DRYING RATES OF WOOD CHIPS DURING COMPRESSION DRYING[1]

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ABSTRACT

Compression drying is basically a process of forcing the free water in wood to move under high hydrostatic pressure through a solid structure. Fundamental information regarding the time-dependent characteristic of compression drying is necessary to develop efficient commercial processes. The purpose of this study is to provide an initial evaluation of the effect of some factors—pressure, wood density, and particle (chip) size—on free water extraction.

Five species—aspen, balsam fir, jack pine, red maple, and red oak—were tested in this study. For each species both typical pulp size chips and particles from hammermilled chips were used. Drying rates were determined under constant ram face pressures at 500 psi, 1,000 psi, 1,500 psi, and 2,000 psi, respectively. The concept of drying rate is one of the important factors in dealing with compression drying, especially in designing dewatering pressure cycles.

The most efficient compression drying is achieved during the first two minutes. Drying rates are negligible after 3 to 4 minutes of constant pressure in the 500 to 2,000 psi range. The analysis of variance for species shows highly significant differences in final moisture contents. Size of chips had a significant effect on final moisture contents. Compressed density of hammermilled chips is slightly higher than that of unrefined chips. High density chips require higher pressure to initiate effective drying rates.

Keywords: Compression drying, wood chips, wood density, particle size, pressure.

INTRODUCTION

The use of woody biomass for industry energy generation is rapidly expanding in the world. It is well known that when wood chips are used as fuel, the heat obtained from the fuel is decreased by the high moisture in the fuel, which in turn reduces both thermal efficiency and boiler capacity (Williams 1976; Blankenhorn and Weyers 1980).

There are two approaches to reduce the moisture in wood chips or bark (Haygreen 1981). One is by supplying heat energy to vaporize the moisture, i.e., by conventional drying. Rotary drum or cascade driers are typically used. Another method of drying is by applying mechanical energy to squeeze the free water from the cell lumens. This method of drying below 100% MC is still in its development stages (Haygreen 1981). The direct energy required for pressing-induced dewatering is many times smaller than that required for heat-induced water removal (Schwartzberg et al. 1973). Haygreen proposed that removal of water below 100% be termed compression drying rather than dewatering (Haygreen 1981, 1982) since the mechanism of water movement is different than in the removal of process water by bark presses in use today. Some characteristics of compression drying

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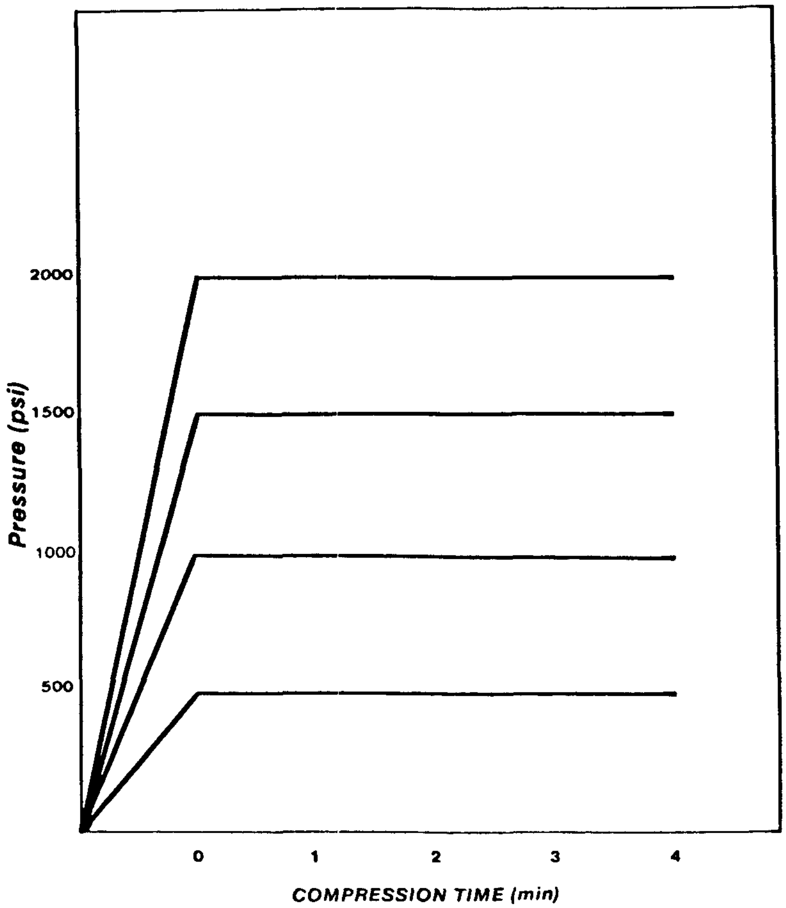

FIG. 1. Pressure-time sequence for the four test conditions.

by mechanical energy are similar to those of conventional drying by heat energy. For example, the shapes of the rate curves for compression drying are similar to those of evaporative drying (McCabe and Smith 1976).

