Seasoning

Bigleaf Maple Lumber

By Charles J. Kozlik

Report D-10
November 1967

Forest Research Laboratory
School of Forestry
OREGON STATE UNIVERSITY
Corvallis

PROGRAM AND PURPOSE

The Forest Research Laboratory of the School of Forestry combines a well-equipped laboratory with a staff of forest and wood scientists in a program designed to provide information that will help managers of forests and mills to improve the forest resource and promote full utilization of forest products. The extensive research done by the Laboratory is supported by the forest industry and by state and federal funds.

The current report results from studies in forest products, where wood scientists and technologists, chemists, and engineers are concerned with properties, processing, utilization, and marketing of wood and of timber by-products.

The PROGRAM of research includes

- identifying and developing chemicals from wood,
- improving pulping of wood and wood residues,
- investigating and improving manufacturing techniques,
- extending life of wood by treating,
- developing better methods of seasoning wood for higher quality and reduced costs,
- cooperating with forest scientists to determine effects of growing conditions on wood properties, and
- evaluating engineering properties of wood and wood-based materials and structures.

The PURPOSE of research on forest products is to expand markets, create new jobs, and bring more dollar returns, thus advancing the interests of forestry and forest industries, by

> developing products from residues and timber now wasted, and

> improving treatment and design of present wood products.

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SUMMARY

Tests were made on bigleaf maple lumber to study effects on drying time and degrade of various dry-bulb temperatures, conditions for EMC (equilibrium moisture content), equalizing and conditioning periods, and stickering.

Conditions were judged favorable if they led to reduction of drying time without excessive increase in degrade. On that basis, four-quarter bigleaf maple can be successfully kiln-dried in about 7 1/2 days by the following schedule:

1. Warm to 140 F in 4 hours, maintaining wet- and dry-bulb temperatures within 2-4 degrees F. Dry at 140 F at conditions for EMC of 12 percent for 24 hours.
2. Raise temperature to 150 F with conditions for EMC of 10 percent for 48 hours.
3. Dry for at least 15 hours at 170 F with conditions for EMC of 10 percent.
4. Dry for 9 hours at 170 F with conditions for EMC of 7 percent.
5. Equalize for 48 hours at 170 F with EMC conditions of 5 percent for an average final moisture content near 8 percent.
6. Condition for 12-14 hours at 180 F with conditions for EMC of 14 percent.

Sticker spacing of 15-18 inches, air velocity of 400-450 feet a minute, and fan reversal every 6 hours are recommended.

Two test charges of five-quarter lumber showed that it could be dried by the same schedule by extending the time in the third and fourth settings of the schedule.

ACKNOWLEDGMENT

On behalf of the Forest Research Laboratory, Oregon State University, grateful appreciation is extended to Don Jenkins Hardwoods, Inc., for donating the lumber studied.

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INTRODUCTION

To meet increasing demand for kiln-dried lumber of bigleaf maple, an increase in kiln-drying capacity would be desirable for most hardwood mills. The increase is possible by addition of dry kilns or by adjustment of kiln schedules for faster drying.

Installation of new kilns requires high capital investment; the use of faster kiln schedules may be more practical. Present kiln schedules for four-quarter, bigleaf maple may require as much as 8 days to dry to a final moisture content of 8 percent, and degrade is often excessive.

Schedules are proposed by Espenas[1] and Rasmussen,[2] but their schedules are based on moisture content. Most hardwood mills in the Northwest follow time schedules, and the development of a time schedule that will shorten kiln time, improve quality, and reduce unit cost of drying is needed.

EXPERIMENTAL PROCEDURE

In eight series of tests, 46 charges of four-quarter lumber were dried to develop a schedule. In a ninth series, four charges of four-quarter lumber were dried to study spacing of stickers. In a final series, two charges of five-quarter lumber were dried by the schedule developed for four-quarter lumber.

Lumber was not specially selected for this study and consisted of either No. 1 Shop and better or No. 2 Shop and better in individual charges. Lumber was collected freshly sawed and stored under water sprays at the laboratory. Generally, the volume of lumber in storage

[1] Espenas, L. D. The Seasoning of Oregon Hardwoods. Information Circular 6, Forest Research Laboratory, Oregon State University, Corvallis. 35 pp. 1951.

[2] Rasmussen, E. F. Dry Kiln Operator's Manual. Handbook 188, Forest Products Laboratory, U. S. Department of Agriculture, Madison, Wisc. 197 pp. 1961.

was only 3-4 charges. Pieces ranged in moisture content from 184 to 47 percent and in composition from complete sapwood to partial pith. Individual pieces varied in grain from very fine to coarse and ranged in width from 3 to 15 inches. Lumber was generally 8 feet long with about 5 percent of each charge consisting of 6- and 7-foot lengths. Volume dried in each charge was 400-500 board feet.

Defects in individual boards, such as checks, splits, or shakes, were marked before drying, so that seasoning degrade could be evaluated. Pieces containing tension wood and stained areas, similar to "red heart" in red alder, were noted to assess warpage, collapse, or areas of high final moisture content in the kiln-dried stock.

