U S D A FOREST SERVICE
RESEARCH PAPER NC-90
1973

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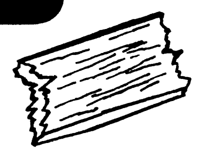

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Manuscript approved for publication May 15, 1973

PREDICTING SEGREGATION OF WOOD AND BARK CHIPS BY DIFFERENCES IN TERMINAL VELOCITIES

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Research is now in progress both in industry and government on developing methods of bark removal after chipping. Reasons for supporting this research have been listed and elaborated on in previous publications (Arola 1968, 1970; Erickson 1968, 1970, 1971). Briefly stated, fuller utilization of our existing forest resources must take place in order to meet the projected demands for pulpwood. One method of utilizing more of the standing tree is to chip the tops and limbs presently left as residue, or chip the whole tree and remove the bark after chipping.

Bark removal after chipping is a twofold problem: it consists of separating the attached bark from the wood chips (breaking of the wood-bark bond) and segregating the "free" bark chips from the "free" wood chips. Air flotation is one process being investigated to segregate bark from wood once it has been separated. The air segregation process depends on basic differences in terminal velocities of the wood and bark chips. The terminal velocity of a particle is defined as the maximum (constant) velocity the particle attains while falling freely through a viscous medium such as air (Korn 1951). This occurs the moment equilibrium is attained between the accelerating force (gravity) and the upward resisting force (drag) acting on the particle. An upward air flow can raise a particle only if the air velocity is greater than the terminal velocity of the particle. Thus, in order to design an efficient air flotation process, it is necessary to know the terminal velocities of the wood and bark chips of the various pulpwood species.

A variety of equipment exists for sorting materials according to differences in size, shape, specific gravity, and color. Such methods are used extensively in the agricultural, mining, and food-processing industries. However, none have proven capable of segregating bark and wood chips on a commercial scale. It therefore is necessary to design and develop new equipment for bark-chip separation-segregation. The first step is obtaining basic engineering data on the physical, mechanical, and chemical properties of wood and bark. Data on bark especially are very limited. This paper presents data on some of the physical properties of wood and bark chips for eight important pulpwood species: aspen, sugar maple, jack pine, red pine, white spruce, balsam fir, slash pine, and loblolly pine. The physical properties measured were length, width, thickness, moisture content, specific gravity, and terminal velocity. Differences in the terminal velocities of the wood and bark chips caused by differences in the other physical properties were used to predict the degree of segregation possible by air flotation.

EXPERIMENTAL PROCEDURE AND APPARATUS

Data were obtained on wood and bark chips made by chipping unbarked logs with a Morbark Chip-Pac[1] chipper (48-inch diameter disc with three knives). The chips were classified on a Sweco classifier and the following three chip sizes were measured and tested: less than 1-1/8 inch and greater than 5/8 inch (passed through the 1-1/8 inch screen and retained on the 5/8 inch screen); less than 5/8 inch and greater than 3/8 inch; and less than 3/8 inch and greater than 3/16 inch. Random samples of 100 wood and bark chips in each size

[1] *The use of trade, firm, or corporation names in this publication are for the information and convenience of the reader. Such does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service by the U.S. Department of Agriculture to the exclusion of others which may be suitable.*

class were tested. The laboratory procedure on the individual chips was as follows:

1. The chips were weighed as received.
2. Length, width, and thickness were measured (length was measured along the grain).
3. Terminal velocity was determined.
4. Specific gravity[2] was determined.
5. Chips were ovendried.
6. Ovendried chips were weighed (for moisture content determination).

Terminal velocity was determined in a vertical wind tunnel with the wood or bark chips initially at rest on a stationary screen. When the terminal air velocity was reached, the chip floated in the air stream just above the screen. This technique has been described in detail in a previous publication (Sturos 1972). A unique flow straightener was designed to give a uniform air velocity distribution in the center portion of the vertical tube and a higher velocity near the tube wall, thus preventing the chip from moving up on its edge against the wall. A calibration curve correlating the air velocity to the voltage applied to the blower motor eliminated the need of the pitot tube and manometer in each velocity measurement.