One purpose of this paper is to examine the time-dependence of compression drying. Compression drying is basically a process of forcing the free water in wood to move under high hydrostatic pressure through a solid wood structure that becomes increasingly impervious as the process proceeds. Fundamental information regarding the time-dependence of compression drying is necessary to develop efficient commercial processes.

The compression drying of a chip mat in a baling type press, which is simulated in this study, is fundamentally different than dewatering accomplished by roller nip presses. In roller presses, water is expelled as the chip or bark particle passes the nip, but much of this water may be reabsorbed as the particle recovers to its original volume once the nip is passed. In a baling press, once water is forced from the chip mat out of the press, it cannot be reabsorbed when pressure is

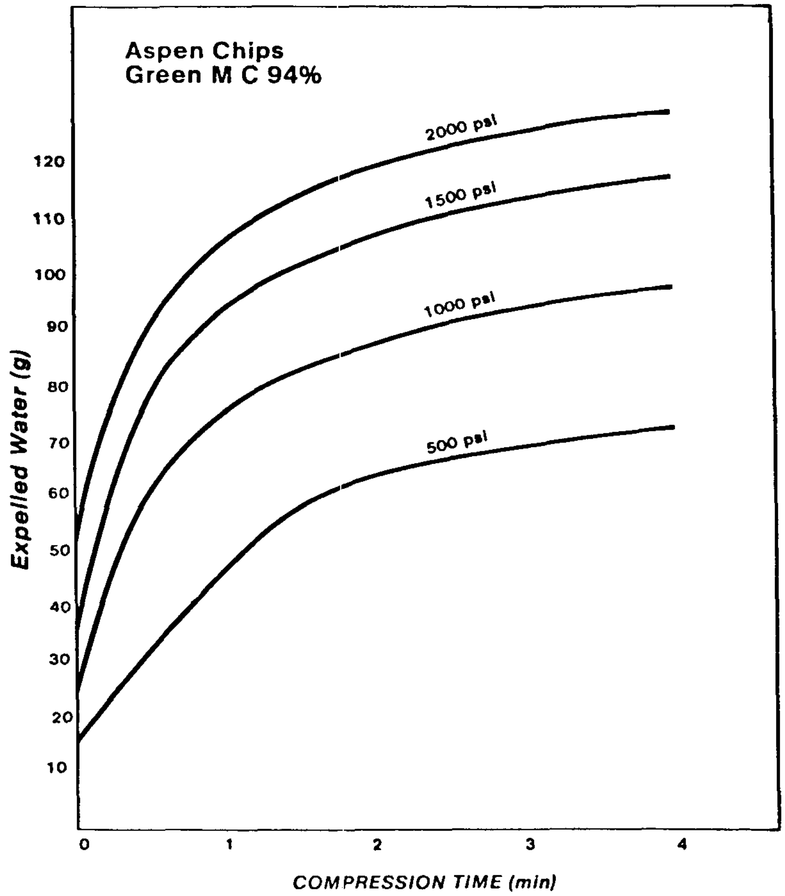

FIG. 2. Water loss at four test pressures during a four-minute pressure cycle.

released. However, in such a press, water must be forced through the chip mat to the vents from the press. In a press large enough for commercial applications, this could be a distance of up to 12 inches. It seems apparent that such water flow is a time-dependent process that may be affected by pressure, wood density, and particle (chip) size. Another purpose of this study is to provide an initial evaluation of the effect of these variables on free water extraction.

EXPERIMENTAL PROCEDURE

A 60-thousand-pound capacity universal testing machine was used in these compression drying tests in conjunction with a 5½-inch-diameter pressure cell used in previous research (Haygreen 1982). The wall of this pressure cell is provided with slots ⅛ inch wide and ¼ inch deep, spaced every one inch around the circumference. The water expelled by ram pressure is forced to these slots and then downward to the base of the cell. Thus free water must travel a distance ranging from 0 to 2.75 inches to reach a point outside the pressure cell. The water