All charges were weighted to prevent excessive warping in the upper two or three layers. Although 420 pounds of weight was used, cupping and twisting were not completely eliminated.

<u>Development of schedules</u>

To develop dry-kiln schedules for lumber, two variables, dry-bulb temperature and conditions for EMC (equilibrium moisture content), must be closely studied. Other variables,[3] such as air velocity, fan reversal, and sticker spacing, are also important. Modern conventional dry kilns deliver ample volumes of air and most installations have means for fan reversal, so these two variables were not studied. Only three spacings for stickers were studied, because sticker spacing is usually prescribed by the type of stacking operation and location of bunks on the kiln trucks. A charge with stickers spaced at 15-inch intervals and a charge with stickers spaced at 18-inch intervals were each matched with a charge on stickers spaced at 24-inch intervals.

Before the drying cycle was started for each charge, 4-5 hours were taken to heat the kiln structure and lumber to wet-bulb temperature. During this period, the wet- and dry-bulb temperatures were maintained as closely alike as possible, with only 2-4 degrees F difference. Total kiln time in Tables 1 through 7, 10, and 11 includes the warming-up period and from 2 to 5 hours for periodic weighings of kiln samples.

After the kiln and lumber had heated to proper wet-bulb temperature, each step of the schedule was developed in turn by studying variables separately for their effect on total drying time, degrade, and loss of clear cuttings. In steps following a phase under study, dry-bulb and

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[3] Kozlik, C. J. Seasoning Red Alder. Rpt D-6, Forest Research Laboratory, Oregon State University, Corvallis. 20 pp. 1962.

wet-bulb temperatures were based on moisture content of the lumber, as recommended by Rasmussen.[4]

The effect of dry-bulb temperature with constant conditions for EMC was studied in series 1. Temperatures of 130 F, 150 F, and 170 F were held for about 92 hours while the wet-bulb temperature was set to provide an EMC of 14 percent.

The effect of initial conditions for EMC with constant dry-bulb temperature was studied in series 2. The conditions were for EMC of 10, 12, or 14 percent; dry-bulb temperatures were 130 F and 140 F.

The time required at initial dry- and wet-bulb temperatures before changing to a second setting was tested in series 3.

Series 4 through 7 were studied to determine subsequent dry- and wet-bulb temperature settings for different time periods to produce near- optimum conditions during the drying cycle.

The validity of the proposed laboratory schedule was verified by the charges of series 8. Two charges in series 10 extended the findings to five-quarter lumber, with the third and fourth steps of the schedule lengthened but with the same temperatures.

Throughout the entire schedule-testing procedure, the effects of various conditions for EMC during several different lengths of time were tested to ensure uniformity of final moisture content (equalization) and adequate relief of drying stresses (conditioning).

Methods of measurement

While unseasoned lumber for each charge was being stacked, six representative boards were selected as kiln samples to furnish data on moisture content during drying. The kiln samples generally consisted of three boards of sapwood and three boards of heartwood. The kiln samples were weighed periodically during each run, and, at the end of each run, small cross sections of the kiln samples were tested for moisture content by the oven-drying method. One additional section was cut from each kiln sample to test for drying stresses. The average and range of final moisture content were determined with an electrical resistance moisture meter at a depth of one-half the board thickness on all pieces in each charge. The means of the moisture meter readings were in close agreement with the means for final moisture content of the kiln samples.

Primary evaluation of all charges was based on total kiln time, percentage loss of clear-cutting area, and degrade. After lumber was

[4] Dry Kiln Operator's Manual, pp. 117-128.

dried and surfaced, it was graded twice to determine degrade in accordance with rules of the National Hardwood Lumber Association for bigleaf maple. The first grading disregarded seasoning defects, but the second grading took them into account. The comparison of the two gradings gave an indication of the seasoning degrade.

Percentage loss of clear-cutting area was determined as follows: Each board was measured in square inches for total clear-cutting area, disregarding seasoning defects, and measured again when seasoning defects were considered. The areas measured were converted into percentage loss of clear-cutting area by the following formula:

$$\frac{(Ng - Nd)}{Ng} \times 100 = \text{percentage loss of clear-cutting area,}$$

where Ng = total square inches in clear cuts disregarding seasoning defects

and Nd = total square inches in clear cuts considering seasoning defects.

Secondary evaluation of each charge was based on uniformity of final moisture content and relief of drying stresses.

RESULTS AND DISCUSSION

Results for test conditions on four-quarter lumber are summarized by series in Tables 1-9. Results are detailed in Table 10. The complete lists of dry-bulb temperature, conditions for EMC, time at test conditions, and requirements for equalization and conditioning are not shown in the tables; only the testing phases of the schedule and steps of the recommended schedule that were pretested are shown. Following the testing phase, the remaining portion of the schedule, based on moisture content of the kiln samples, was controlled at dry-bulb temperatures and conditions for EMC as recommended by Rasmussen.[5]

General results for five-quarter lumber are given in Table 11.