Two density-gradient columns of different ranges were used to measure the true specific gravities of the wood and bark chips. The preparation of the density-gradient columns used in this study have been described in detail previously (Julien *et al.* 1971). The technique is based upon the fact that when two immiscible liquids of different specific gravities are placed in a cylinder, the liquids diffuse and form a density gradient whose upper and lower limits are equal to the densities of the two liquids. Petroleum ether and chlorobenzene were used for one of the columns, and toluene and bromobenzene were used for the other. The columns were calibrated by small glass beads whose specific gravities were accurately determined according to ASTM standards. The gradients of the two columns as prepared were 0.67 to 1.09 and 0.93 to 1.28. When carefully placed in the column, a wood or bark chip having a specific gravity value between these limits would sink to the level at which its specific gravity equaled that of the surrounding liquid mixture. The position of the chip was compared with the standardized beads for determining the specific gravity. Linear interpolation was used between the beads. A limiting factor of the density-gradient column technique is that specific gravity values less than 0.67 could not be determined. Therefore the specific gravities of chips that floated in the lower range column were determined by using their calculated moisture contents. Specific gravity-moisture content relationships developed in a cooperative study by Conder (1971) were used. These relationships were linear prediction equations. The data were obtained by soaking ovendried wood and bark chips for time intervals ranging from 2 minutes to 12 days. The moisture content and specific gravity were measured at the end of each interval.

For each of the 100 chips, the weight, length, width, thickness, blower motor velocity required to float the chip, specific gravity, and ovendry weight were recorded on prepared data sheets from which the data were keypunched on computer cards. A computer program calculated the terminal velocities from a predetermined velocity vs. voltage calibration equation and also determined the moisture content of each chip.

RESULTS AND DISCUSSION

The tabular output from the computer program gave the mean, standard deviation, the upper and lower 95-percent confidence limits on the mean, and the minimum and maximum values for each of the measured variables. The summary statistics for each species tested are given in tables 1 through 8. Comparing the differences in the mean terminal velocities between the wood and bark chips in each size shows that the four most promising species tested were aspen, sugar maple, balsam fir, and white spruce. The mean terminal velocities of the wood and bark chips of these species differed by 2.9 to 8.9 feet per second. Comparing the values of the other chip variables shows that the differences in terminal velocities are highly correlated to differences in the surface density (the product of specifc gravity and thickness) of the wood and bark chips.

By assuming a normal distribution as an approximation to the terminal velocity, the percentages of the total wood and bark chips in each size that one would expect to be lifted at any given air velocity were calculated for

[2]*Specific gravity as used in this study is the true or "natural" specific gravity defined as the green weight per green volume.*

Table 1. – Mean measurements of aspen wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity Mean value	Terminal velocity Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.78	1.14	0.13	49	0.78	13.9	2.0
5/8	Bark	.81	.90	.24	44	1.07	21.4	2.7
3/8	Wood	.72	.54	.11	39	.73	13.2	2.3
3/8	Bark	.77	.40	.19	43	1.06	20.3	3.3
3/16	Wood	.68	.30	.08	42	.75	11.9	2.7
3/16	Bark	.62	.24	.11	48	1.06	17.0	3.6

* Green weight over green volume.

Table 2. – Mean measurements of white spruce wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity Mean value	Terminal velocity Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.85	1.05	0.13	30	0.61	11.6	2.1
5/8	Bark	.78	1.28	.20	52	.92	19.4	2.2
3/8	Wood	.79	.50	.10	37	.67	11.8	2.5
3/8	Bark	.81	.66	.17	51	.91	19.1	4.2
3/16	Wood	.76	.29	.08	32	.64	10.5	2.3
3/16	Bark	.46	.33	.09	39	.92	13.4	2.1

* Green weight over green volume.

Table 3. – Mean measurements of sugar maple wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity Mean value	Terminal velocity Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.86	1.43	0.15	35	0.94	16.2	1.8
5/8	Bark	.86	.78	.20	35	1.04	21.8	2.1
3/8	Wood	.74	.64	.11	29	.86	14.6	2.3
3/8	Bark	.77	.49	.18	40	1.01	21.3	3.1
3/16	Wood	.65	.30	.08	43	.83	13.6	2.1
3/16	Bark	.57	.27	.12	24	1.05	18.9	3.2

* Green weight over green volume.

Table 4. – Mean measurements of balsam fir wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity Mean value	Terminal velocity Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.90	1.09	0.15	54	0.77	14.7	1.3
5/8	Bark	.91	1.26	.27	45	.97	23.6	1.9
3/8	Wood	.76	.54	.11	54	.77	14.3	2.6
3/8	Bark	.70	.55	.21	46	1.00	22.8	2.6
3/16	Wood	.73	.28	.08	30	.69	12.6	2.5
3/16	Bark	.55	.29	.09	36	1.00	16.5	3.1

* Green weight over green volume.