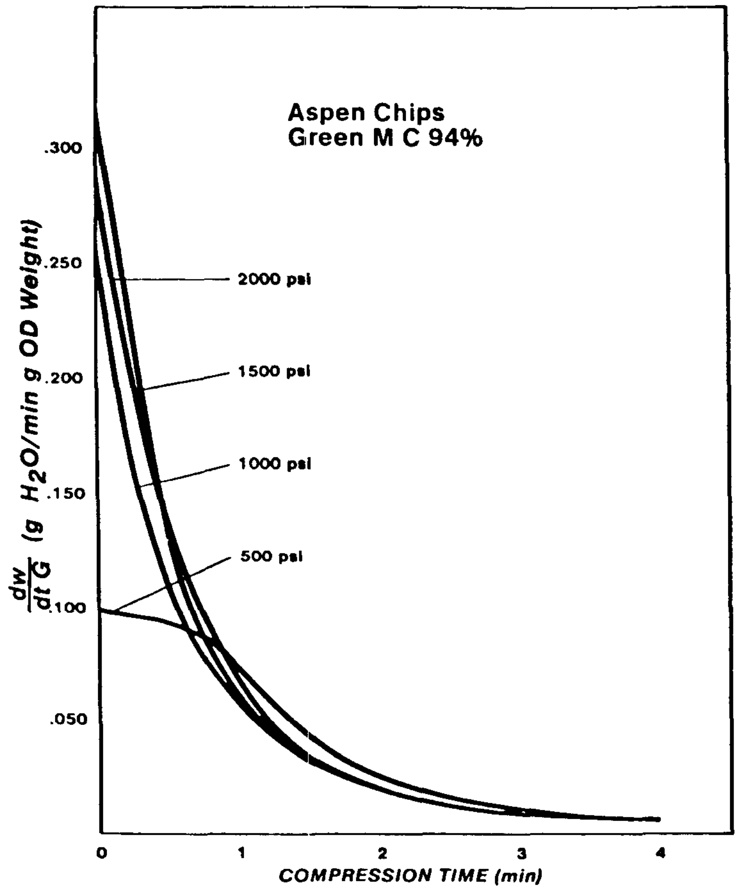

FIG. 3. Rate of drying per unit of OD weight for aspen.

is moved from the slots by vacuum into a flask and there weighed by an electronic balance to provide a continuous measure of the water loss. A dial gauge measures the vertical displacement of the ram, providing the data for calculating the chip mat density at any time. Ram face pressure is calculated from total force indicated on the universal testing machine.

Five species—aspen, balsam fir, jack pine, red maple, and red oak—were analyzed in this study. For each species both pulp size chips and hammermilled chips were used. Pulp size chips averaged ¾ inch long by ¼ inch thick, and hammermilled chips averaged 0.32 inch long by 0.04 inch thick. In each test 700 grams of chips, wet weight, were placed in the pressure cell. All moisture content (MC) calculations in this report are based upon oven-dry weight.

Drying rates were determined under constant ram face pressures as follows: 500 psi, 1,000 psi, 1,500 psi, 2,000 psi. Pressure was increased from zero to the selected test pressure, indicated above, within one minute (Fig. 1). The time zero is the time after the selected pressure is reached.

A split-plot design (Steel and Torrie 1980) was chosen in this experiment. The experimental design used in this experiment was as follows:

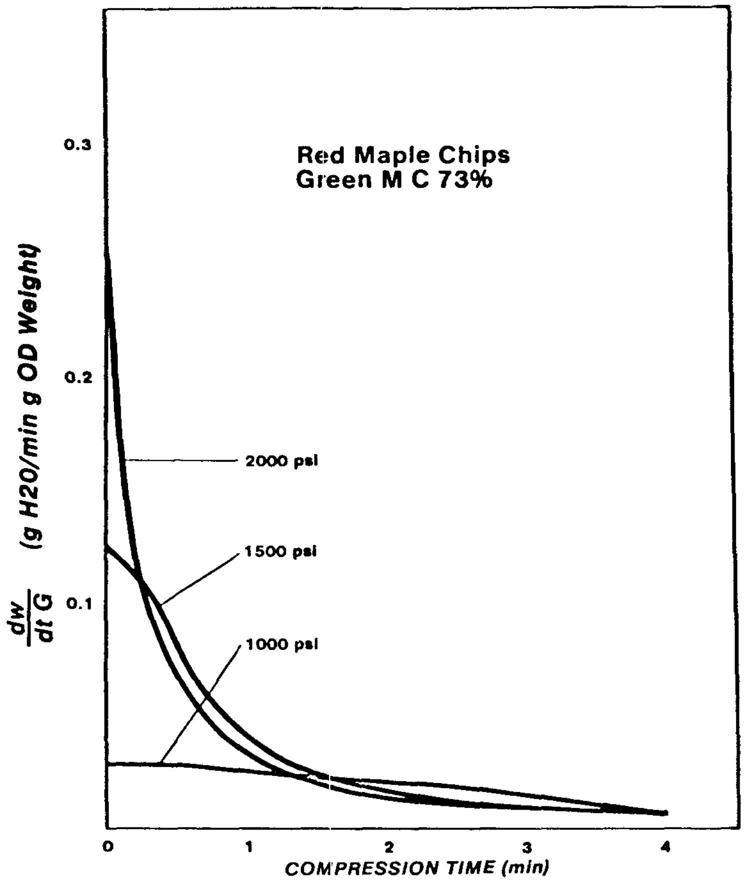

FIG. 4. Rate of drying per unit of OD weight for red maple.

Species	5
Size of chips	x2
Pressures	x4
Replications	x3
TOTAL	120

The IVAN statistical package developed by the University of Minnesota was used for the statistical analysis (Weisberg and Koehler 1981).

RESULTS AND DISCUSSION

The relationship between the weight of expelled water from 700 grams of wet chips and the compression time was obtained for the five species. Figure 2 shows the relationship for aspen chips. It indicates the time-dependence of compression drying under constant pressure and shows the rapid decrease in rate after about one minute.

The curves show that the amount of water expelled from chips initially varies directly with compression time. The slopes of the curves decrease gradually until after 3 to 4 minutes there is only small further water loss.