Initial dry-bulb temperature, series 1

Drying time increased with lower initial dry-bulb temperatures, but a difference of only 20 hours existed between the high temperature

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[5] Dry Kiln Operator's Manual.

Table 1. Relations of Initial Dry-Bulb Temperature to Drying Time, Loss of Clear Cuttings, and Degrade.

Charge	Total kiln time	Test conditions: Dry-bulb temperature	Kiln time	Clear cuts lost	Degrade: Pieces	Grades
	Hours	Deg F	Hours	Percent		
1A	261	170	94	3.4	0	---
1B	270	150	92	1.7	0	---
1C	281	130	93	1.0	2	2 to out
					1	2 to 3

170 F, and the low temperature, 130 F (Table 1). The loss of clear-cutting area at 170 F was 3.4 percent--considerably higher than for the charges dried at 130 and 150 F. Although no boards were degraded at 170 and 150 F, three boards in the charge were degraded at 130 F.

With the higher percentage loss of clear cuttings at 170 F, initial dry-bulb temperatures of 130 and 140 F were used to study the effect of initial conditions for EMC.

Initial conditions for EMC, series 2

Total kiln time was longer at conditions for EMC of 14 percent than at 10 and 12 percent (Table 2).

Degrade of individual pieces was about the same for all charges in series 2, except charge 2B, which had no degrade. The loss of clear-cutting area in the charges dried at conditions for EMC of 10 percent was higher than at 12 or 14 percent. The charges dried at conditions for EMC of 10 percent exhibited end-checking and checks passing through the knots into clear wood. These checks were 3/4-1 1/2 inches long, which increased the loss of clear-cutting area.

Charges 2AAAAA and 2BBBB were dried at 140 F and at conditions for EMC of 10 and 12 percent. These charges did not lose more clear-cutting area than the matched charges dried at 130 F. In addition, the difference in loss of clear-cutting area between charge 1B at 150 F dry-bulb temperature and charge 1C at 130 F dry-bulb temperature, as shown in Table 1, was not excessive.

Initial conditions of 140 F dry-bulb temperature and wet-bulb temperature for EMC of 12 percent were, therefore, most favorable because of reduced total kiln time from 130 F at conditions for EMC of 14 percent.

Table 2. Relations of Conditions for EMC to Drying Time, Loss of Clear Cuttings, and Degrade.

Charge	Total kiln time	Test conditions: Dry-bulb temp	Test conditions: EMC conditions	Test conditions: Kiln time	Test conditions: MC after test	Clear cuts lost	Degrade: Pieces	Degrade: Grades
	Hours	Deg F	Percent	Hours	Percent	Percent		
2A	297	130	10	139	12.8	2.5	0	---
2AA	201	130	10	92	16.5	1.9	1	2 to out
2AAA	251	130	10	139	12.2	1.9	3	1 to 2
2AAAA	238	130	10	137	13.2	2.6	1	Sel to 1
							3	Sel to 2
							2	1 to 2
							1	2 to 3
2AAAAA	228	140	10	114	14.1	1.7	2	Sel to 2
							5	1 to 2
2B	293	130	12	156	15.9	1.2	0	---
2BB	232	130	12	113	15.5	1.2	1	1 to 2
							1	2 to 3
							1	2 to out
2BBB	327	130	12	136	17.3	1.0	2	Sel to 2
							2	1 to 2
							2	2 to 3
2BBBB	227	140	12	89	20.9	0.9	3	1 to 2
							2	2 to 3
2C	255	130	14	120	16.6	1.9	1	1 to out
							1	1 to 2
							1	2 to 3
2CC	320	130	14	160	18.6	1.0	1	1 to out
							2	2 to out
2CCC	345	130	14	132	15.7	1.1	1	Sel to 1
							1	1 to 2
							3	2 to 3

Time at the first step in the schedule, series 3

The 24-hour initial period of 140 F dry-bulb temperature at conditions for EMC of 12 percent appeared most favorable because total time in kiln was short and loss of clear-cutting area was low (Table 3).

The low percentage of clear-cutting area lost for charges in series 3, compared with previous charges, was ascribed to the high grade of lumber used in this part of the study. The grades were No. 1

Table 3. Effects of Changing Initial Drying Conditions after 12, 24, and 48 Hours for Series 3.

Charge	Total kiln time	Test conditions		Clear cuts lost	Degrade	
		Kiln time	MC after test		Pieces	Grades
	Hours	Hours	Percent	Percent		
3A	252	48	30.7	0.2	None	---
3AA	264	48	34.4	0.3	None	---
3B	222	24	52.1	0.3	None	---
3BB	236	24	51.8	0.3	1	Sel to 1
					2	1 to 2
3C	235	12	72.0	0.8	None	---

Table 4. Effect of Conditions for EMC of 10 Percent during the Second Step.

