METHOD FOR ESTIMATING AIR-DRYING TIMES OF LUMBER

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ABSTRACT

Published information on estimated air-drying times of lumber is of limited usefulness because it is restricted to a specific location or to the time of year the lumber is stacked for drying. At best, these estimates give a wide range of possible times over a broad range of possible locations and stacking dates. In this paper, we describe a method for estimating air-drying times for specific locations by optimizing a drying simulation using existing experimental air-drying times for northern red oak, sugar maple, American beech, yellow-poplar, ponderosa pine, and Douglas-fir. The results of the optimization are simulation parameters that make it possible to estimate the air-drying times of these species regardless of when they are stacked, in any location where average temperature and relative humidity are known, and for lumber of any thickness dried to any final moisture content.

Estimating the time required to air-dry lumber is not an easy task because of the many variables involved. Drying time depends on both species and thickness. In general, low density species dry faster than do higher density species. Estimation becomes more complicated when the influence of weather is considered. Even at a given location, temperature and relative humidity (RH), which have major effects on the drying rate, vary from year to year. The best we can do to characterize any location is to consider weather conditions that represent the average of many years of meteorological data. In addition to the effect of summer-winter temperature differences, estimates of air-drying time are affected by the time of year when the lumber is stacked. Lumber stacked in the spring may dry in a relatively short time because a large portion of the drying may be in the warm spring and summer months. In contrast, lumber stacked for air-drying in late summer or early fall may take a relatively long time to dry because it will be exposed to winter temperatures, when drying may almost stop.

Some air-drying installations may have records of past experience that are useful for drying time estimates. However, it is likely that some installations have incomplete records that are limited in data on species, thickness, and stacking date. Newer installations, or planners for new installations, may have no records to help in facility and production planning.

The objective of our study was to develop a method for estimating air-drying times from experimental air-drying data for lumber of certain species stacked at different times of the year in locations where data on the monthly average temperature, RH, and wind speed are available. The ultimate objective is to generalize the method so that it can be applied to other locations with weather data and to lumber that is stacked at any time of theyear.

BACKGROUND

Rietz and Page (21) tabulated approximate air-drying times to 20 percent moisture content (MC) for nominal 1-inch- (standard 19-mm-) thick hardwood and softwood species. Presumably because of the lack of data, these values are only ranges of time estimates. The authors state that the minimum air-drying times listed are for lumber stacked for drying in southern locations in the spring or early summer, and the maximum times are for lumber stacked in northern locations in the fall or early winter. For example, the time range for air-drying northern red oak is 70 to 200 days; the width of this range limits its usefulness for air-drying in specific locations.

Rietz (20) improved these estimates by developing an air-drying map that divides the eastern United States into five zones. The boundaries of the zones are based on the average cumulative “growing degree days” developed by the U.S. Department of Agriculture (26). The five

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zones are based on estimates of the length of good air-drying conditions, ranging from 12 months in the south to 4 months in the north. Rietz also presented his estimates in terms of an effective air-drying calendar for the Upper Midwest. For example, he estimated 5 "effective air-drying days" in December, January, and February, with gradually increasing numbers of effective days (up to 30 days) in June through August. McMillen and Wengert (8) tabulated air-drying times to 20 percent MC for most nominal 1- and 2-inch- (standard 19- and 38-mm-) thick lumber of hardwood species dried in the South, Mid-South, Central, and Mid-North. These estimates are given in terms of ranges that depend on the time of the year the lumber is stacked.

The Tennessee Valley Authority published an air-drying guide (25) applicable to the Tennessee Valley. Charts presented in this guide show estimated air-drying times to 20 percent MC for nominal 1- and 2-inch- (standard 19- and 38-mm-) thick lumber stacked on the 5th, 15th, and 25th days of each month. However, because the charts purportedly represent all hardwood species, they are likely to be inaccurate for some individual species.

Denig (1) and Denig and Wengert (2) developed a method for estimating air-drying times for red oak and yellow-poplar. Air-drying samples were exposed to the environmental conditions of three commercial air-drying yards over a 5-month period. The daily rate of moisture loss was then related to meteorological variables obtained from a regional weather station. That result was developed into regression equations for each species that estimate daily MC loss from initial MC, temperature, and RH data.