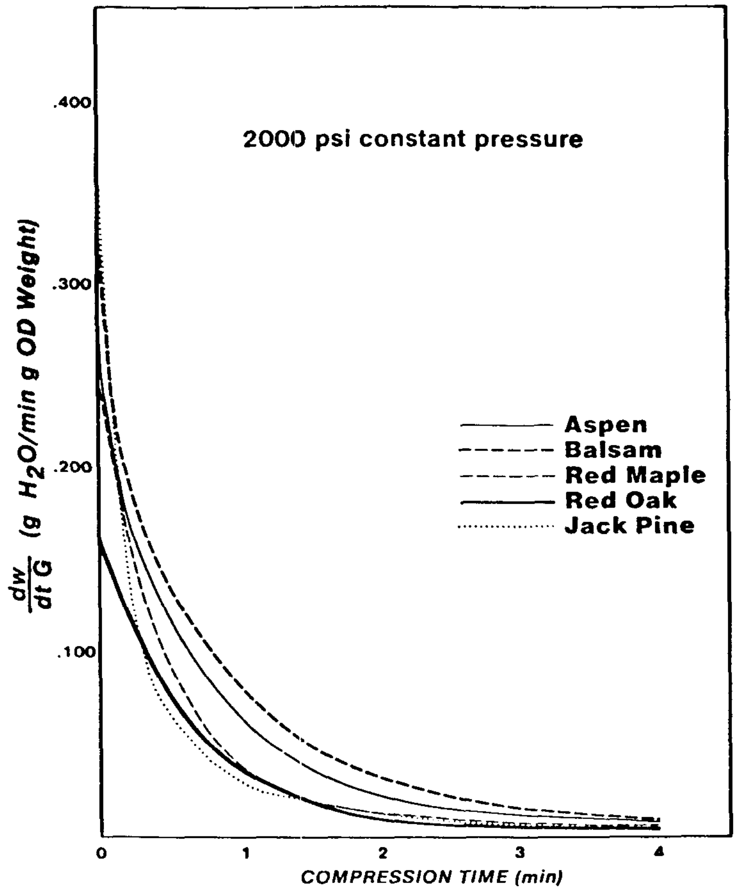

FIG. 5. Rate of drying per unit of OD weight for five species at 2,000 psi.

The rate of water lost was determined by calculating the slope of the tangent of w versus t shown in Fig. 2. However, dw/dt does not indicate the quantity of chips from which water is expelled. Therefore, dw/dt·G, the rate of expelled water per unit of chips, is used to describe the experimental results in comparable terms. G is the oven-dry weight of the chips in the pressure cell. Using dw/dt·G accounts for the effect of any difference in the oven-dry weight of the chips in the pressure cell.

The relationship between dw/dt·G and compression time for aspen chips is shown in Fig. 3. At 500 psi the drying rate does not exceed 0.1 grams per minute per gram of dry wood, and initially there is almost a constant rate. As 500 psi the drying rate decreases gradually between 1 and 3 minutes and after 3 minutes reaches a drying rate of only 0.01 grams water per minute per gram of dry wood.

The dw/dt·G versus compression time curves under 1,000 psi, 1,500 psi, and 2,000 psi, start at drying rates of 0.25 to 0.30 grams water per minute per gram of dry wood and decrease rapidly until from 1 to 4 minutes they are similar to the rate under 500 psi.

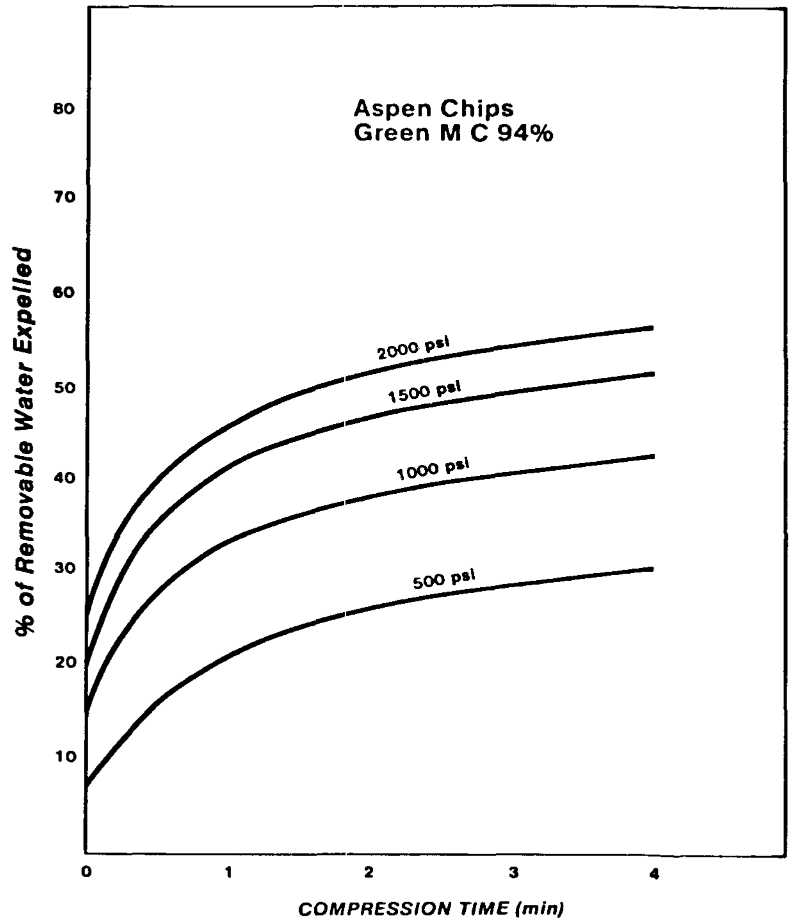

FIG. 6. Removable water expelled from aspen at four pressure levels.