Charge	Total kiln time	Test conditions			Clear cuts lost	Degrade	
		Dry-bulb temp	Kiln time	MC after test		Pieces	Grades
	Hours	Deg F	Hours	Percent	Percent		
Comparing 140 F with 150 F							
4A	199	150	65	13.6	0.8	1	2 to 3
4B	274	140	113	12.2	0.7	1	2 to 3
4C	197	150	24	13.2	0.6	2	2 to out
Comparing time at 150 F							
5A	217	150	48	18.3	1.2	1	1 to 2
						1	2 to 3
						1	2 to out
						2	3 to out
5AA	180	150	48	22.1	0.4	1	Sel to 1
						1	1 to 2
						1	2 to 3
5B	219	150	72	16.1	1.1	1	Sel to 1
						1	2 to 3
						1	2 to out
5BB	228	150	72	13.7	0.4	1	1 to 2
5C	198	150	24	28.5	2.0	2	1 to 2
						2	2 to 3
5CC	175	150	24	31.6	3.0	0	---

and No. 2 Shop in most charges, but lumber in series 3 had about 60 percent Selects.

The highest percentage loss of clear-cutting area was in charge 3C, which was dried only 12 hours at 140 F with conditions for EMC of 12 percent. This loss was mostly confined to small hairline end-checking. Other charges that were dried for 24 and 48 hours at the test conditions had very low loss in clear-cutting area. The only degrade occurring was in charge 3BB and this was confined to end splits diverging from a straight line.

Total kiln time was longest for charges 3A and 3AA, which were dried at the initial conditions for 48 hours.

Establishing the second step in the schedule, series 4 and 5

The second step in the recommended schedule would include dry-bulb temperature of 150 F at conditions for EMC of 10 percent, because total time was less but degrade no greater than at 140 F (Table 4). Optimum time at 150 F was 48 hours.

Charge 4B was the control, for which a temperature of 140 F at conditions for EMC of 10 percent was maintained for a prolonged period. For charges 4A and 4C, a temperature of 150 F was used to increase the drying rate and determine whether or not additional degrade would occur. The degrade and percentage loss of clear-cutting area were similar for all charges in series 4.

Total drying times increased with increased kiln time at the test condition. Degrade was similar for all test charges except charge 5AA, but percentage loss of clear-cutting area was highest for charges 5C and 5CC, which held the second setting in the schedule for only 24 hours. Considerable hairline end-checking and checking in knot areas occurred in charges 5C and 5CC.

Establishing the third step in the schedule, series 6

If charge 6A is excluded from consideration, the most favorable results for the third step were achieved by drying at 170 F with conditions for EMC of 10 percent for at least 15 hours (Table 5).

Total kiln time generally decreased with shorter time in test condition. Loss of clear-cutting area was nearly the same for all charges in series 6 and degrade was highest in charges 6A and 6E, for which test conditions were maintained for longest time (36 hours) and shortest (12 hours). The moisture content of sample boards in each charge was least with long drying times in the testing phase of the schedule. During the first 24 hours of drying charge 6A, however, the kiln was out of control with temperatures of 150 F and conditions for

Table 5. Comparing Conditions for EMC of 10 Percent during the Third Step.

Charge	Total kiln time	Test conditions		Clear cuts lost	Degrade	
		Kiln time	MC after test		Pieces	Grades
	Hours	Hours	Percent	Percent		
6A	184	36	15.3	0.9	1	Sel to 1
					2	1 to 2
					1	1 to 3
					1	2 to 3
6B	184	24	16.3	0.8	2	3 to out
6C	177	18	16.5	0.6	3	Sel to 1
					1	1 to 2
6D	150	15	17.5	0.6	2	1 to 3
6E	165	12	21.7	1.0	1	Sel to 1
					3	1 to 2
					2	2 to 3
					1	2 to out

EMC of 10 percent, which probably accounts for the higher degrade and loss of clear-cutting area. Charge 6A had considerable hairline end-checking and checking around large knots. The remaining charges in series 6 did not show this checking pattern except charge 6E which had some checking around large knots.

Establishing the fourth step in the schedule, series 7

A fourth step of changing EMC to conditions of 7 percent while holding the dry-bulb temperature at 170 F appeared warranted, because total time in the kiln was lengthened only 10 hours by the fourth step and loss of clear-cutting area was held to two-thirds of the loss that occurred when the fourth step was omitted (Table 6).

Need for a fourth step in the test schedule was studied by comparing alternatives: by going directly to an equalization period after drying at 170 F with conditions for EMC of 10 percent, or by adding a fourth step at 170 F at conditions for EMC of 7 percent for 9-24 hours.

This testing of the schedule was introduced because the moisture contents at the end of the test condition of 170 F at conditions for EMC of 10 percent for 15 hours or more ranged from 15.3 to 17.5 percent, as shown in Table 5. At these lower moisture contents, going directly to conditions for EMC of 5 percent for equalizing did not seem likely to worsen the degrade.

Table 6. Data on Test of Need for a Fourth Step in the Recommended Schedule before Equalizing.