Table 5. – Mean measurements of jack pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.91	1.06	0.14	32	0.72	13.0	2.1
5/8	Bark	.74	.94	.12	46	.92	15.4	2.7
3/8	Wood	.72	.50	.11	39	.76	12.8	2.4
3/8	Bark	.70	.61	.10	50	.93	14.5	3.0
3/16	Wood	.69	.27	.08	38	.79	11.9	2.2
3/16	Bark	.54	.28	.07	33	.89	11.4	2.8

* Green weight over green volume.

Table 6. – Mean measurements of red pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.85	0.96	0.14	52	0.84	15.7	1.9
5/8	Bark	1.04	.81	.11	36	.95	13.4	3.4
3/8	Wood	.81	.47	.12	47	.83	15.2	2.2
3/8	Bark	.80	.53	.08	36	.96	12.2	3.3
3/16	Wood	.72	.26	.09	41	.80	12.9	2.3
3/16	Bark	.56	.28	.04	37	1.09	8.5	3.1

* Green weight over green volume.

Table 7. – Mean measurements of slash pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.86	0.84	0.15	45	0.92	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.

each of the above four species (fig. 1, tables 9-12). The 0.95 upper confidence limit on the wood chip mean and the 0.95 lower confidence limit on the bark chip mean were used to position the wood chip and bark chip distributions (fig. 1). This would lead to more overlap of the wood and bark terminal velocity distributions and result in more bark being lifted with the wood, approximating a lower limit on system effectiveness. In tables 9 through 12, the output bark content in the wood product (that is, the chips that were lifted)

Table 8. – Mean measurements of loblolly pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity*	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.94	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 less than 0.67.

* Green weight over green volume.

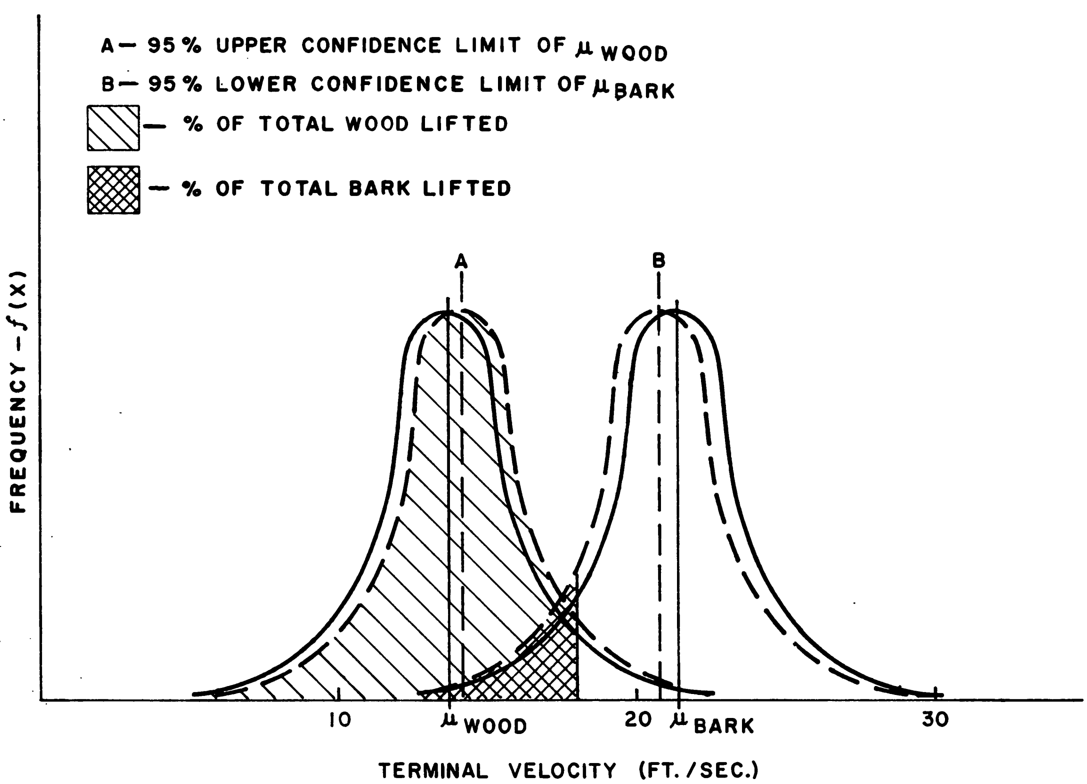

Figure 1. – Normal distributions of the terminal velocity of 5/8-inch aspen wood and bark chips. The distributions have been positioned at the 0.95 upper confidence limit on the wood mean and at the 0.95 lower confidence limit on the bark mean.