Figure 4 shows the dw/dt·G versus time curves for red maple chips. Several basic differences can be seen from Fig. 3, aspen. Red maple is a higher density species, with an average green specific gravity of 0.49, as compared to 0.34 for aspen. In addition it has a lower green moisture content than the aspen chips, 73% versus 94%. As explained in Haygreen (1982), water extraction is affected both by wood specific gravity and green moisture content. The higher the specific gravity, the less wood compression is accomplished at a given ram-face pressure. Also, the higher the green moisture content, the greater the amount of water removed from a unit volume of chips as a result of a given degree of volumetric compression. Because of its higher specific gravity and lower green MC, very slow dewatering occurred in red maple until ram face pressure was increased to 2,000 psi. Essentially no drying was accomplished at 500 psi and even at 1,000 psi the drying rate was negligible, not exceeding 0.03 grams water per minute per gram of dry wood.

Figure 5 compares the dw/dt·G versus time curves of the 5 species at 2,000

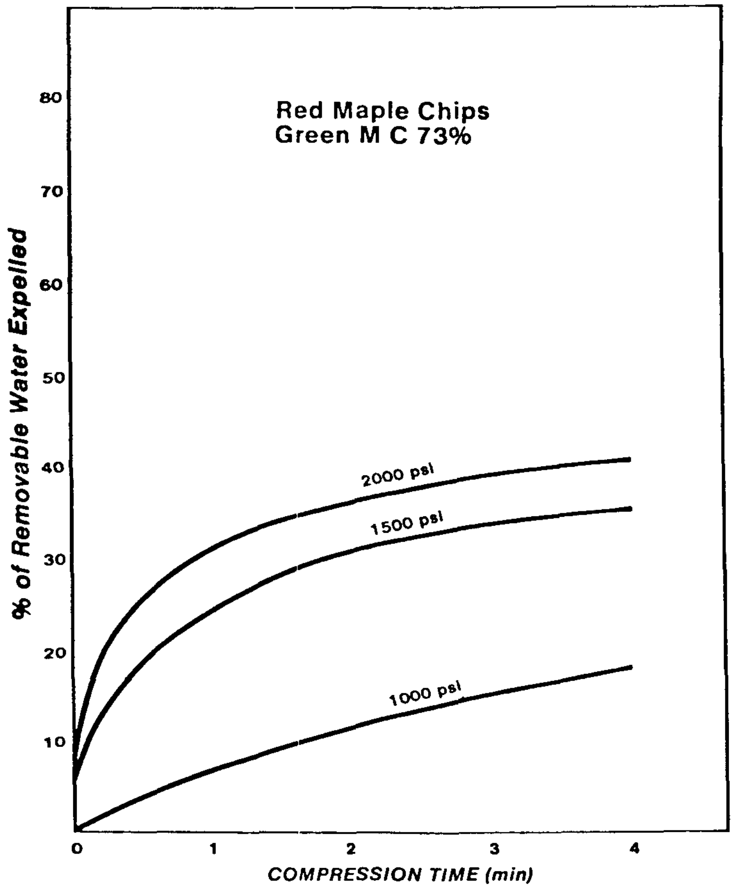

FIG. 7. Removable water expelled from red maple at three pressure levels.

psi constant pressure. The dw/dt·G versus time curves are very similar in shape during the first 30 seconds of drying. The two low density species, aspen and balsam fir, maintain a higher drying rate up to 4 minutes, however.

One of the main reasons for this similarity in drying curves is that much of the "removable water" is expelled during the first minute. Removable water could be defined as the free water, i.e., the difference between the green moisture content and the fiber saturation point (FSP). We assumed a FSP of 30% for all species. Figures 6 and 7 for aspen and red maple chips show the relationship between the percent of the removable water expelled and compression time. It is evident that the percentage of removable water expelled during the first minute is much higher than that during the following three minutes.

Figures 8 and 9 show the relationship between the rate of compression drying and the moisture content for aspen and red maple chips. Even at 2,000 psi ram face pressure, the rate of drying decreases very rapidly once the MC is reduced to between 70% and 60%. By the time the MC is reduced to 60%, the rate of drying is prohibitively slow. This suggests the value of increasing ram face pressure above 2,000 psi once the MC drops to about 70%.