Charge	Total kiln time	Test conditions: Dry-bulb temp	Test conditions: EMC	Test conditions: Kiln time	Test conditions: MC after test	Clear cuts lost	Degrade: Pieces	Degrade: Grades
	Hours	Deg F	Percent	Hours	Percent	Percent		
7A	169	170	10	24	13.4	1.2	2	1 to 2
		170	7	24	8.3		1	1 to 3
		Equalize					1	1 to out
							2	2 to 3
							2	2 to out
							1	3 to out
7AA	195	170	10	24	13.0	1.6	8	1 to 2
		170	7	24	8.6		2	1 to out
		Equalize					1	2 to out
							1	3 to out
7B	165	170	10	14	16.5	1.2	4	1 to out
		170	7	9	9.9		1	2 to out
		Equalize					1	2 to out
							1	3 to out
7BB	148	170	10	12	15.4	1.2	1	Sel to 1
		170	7	11	10.4		3	1 to 2
		Equalize					1	3 to out
7C	175	170	10	27	15.2	1.8	1	Sel to 1
		Equalize					4	1 to 2
							1	1 to out
							1	2 to out
							1	3 to out
7D	148	170	10	15	17.2	2.4	2	1 to 2
		Equalize					4	1 to 3
							1	1 to out
							1	2 to 3
							2	3 to out
7DD	162	170	10	14	13.6	1.8	1	Sel to 1
		Equalize					5	1 to 2
							1	1 to out
7E	151	170	10	12	18.8	1.2	1	Sel to 1
		Equalize					2	1 to 2
							3	2 to 3
							1	3 to out
7EE	158	170	10	11	16.9	2.0	1	Sel to 1
		Equalize					1	Sel to 2
							5	1 to 2
							2	1 to out
							3	2 to 3
							2	3 to out

Increased loss of clear-cutting area in charges without the fourth step was hard to explain, because the stress pattern at this stage of drying should not cause additional degrade when extreme changes are made in the drying conditions. End-checking was not more evident in either group of charges but there appeared to be larger checks forming in areas of knots or distorted grain in charges 7C through 7EE. Moisture content averaged slightly higher for charges 7C through 7EE at the start of equalizing, but the loss of clear-cutting area was low at 1.2 percent in charge 7E, which had a high average moisture content of 18.8 percent.

Verifying need for the fourth step in the schedule, series 8

To verify need for a fourth step in the schedule, three matched charges were dried: for 8A the drying time was extended at 170 F with EMC conditions of 10 and 7 percent; for 8B the proposed schedule was followed; for 8C the fourth step was not included. The results are shown in Table 10 (APPENDIX), which includes total kiln time, dry-bulb temperature and conditions for EMC, average and range of initial and final moisture content, loss of clear-cutting area and degrade.

Total kiln time was 187 hours for the control charge and 148 hours for the two test charges. The final moisture content averaged slightly higher in the control charge; in the two test charges the range was greater, as shown in Table 10.

Under conditions of the modified laboratory schedule, nine boards were degraded in the control charge 8A, 10 boards in test charge 8B, and 11 boards in test charge 8C. Loss of clear-cutting area was lowest in charge 8B at 0.3 percent, increased to 1.1 percent in the control charge 8A, and was highest at 1.5 percent in charge 8C.

For total kiln time, test charges 8B and 8C were most favorable. For loss of clear-cutting area, the recommended schedule followed with charge 8B was more satisfactory than that with charges 8A and 8C.

Equalizing

Results showed that, with the proposed schedule, equalization of at least 48 hours at 170 F with conditions for EMC of 5 percent would produce a fairly uniform average final moisture content near 8 percent.

Following the drying stages of all charges in this study, an equalization period was introduced with conditions for EMC of 5 percent at 170 F for various periods. The average moisture content before and after equalization and the range in final moisture content were noted to evaluate time required for equalization (Table 7).

Table 7. Results of Various Conditions for Equalization.

Charge	Equalization time	Average MC before equalizing[1]	Final moisture content[2]		
			High	Low	Average
	Hours	Percent	Percent	Percent	Percent
6D	19	7.9	12.0	8.0	9.4
2AA	24	8.2	10.0	7.0	8.3
6C	24	8.8	9.5	7.0	8.1
2C	48	7.8	9.5	7.0	7.9
4B	48	10.1	9.5	7.5	8.7
5BB	50	7.8	8.5	7.0	7.5
6B	48	11.0	10.5	7.0	8.0
7B	61	9.9	10.6	7.0	8.0
7C	60	15.2	9.5	7.0	8.4
7DD	60	13.6	10.5	7.0	7.9

[1] Moisture content based on kiln sample boards.

[2] Moisture content based on moisture meter readings on all boards after drying.