APPROACH TO DRYING TIME ESTIMATION

EXPERIMENTAL DATABASE

Six previous air-drying studies provided the experimental data necessary to develop the estimation method. Four of these studies were conducted by Edward Peck of the Forest Products Laboratory, USDA Forest Service: northern red oak (Madison, Wisconsin [16]), sugar maple (Upper Michigan [15]), American beech (Philadelphia, Pennsylvania [14]), and ponderosa pine (Flagstaff, Arizona [18]). Denig (1) and Denig and Wengert (2) studied yellow-poplar in Roanoke, Virginia. Johnson and Gibbons (5) studied Douglas-fir in the Seattle-Tacoma area of Washington, and their data were further analyzed by Peck (17).

In the studies by Peck (14-16,18), the lumber was stacked four times during the year (each season) and the air-drying time to 20 percent lumber MC was noted. In the study by Johnson and Gibbons (5) the lumber was stacked five times during the year. It is difficult to determine the air-drying times from the information presented in that report. Peck, who apparently had access to more detailed information, tabulated the five experimental air-drying times (17). The yellow-poplar data were for lumber stacked at the beginning of each month and dried to final MCs ranging from 15 to 23 percent, depending on the month of stacking (1,2). These data were the results of a regression equation, not the actual experimental data.

All of these air-drying studies were conducted at commercial air-drying facilities. Temperature and RH were either recorded or taken from weather records.

Several points merit special note. In regard to the ponderosa pine study, Peck (18) did not list the actual experimental air-drying times. Instead, he used estimation and interpolation to tabulate air-drying times for stacking dates of all 12 months of the year. By Peck's own admission, these time estimates "are subject to large errors." More detailed results were found in Peck's progress reports (10-13), including the four actual experimental air-drying times. Those times were used as the experimental base for our analysis.

The drying times from the studies by Johnson and Gibbons (5) and Peck (14-16,18) apply only to the five locations studied. The major objective of our study was to expand these data to any location where weather data are available. The results of Denig (1) and Denig and Wengert (2) can be expanded to other locations through the regression equations of these authors.

ANALYTICAL METHODS

GENERAL DESCRIPTION

The computer drying simulation developed by Hart (3) offers a method for expanding the air-drying time estimates in the experimental database to other locations, as well as an interpolation method for the months when no lumber had been stacked in these experiments. The general nature of the method for expanding the estimates is to determine simulation parameters from the experimental data and apply them in the simulation using weather data for other locations.

Resch et al. (19) applied Hart's drying simulation to Douglas-fir lumber and concluded that it is an excellent tool for use in lumber drying research and improvements in kiln schedules. Simpson et al. (24) used this simulation to place the kiln-drying time of five kiln runs on a common basis for better comparison between them than could the times provided by raw data.

A detailed description of how the complete drying simulation works is beyond the scope of this paper. The simulation was described in detail by Hart (3). However, Hart continued to refine the simulation after publishing that report, and the version used for our work differs from the original publication. Although Hart's refinements were not published, they are available on the Internet. The executable FORTAN computer program and a user's manual are available at www.fpi.fs.fed.us/documents/programs/dds/dds.htm.

The simulation involves adjusting computer program input coefficients until the simulation calculates a drying time that closely approximates the observed experimental drying time. One of these coefficients is the apparent diffusion coefficient *D*, which is defined in the program as corresponding to some base temperature. Because diffusion of water through wood is highly temperature dependent, the simulation requires adjustment of *D* as drying temperature changes. This adjustment is in proportion to the saturated vapor pressure of water, and the adjustment can be further refined through a coefficient designated by Hart as relative activation energy (RAE). The adjustment can be increased by setting RAE to greater than 1 and decreased by setting it to less than 1. Other input variables to the simulation are board thickness and width, initial temperature of the lumber, dry- and wet-bulb temperatures, air velocity, and initial MC.