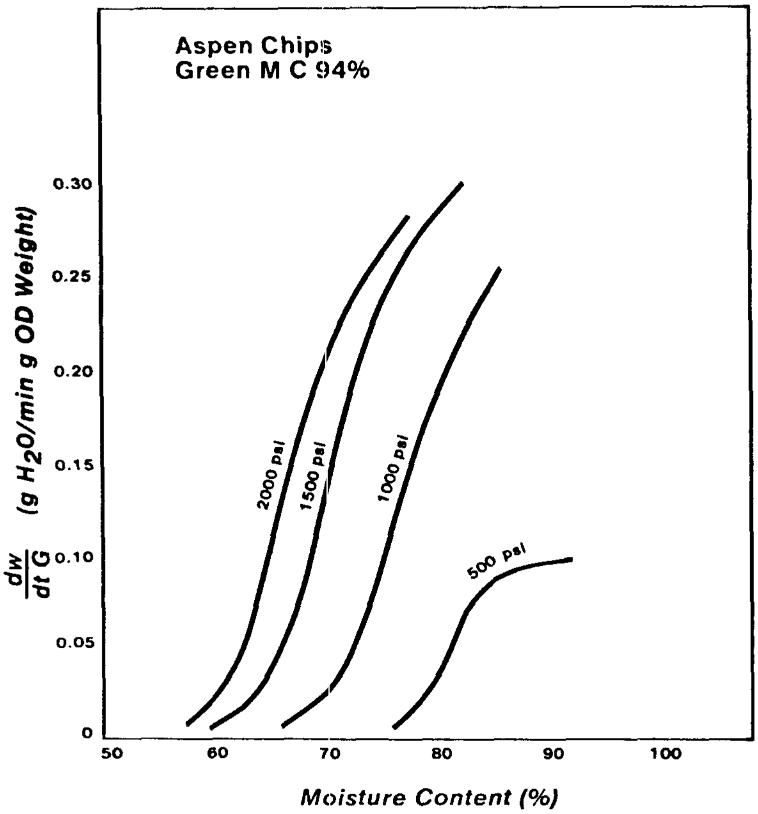

FIG. 8. Rate of compression drying as a function of moisture content for aspen.

The concept of declining drying rate is one of the important factors in dealing with compression drying, especially in designing dewatering pressure cycles. When the rate of compression drying can be kept high, the advantage of compression drying over thermal methods is evident. But when the rate of compression drying decreases to a low rate, certainly below 0.1 gram per minute per gram of dry wood, the process may no longer prove advantageous.

TABLE 1. *Mat density after 4 minutes of compression drying (OD grams per cc).*

Pressure (psi)	Size	Species and mat density				
		Balsam fir, green MC 175%	Aspen, green MC 98%	Jack pine, green MC 77%	Red maple, green MC 74%	Red oak, green MC 72%
500	Hammermilled	1.25	1.16	1.01	—	—
	Chips	1.16	1.03	0.95	—	—
1,000	Hammermilled	1.48	1.36	1.28	1.21	—
	Chips	1.38	1.29	1.20	1.10	—
1,500	Hammermilled	1.58	1.46	1.42	1.34	1.27
	Chips	1.51	1.40	1.37	1.23	1.24
2,000	Hammermilled	1.64	1.50	1.47	1.43	1.35
	Chips	1.57	1.46	1.44	1.36	1.33

TABLE 2. *Final MC (%) of the 120 test runs after 4 minutes of compression drying.*

Species	Size	Pressure (psi)	Replication 1	Replication 2	Replication 3
Aspen	Pulp	500	75.7	78.4	73.2
		1,000	67.1	67.3	64.6
		1,500	60.7	59.3	59.5
		2,000	56.5	58.1	56.3
	Hammermill	500	76.5	74.8	78.5
		1,000	66.3	64.8	66.3
		1,500	59.9	61.5	61.1
		2,000	56.4	55.8	55.3
Balsam fir	Pulp	800	89.0	92.9	91.6
		1,000	66.5	66.6	63.7
		1,500	57.4	57.7	59.5
		2,000	51.6	53.4	54.2
	Hammermill	500	82.9	88.0	85.0
		1,000	66.3	66.7	68.7
		1,500	59.3	61.4	60.5
		2,000	55.7	56.0	53.5
Jack pine	Pulp	500	70.1	71.9	66.0
		1,000	57.0	55.9	53.4
		1,500	52.2	51.9	50.0
		2,000	47.5	47.3	47.9
	Hammermill	500	67.6	65.3	67.2
		1,000	58.0	58.1	58.9
		1,500	56.0	56.2	55.2
		2,000	50.1	51.9	51.6
Red maple	Pulp	500	74.8	69.2	72.0
		1,000	65.9	66.3	66.3
		1,500	56.0	57.0	57.8
		2,000	56.7	53.3	55.5
	Hammermill	500	74.1	73.5	72.2
		1,000	67.3	65.7	65.7
		1,500	61.6	62.8	63.5
		2,000	57.4	57.5	57.8
Red oak	Pulp	500	71.8	69.8	70.0
		1,000	72.4	71.4	71.3
		1,500	59.0	63.4	62.9
		2,000	54.8	53.7	53.6
	Hammermill	500	71.4	70.7	70.1
		1,000	71.2	70.5	69.8
		1,500	58.8	58.4	58.8
		2,000	51.1	51.1	51.1

Figures 10 and 11 show the relationship between moisture content and time-dependence for aspen and red oak chips. The time-dependence of drying shown in this form may be most helpful in illustrating the joint effect of pressure and time. Such information can be used to design a drying cycle needed for a specific output moisture content.