The length of the equalization period depends upon the average moisture content before equalizing, average final moisture content, and the uniformity desired. Although the average moisture content in charge 6D was 7.9 percent before equalizing, 19 hours were not sufficient to reduce the final average moisture to 8.0 percent, and uniformity of final moisture content was not satisfactory. When average moisture content before equalizing ranged from 7.8 to 9.9 percent, equalizing periods of 24-60 hours were sufficient to produce uniformity of final moisture content, as shown by charges 2AA, 6C, 2C, 5BB, and 7B (Table 7).

As the average moisture content before equalizing increases, the required kiln time increases. In charges 4B and 6B, the moisture content before equalizing averaged 10.1 and 11.0. With a 48-hour equalization period, the uniformity of final moisture content was very good and the average final moisture content was within prescribed limits. When the moisture content before equalizing was 13.6-15.2 percent, as in charges 7C and 7DD, additional equalizing time was required to produce uniformity.

Conditioning

Case-hardening stresses were relieved most favorably by conditioning for 12 hours at 180 F with wet-bulb temperature set for EMC of 14 percent--when moisture content after equalizing averaged near 6 percent (Table 8).

Conditioning is required to relieve case-hardening stresses for all stock that is to be remanufactured and depends upon moisture content before conditioning, temperature, conditions for EMC, and time.

By observing prong samples from each charge, the relief of case-hardening stresses was visually rated as excellent (no case-hardening stresses present), good (slight appearances of stresses), fair (presence of moderate stresses), or poor (presence of severe stresses).

The average moisture content before conditioning was about 6 percent for all charges except 6A, which averaged 8.6 percent. With average moisture contents nearly the same, this variable would not be expected to require consideration in studying effects on the conditioning period. Conditioning time and conditions for EMC are so closely related that effects are difficult to isolate.

In charges 5B, 7B, and 6D, the conditioning time was 4, 6, and 9 hours. Charges 5B and 7B had nearly the same conditions for EMC, 14-15 percent, but charge 6D had conditions for EMC of 19 percent. Stress relief was poor in charges 5B and 7B but was excellent in charge 6D. Conditions for EMC of 19 percent for at least 9 hours, therefore, will relieve case-hardening stresses when the average moisture content before conditioning is about 6 percent. The requirements for such conditions, however, are impractical in a commercial dry kiln.

Table 8. Results of Conditioning at 180 F Dry-Bulb Temperature.

Charge	Conditioning time	Average MC before conditioning	EMC conditions	Stress relief
	Hours	Percent	Percent	
5B	4	5.8	14	Poor
6B	13	6.7	10	Fair
7B	6	6.1	15	Fair
6A	12	8.6	12	Good
2B	10	5.5	16	Excellent
2BBBB	13	6.0	14	Excellent
5C	12	6.2	14	Excellent
6D	9	5.9	19	Excellent

Extended conditioning periods at conditions for low EMC will produce stress-free lumber. This combination was tested in charges 2B, 2BBBB, and 5C. Conditioning time was 10-13 hours at temperatures for EMC of 14-16 percent. In all three charges, relief of casehardening stresses was excellent when the moisture content before conditioning averaged about 6 percent.

Thirteen hours of conditioning at conditions for EMC of 10 percent gave only fair relief of stresses in charge 6B. Although the time was similar to that for charge 2BBBB where the results were excellent, 10 percent for EMC was not moist enough to condition the lumber properly.

A comparison of results of conditioning for charges 6A and 5C, both conditioned for 12 hours at similar conditions for EMC, illustrates the importance of moisture content before conditioning on effectiveness of conditioning. Moisture content of charge 6A averaged 8.6 percent and that of charge 5C only 6.2 percent. Relief of stresses for 6A was good, but for 5C was excellent.

Stickering, series 9

The charge stickered on 15-inch spacing had 28 percent less degrade from warping than the matched charge stickered on 2-foot spacing. The charge stickered on 18-inch spacing had 16 percent less degrade from warping than the matched charge stickered on 2-foot spacing. The greatest degrade occurred with waviness the full length of the board in the charges with 2-foot sticker spacing. Cup, bow, and twist were lessened by 15- and 18-inch sticker spacing. Other forms of warping, such as crook, were not decreased by narrow sticker spacing.

Five-quarter lumber, series 10

Of the five-quarter lumber, charge 10A, dried in 205 hours, had no boards degraded, only 0.4 percent loss of clear-cutting area, and excellent uniformity of final moisture content. Charge 10B, dried in 181 hours, had five boards degraded, 1.1 percent loss of clear-cutting area, and increased range in final moisture content. The two test charges showed that, by extending the time in the third and fourth steps, the recommended schedule would be satisfactory for five-quarter lumber.

CONCLUSIONS

Four-quarter bigleaf maple can be successfully kiln-dried in about 7 1/2 days. Total kiln time is equivalent to, or less than, present commercial practices and loss by degrade is low. The schedule developed (Table 9) is suited for use in modern, conventional, steam-heated dry kilns where good practices are followed.

Recommendation of the schedule assumes an air velocity on the leaving-air side of 400 feet a minute or higher, with fans reversed every 6 hours or less. Sticker spacing of 15-18 inches is recommended to reduce degrade by warping.