Table 9. – Possible results of segregating aspen wood and bark chips by air flotation methods

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	7.2	16.0	81.4	3.8	0.4
5/8	7.2	17.0	92.0	7.9	.7
5/8	7.2	18.0	97.2	9.5	.8
3/8	32.4	14.0	55.9	4.4	3.6
3/8	32.4	15.0	71.9	7.9	5.0
3/8	32.4	16.0	84.4	13.4	7.1
3/16	53.9	11.0	30.1	7.0	21.3
3/16	53.9	12.0	43.9	11.5	23.5
3/16	53.9	13.0	58.6	17.8	26.3

Table 10. – Possible results of segregating sugar maple wood and bark chips by air flotation

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	1.5	18.0	78.6	5.5	0.1
5/8	1.5	19.0	91.2	13.0	.2
5/8	1.5	20.0	97.3	25.6	.4
3/8	22.1	15.0	48.7	3.4	2.0
3/8	22.1	16.0	65.5	6.7	2.8
3/8	22.1	17.0	79.7	11.9	4.1
3/16	52.7	13.0	32.1	5.1	15.0
3/16	52.7	14.0	50.8	9.3	17.0
3/16	52.7	15.0	69.3	15.6	20.1

Table 11. – Possible results of segregating white spruce wood and bark chips by air flotation

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	16.3	14.0	82.7	1.1	0.3
5/8	16.3	15.0	92.3	3.3	.7
5/8	16.3	16.0	97.2	8.5	1.7
3/8	10.8	14.0	75.1	15.8	2.5
3/8	10.8	15.0	86.0	22.2	3.0
3/8	10.8	16.0	93.1	29.9	3.8
3/16	22.5	10.0	34.4	7.4	5.9
3/16	22.5	11.0	51.1	17.0	8.8
3/16	22.5	12.0	67.6	31.9	12.1

Table 12. – Possible results of segregating balsam fir wood and bark chips by air flotation methods

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	14.8	19.0	99.8	1.5	0.3
5/8	14.8	20.0	100.0	5.0	.9
5/8	14.8	21.0	100.0	12.8	2.2
3/8	12.8	17.0	80.7	2.0	.4
3/8	12.8	18.0	89.6	4.8	.8
3/8	12.8	19.0	95.0	10.1	1.5
3/16	7.5	12.0	32.9	10.6	2.6
3/16	7.5	13.0	48.1	17.8	2.9
3/16	7.5	14.0	63.7	27.4	3.4

was calculated for each of the three air velocities chosen for each chip size. The degree of bark removal possible by air flotation methods is realized by comparing the output and input bark contents. Also, the percent of the total wood chips lifted gives an indication of the amount of wood recovery in each size class. The optimum air setting for each size would not be determined solely on output bark content but on a combination of bark removal and an acceptable wood recovery.

The data would suggest that in an industrial process, a minimum of three air flotation machines would be operating simultaneously – at least one machine for each nominal chip size. The wood product from each machine (chip size) would ultimately be combined to form a single wood product. Based on this assumption, typical combined wood products were calculated for aspen, sugar maple, white spruce, and balsam fir (table 13). For each species an air velocity was selected for each chip size. Also, realistic weighted fractions of the total chip mix were assumed for each size. These were based on actual classification tests of the random mix as received from the chipper. As table 13 shows, the calculated wood recovery ranged from 91 to 93 percent for the four species and the residual bark content from 1.8 to 2.6 percent.

Numerous pulpmills accept chips with 3 percent or less bark – thus, the above results indicate that air flotation is a promising method of segregation with the four species mentioned above. Also, similar results would most likely occur with the species whose wood and bark chips have similar differences in specific gravity and shape.

Table 13. – Results obtained by combining the wood product from the three size classes in each species

Species	Air velocities selected for each chip size (inches)			Percent of total chips assumed in each chip size (inches)			Combined input bark content	Combined wood product	
	5/8	3/8	3/16	5/8	3/8	3/16		Wood recovered	Bark content
	Ft./sec.	Ft./sec.	Ft./sec.				Percent	Percent	Percent
Aspen	18	15	12	72	22	6	15.5	91	1.8
Sugar maple	20	17	15	69	23	8	10.3	92	2.0
White spruce	16	16	11	65	26	9	15.4	92	2.6
Balsam fir	21	19	14	48	38	14	13.0	93	2.1

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