Table 1 shows the compressed densities for hammermilled and pulp chips. The densities of hammermilled chips are consistently higher than those of pulp chips under the same circumstances.

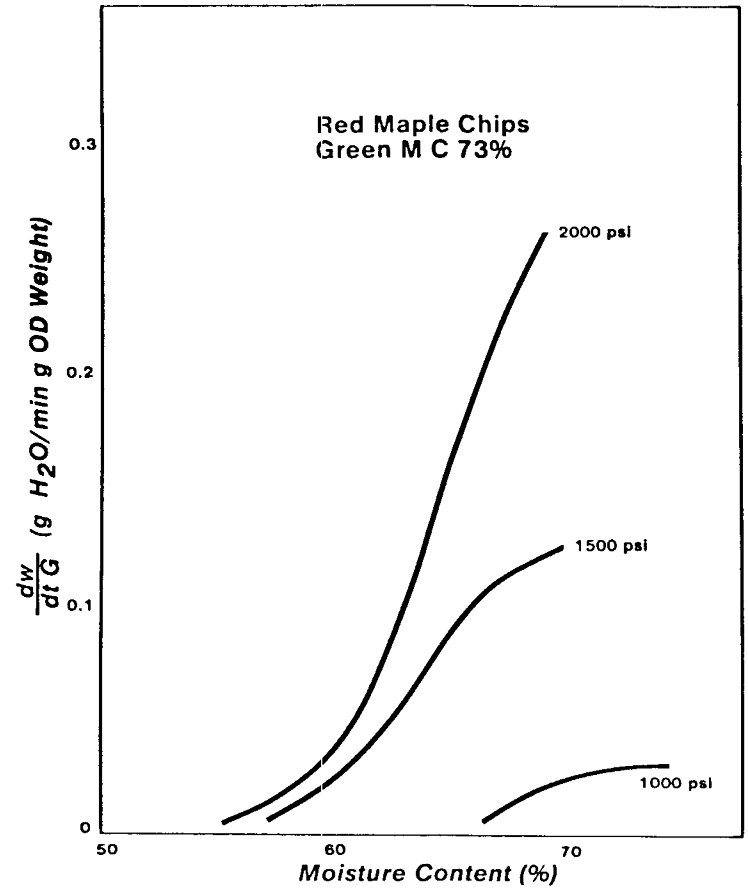

FIG. 9. Rate of compression drying as a function of moisture content for red maple.

Table 2 shows the final moisture contents of compression drying in the 120 test runs.

Table 3 shows the results of analysis of variance of final moisture contents in the 120 test runs. The analysis of variance for species shows highly significant differences in final moisture contents of compression drying. However, in further

TABLE 3. *Analysis of variance of final moisture content for species, size, and pressure.*

Source	Degrees of freedom	F value
Species	4	$F(4,10) = 133.9^{**}$
Size	1	$F(1,70) = 4.818^{*}$
Pressure	3	$F(3,70) = 1398^{**}$
Size and pressure	3	$F(3,70) = 7.485^{**}$
Species × size	4	$F(4,70) = 9.399^{**}$
Species × pressure	12	$F(12,70) = 54.21^{**}$
Species × pressure × size	12	$F(12,70) = 5.266^{**}$

* Significant ($0.01 < P < 0.005$).
** Highly significant ($P < 0.01$).