Five-quarter lumber can be dried successfully with the recommended schedule by extending the third and fourth settings of the schedule to at least 30 hours at 170 F with conditions for EMC of 10 percent and to 35 hours at 170 F with conditions for EMC of 7 percent.

Table 9. Recommended Schedule for Drying Four-Quarter Bigleaf Maple Lumber in Modern, Efficient Kilns.[1]

Temperature		EMC	
Dry-bulb	Wet-bulb	conditions	Time
Deg F	Deg F	Percent	Hours
Warming to 140 F in 4 hours, maintaining wet- and dry-bulb temperatures within 2-4 degrees F.			
140	130	12.0	24
150	136	10.0	48
170	157	10.0	15
170	146	7.0	9
170	135	5.0	48
180	174	13.7	12

[1] After warming to 140 F in 4 hours, with wet- and dry-bulb temperatures held within 2-4 degrees F of each other.

Table 10. Drying Conditions and Results for Four-Quarter Bigleaf Maple Lumber.

Charge	Total kiln time	Dry-bulb temp	Test conditions		Moisture content				Clear cuts lost	Degrade	
					Initial		Final				
			EMC	Time	Range	Avg	Range	Avg		Pieces	Grades
	Hours	Deg F	Percent	Hours	Percent	Percent	Percent	Percent	Percent		
1A	261	170	14	94	61-166	114	8.0-12.0	9.2	3.4	0	---
1B	270	150	14	92	68-105	83	8.0-11.5	9.4	1.7	0	---
1C	281	130	14	93	80-132	97	8.0-11.0	9.1	1.0	2	2 to out
										1	2 to 3
2A	297	130	10	139	60-111	91	7.0-10.0	9.4	2.5	0	---
2AA	201	130	10	92	61-118	92	7.0-10.0	8.3	1.9	1	2 to out
2AAA	251	130	10	139	80-112	94	7.5-10.0	8.9	1.9	3	1 to 2
2AAAA	238	130	10	137	90-120	106	8.0-10.5	9.1	2.6	3	Sel to 2
										1	Sel to 1
										2	1 to 2
										1	2 to 3
2AAAAA	228	140	10	114	143-163	153	8.5-10.0	9.3	1.7	2	Sel to 2
										5	1 to 2
2B	293	130	12	156	76-126	106	7.0-10.0	8.4	1.2	0	---
2BB	232	130	12	113	62-110	88	7.5-11.0	9.9	1.2	1	1 to 2
										1	2 to 3
										1	2 to out
2BBB	327	130	12	136	82-133	102	7.0-9.0	7.9	1.0	2	Sel to 2
										2	1 to 2
										2	2 to 3
2BBBB	227	140	12	89	110-158	137	8.5-10.5	9.4	0.9	3	1 to 2
										2	2 to 3

[illegible]	[illegible]	150	14	120	101-151	118	7.0-9.5	7.9	1.9	1	1 to 2
										1	1 to out
										1	2 to 3
2CC	320	130	14	160	47-160	100	7.5-10.5	8.7	1.0	1	1 to out
										2	2 to out
2CCC	345	130	14	132	84-136	116	7.0-9.5	8.3	1.1	1	Sel to 1
										1	1 to 2
										3	2 to 3
3A	252	140	12	48	96-138	108	7.5-11.0	8.7	0.2	0	---
3AA	264	140	12	48	123-168	142	7.5-10.0	8.6	0.3	0	---
3B	222	140	12	24	96-135	108	7.5-11.0	8.6	0.3	0	---
3BB	236	140	12	24	100-127	119	8.0-10.0	8.8	0.3	1	Sel to 1
										2	1 to 2
3C	235	140	12	12	97-152	122	7.5-10.0	7.9	0.8	0	---
4A	199	140	12	24	92-124	108	7.0-9.5	8.1	0.8	1	2 to 3
		150	10	65							
4B	274	140	12	24	97-132	121	7.5-9.5	8.7	0.7	1	2 to 3
		140	10	113							
4C	197	140	12	24	100-139	123	7.0-9.5	8.4	0.6	2	2 to out
		150	10	24							
5A	217	140	12	24	68-138	93	7.0-9.5	8.2	1.2	1	1 to 2
		150	10	48						1	2 to 3
										1	2 to out
										2	3 to out
5AA	180	140	12	24	73-170	115	7.0-10.5	8.0	0.4	1	Sel to 1
		150	10	48						1	1 to 2
										1	2 to 3
5B	219	140	12	24	84-116	95	7.5-10.5	8.6	1.1	1	Sel to 1
		150	10	72						1	2 to 3
										1	2 to out
5BB	228	140	12	24	81-152	117	7.0-8.5	7.5	0.4	1	1 to 2
		150	10	72							

Table 10. (Continued)

