Avg. torque (ft-lb) = -221.64 + 114.00 x avg. diameter (inches)	0.97	Yes
Sugar maple	Avg. torque (ft-lb) = -441.07 + 220.87 x avg. diameter (inches)	0.89	Yes
Power			
Aspen	Power (horsepower) = -11.75 + 6.27 x avg. diameter (inches)	0.97	Yes
Sugar maple	Power (horsepower) = -17.36 + 10.57 x avg. diameter (inches)	0.89	Yes
Energy			
Aspen			
Short chunks	Energy (horsepower-min/cu ft) = 0.32 + 0.32 x avg. diameter (inches)	0.95	Yes
Long chunks	Energy (horsepower-min/cu ft) = 0.25 + 0.24 x avg. diameter (inches)	0.94	Yes
Sugar maple			
Short chunks	No significant linear correlation	0.59	No
Long chunks	No significant linear correlation	-0.15	No

The average power transmitted to the cutter by the drive shaft ranged from 9.7 to 23.2 horsepower for aspen and from 17.5 to 33.1 for sugar maple (fig. 9). The short and long chunk length data were combined because there was no significant difference between them. The linear correlation coefficients indicate significant positive linear correlations between power required and log diameter (table 2).

The average energy transmitted to the cutter as it relates to the various log diameters tested is shown in figures 10 and 11. Species and nominal chunk length factors are presented separately because they were found to be significant. For aspen, energy ranged from 1.3 to 2.1 horsepower-minutes/cubic foot (hp-min/cu ft) for short chunks and from 1.0 to

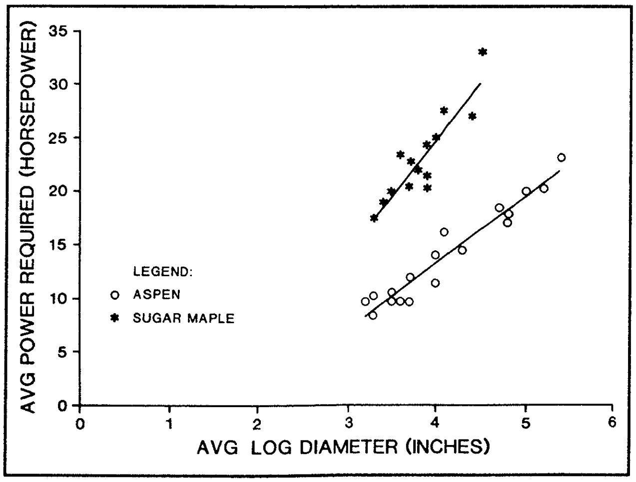

Figure 9.—*Test data and the linear regression lines for average power required to produce aspen and sugar maple chunks.*

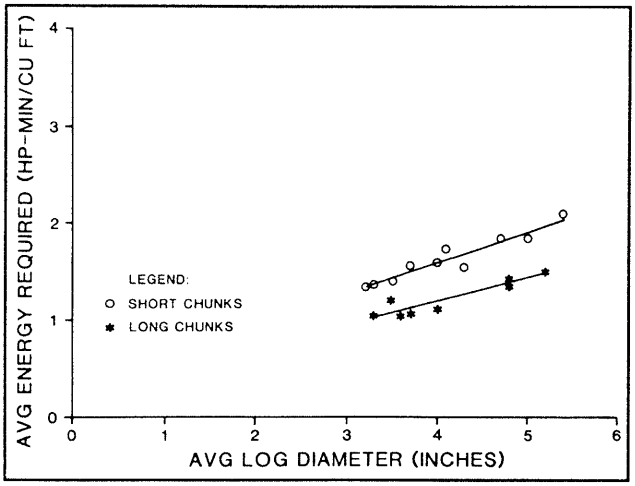

Figure 10.—*Test data and the linear regression lines for average energy required to produce aspen short and long chunks.*

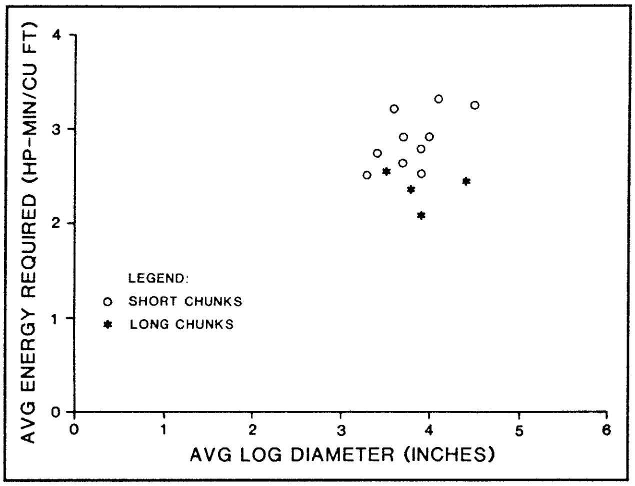

Figure 11.—*Average energy required to produce sugar maple short and long chunks.*

1.5 hp-min/cu ft for long chunks (fig. 10). Sugar maple energy ranged from 2.5 to 3.3 hp-min/cu ft for short chunks and from 2.1 to 2.6 hp-min/cu ft for long chunks. The aspen data show significant positive linear correlations between energy and log diameter. However, because the sugar maple linear correlation factors were not found to be significant at the 0.01 level, the linear regression equations and lines were not determined. The small number of data points made it impossible to explain the scatter in the sugar maple data.

CONCLUSIONS AND RECOMMENDATIONS

The Teardrop Chunker successfully produced short, round, intact chunkwood sections from both aspen and sugar maple logs. Short and long chunks were made from the two species.

Species did not significantly affect actual average chunk length or production rate; nominal chunk length did not significantly affect torque or power. However, energy was significantly affected by both. Over the range tested, average log diameter had a linear effect on chunk length, productivity, power, and energy. However, because the range of log diameters and the number of data points are limited, the linear regression equations should be used with care, and extrapolation should be avoided.

Although the Teardrop Chunker's maximum size limit was not established for aspen, it appears to be less than 5 inches in diameter (maximum) for sugar maple, especially when producing long chunks where the rotational speeds and thus the kinetic energy stored in the drum and flywheel are reduced.

The Teardrop Chunker is a laboratory prototype built to test the teardrop cutter concept. Commercial application would require further engineering and testing based on the data we have developed here. We believe that the Teardrop Chunker's small size, simple design, and low horsepower requirements make it a good candidate for a tractor-mounted, three-point-hitch attachment. Such an attachment could be used to process low-valued, small-diameter woodlot thinnings into chunks of wood suitable for small-scale, hand-fired combustors often found in residences, farms, and small industries.

METRIC CONVERSIONS

1 cubic foot = 0.0283 cubic meters
1 cubic foot/minute = 0.00047 cubic meters/second
1 foot = 0.3048 meters
1 foot/minute = 0.0051 meters/second
1 foot-pound = 1.3558 newton-meters
1 horsepower = 746 watts
1 horsepower-minute/cubic foot = 1,580 kilowatt-hours/cubic meter
1 inch = 2.54 centimeters
1 pound = 0.4536 kilograms
1 pound/cubic foot = 16.02 kilograms/cubic meter
1 square foot = 0.0929 square meters

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