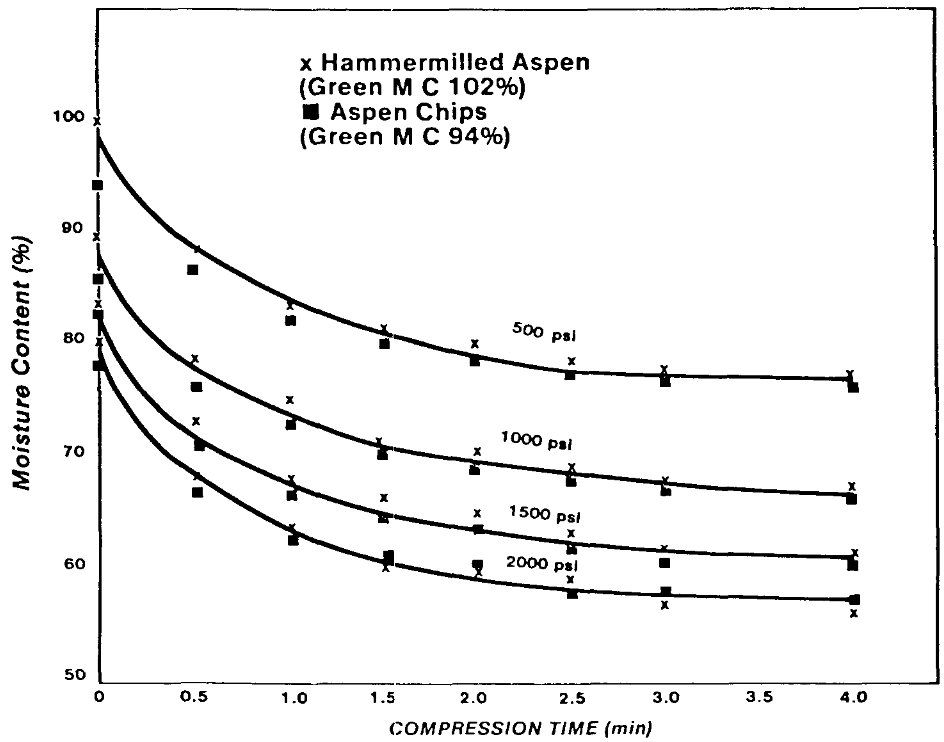

FIG. 10. MC vs. time for aspen chips and hammermilled particles at the four test pressures. Differences in MC at time zero is due to moisture expelled prior to obtaining desired pressure.

analysis using CONTRAST (Weisberg and Koehler 1981), it was shown that red maple and red oak were not significantly different in final moisture content (Table 4).

The analysis of variance for size shows significant differences in final moisture contents. Pressure also had a highly significant effect on final moisture contents. All the interactions among the three factors were highly significant.

CONCLUSIONS

1. The rate of water extraction is one of the important factors that must be considered in designing dewatering machines and operating a compression drying process.

TABLE 4. *Contrasts among species.*

Item of contrasts	Coefficients	F-value
Aspen and balsam fir vs. Red maple and red oak	1 1 0 −1 −1	F(1,10) = 45.61**
Red maple vs. red oak	0 0 0 1 −1	F(1,10) = 0.0649−
Aspen vs. red maple	1 0 0 −1 0	F(1,10) = 4.766*
Balsam fir vs. jack pine	0 1 −1 0 0	F(1,10) = 480.2**

* Significant ($0.01 < P < 0.05$).
** Highly significant ($P < 0.001$).
− Nonsignificant ($P > 0.05$).

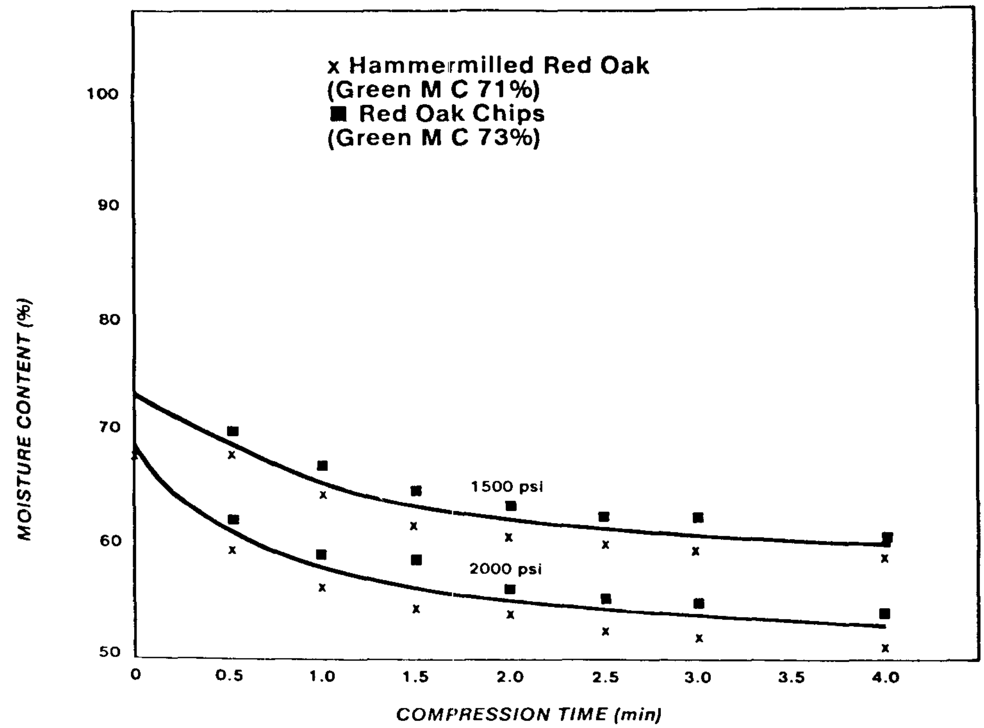

FIG. 11. MC vs. time for red oak at 1,500 and 2,000 psi.

2. The most efficient compression drying is achieved during the first two minutes. This includes approximately one minute required to bring the press to the intended pressure and one minute of constant pressure. About 90% of water removed is expelled during this period.

3. Drying rates are negligible after three to four minutes of constant pressure in the 500 to 2,000 psi ram face pressure range.

4. The analysis of variance for species shows highly significant differences in final moisture contents. However, red maple and red oak were not significantly different in contrast.

5. Size of chips had a significant effect on final moisture contents.

6. In the pressure range studied here, the higher the density of the wood chips, the less the compression that results from the process. Thus high density chips require higher pressure to initiate effective drying rates.

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