Charge	Total kiln time	Dry-bulb temp	Test conditions		Moisture content				Clear cuts lost	Degrade	
			EMC	Time	Initial Range	Initial Avg	Final Range	Final Avg		Pieces	Grades
	Hours	Deg F	Percent	Hours	Percent	Percent	Percent	Percent	Percent		
5C	198	140	12	24	62-105	86	7.5-10.5	9.1	2.0	2	1 to 2
		150	10	24						2	2 to 3
5CC	175	140	12	24	70-159	92	7.0-11.0	8.0	3.0	0	---
		150	10	24							
6A	184	140	12	24	85-184	119	7.0-9.5	8.1	0.9	1	Sel to 1
		150	10	48						2	1 to 2
		170	10	36						1	1 to 3
										1	2 to 3
6B	184	140	12	24	64-155	104	7.0-10.5	8.0	0.8	2	3 to out
		150	10	48							
		170	10	24							
6C	177	140	12	24	58-138	96	7.0-9.5	8.1	0.6	3	Sel to 1
		150	10	48						1	1 to 2
		170	10	18							
6D	150	140	12	24	60-130	104	8.0-12.0	9.4	0.6	2	1 to 3
		150	10	49							
		170	10	15							
6E	165	140	12	24	62-168	109	7.0-9.5	8.3	1.0	1	Sel to 1
		150	10	48						3	1 to 2
		170	10	12						2	2 to 3
										1	2 to out
7A	169	140	12	24	66-148	116	8.0-12.0	9.2	1.2	2	1 to 2
		150	10	48						1	1 to 3
		170	10	24						1	1 to out
		170	7	24						2	2 to 3

										2	2 to out
										1	3 to out
7AA	195	140	12	24	70-123	101	7.0-10.5	8.0	1.6	8	1 to 2
		150	10	48						2	1 to out
		170	10	24						1	2 to out
		170	7	24						1	3 to out
7B	165	140	12	24	84-152	114	7.0-10.5	8.0	1.2	4	1 to 2
		150	10	48						1	2 to 3
		170	10	14						1	2 to out
		170	7	9						1	3 to out
7BB	148	140	12	24	91-146	132	7.0-10.5	7.8	1.2	1	Sel to 1
		150	10	48						3	1 to 2
		170	10	12						1	3 to out
		170	7	11							
7C	175	140	12	24	61-138	106	7.0-9.5	8.4	1.8	1	Sel to 1
		150	10	48						4	1 to 2
		170	10	27						1	1 to out
										1	2 to out
										1	3 to out
7D	148	140	12	24	90-139	126	7.0-10.5	7.8	2.4	2	1 to 2
		150	10	48						4	1 to 3
		170	10	15						1	1 to out
										1	2 to 3
										2	3 to out
7DD	162	140	12	24	75-112	92	7.0-10.5	7.9	1.8	1	Sel to 1
		150	10	48						5	1 to 2
		170	10	14						1	1 to out
7E	151	140	12	24	56-125	86	7.0-9.5	8.5	1.2	1	Sel to 1
		150	10	48						2	1 to 2
		170	10	12						3	2 to 3
										1	3 to out

Table 10. (Continued)

Charge	Total kiln time	Dry-bulb temp	Test conditions		Moisture content				Clear cuts lost	Degrade	
					Initial		Final				
			EMC	Time	Range	Avg	Range	Avg		Pieces	Grades
	Hours	Deg F	Percent	Hours	Percent	Percent	Percent	Percent	Percent		
7EE	158	140	12	24	88-159	126	7.0-9.0	7.9	2.0	1	Sel to 1
		150	10	48						1	Sel to 2
		170	10	11						5	1 to 2
										2	1 to out
										3	2 to 3
										2	3 to out
8A	187	140	12	24	56-106	81	7.0-9.0	8.0	1.1	2	Sel to 1
		150	10	48						4	1 to 2
		170	10	24						1	1 to 3
		170	7	48						2	2 to 3
8B	148	140	12	24	80-140	108	7.0-10.5	7.6	0.3	1	Sel to 1
		150	10	48						2	Sel to 2
		170	10	15						1	Sel to 3
		170	7	9						4	1 to 2
										1	2 to 3
										1	2 to out
8C	148	140	12	24	86-123	104	7.0-10.5	7.7	1.5	1	Sel to 1
		150	10	48						7	1 to 2
		170	10	15						1	1 to out
										2	2 to 3

Table 11. Drying Conditions and Results for Five-Quarter Bigleaf Maple Lumber.

Charge	Total kiln time	Dry-bulb temp	Testing condition		Moisture content				Clear cuts lost	Degrade	
					Initial		Final				
			EMC	Time	Range	Avg	Range	Avg		Pieces	Grades
	Hours	Deg F	Percent	Hours	Percent	Percent	Percent	Percent	Percent		
10A	205	140	12	24	71-119	90	7.0-9.5	7.8	0.4	0	---
		150	10	49							
		170	10	32							
		170	7	39							
10B	181	140	12	24	83-160	113	8.0-11.0	9.1	1.1	4	1 to 2
		150	10	49						1	2 to out
		170	10	25							
		170	7	29							

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