The dry- and wet-bulb temperatures can be entered in two ways: 1) as MC-controlled schedules (dry- and wet-bulb temperatures are changed as lumber MC decreases); and 2) as time-based kiln schedules (dry- and wet-bulb temperatures are changed at predetermined times regardless of MC). For this study, the dry- and wet-bulb temperatures were changed every 15 days for northern red oak, sugar maple, and American beech, and, because of anticipated faster drying, every 5 days for yellow-poplar, ponderosa pine, and Douglas-fir. The weather data were generally taken as monthly averages and then linearly interpolated to 5- and 15-day increments. Shorter time increments could have been chosen and might have resulted in finer tuned estimates, but the level of computer time required would have become excessive and probably not justifiable given the "approximate" accuracy of the estimates. For input to the simulation, wet-bulb temperatures were calculated from RH and dry-bulb temperature by using the method of Lily (6).

The selection of air velocity in the simulation was somewhat of a problem. Wind speed data were available, but direct use of those values did not seem justifiable because it is unlikely that the air flow through the lumber stacks would be that high. The amount of air flow depends on yard orientation and other local disturbances that lower the air velocity to less than that in an open and free space. Therefore, the air velocity in the simulation was, perhaps somewhat arbitrarily, taken as 25 percent of the meteorologically reported wind speed. As it turned out, the differences in estimated air-drying times using full wind speed differed by only 1 or 2 days from the times estimated using 25 percent of full wind speed. Denig and Wengert (2) also found that meteorologically reported wind speed had only a minor effect on air-drying time.

Another issue was the validity of applying diffusion analysis to moisture movement above the fiber saturation point, as the simulation does. During lumber drying, water moves by two mechanisms: capillary flow above the fiber saturation point and diffusion below the fiber saturation point. Therefore, it may seem invalid to apply diffusion analysis to characterize drying that also includes water movement by capillary flow. However, there are legitimate reasons for estimating drying times of wood from above the fiber saturation point with a diffusion-based analysis. One rationale is to accept the mathematics of diffusion at face value, which

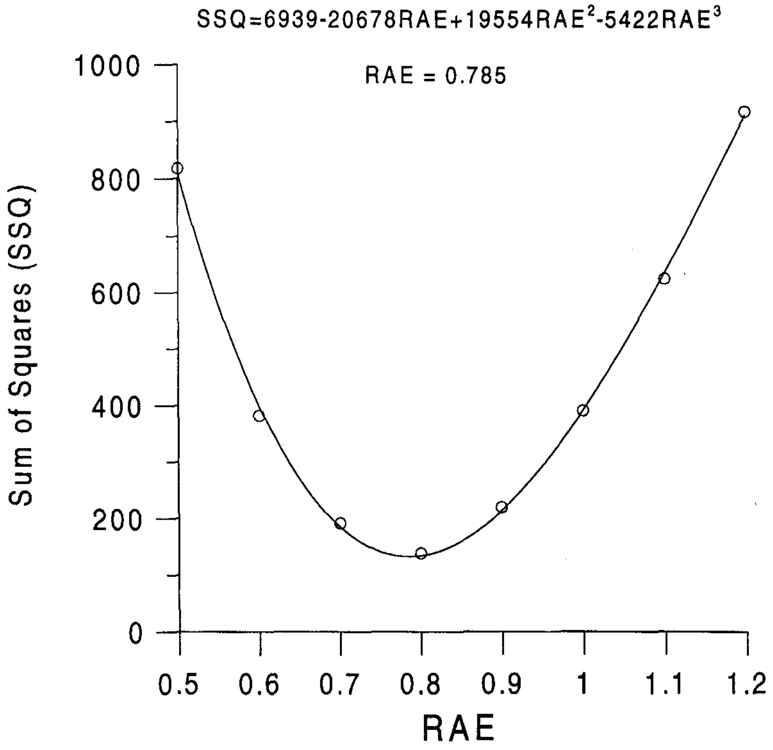

Figure 1.-Example graph of sum of squared deviations between experimental and simulated air-drying times vs. RAE for determining optimum value of RAE for one particular value of diffusion coefficient *D*.

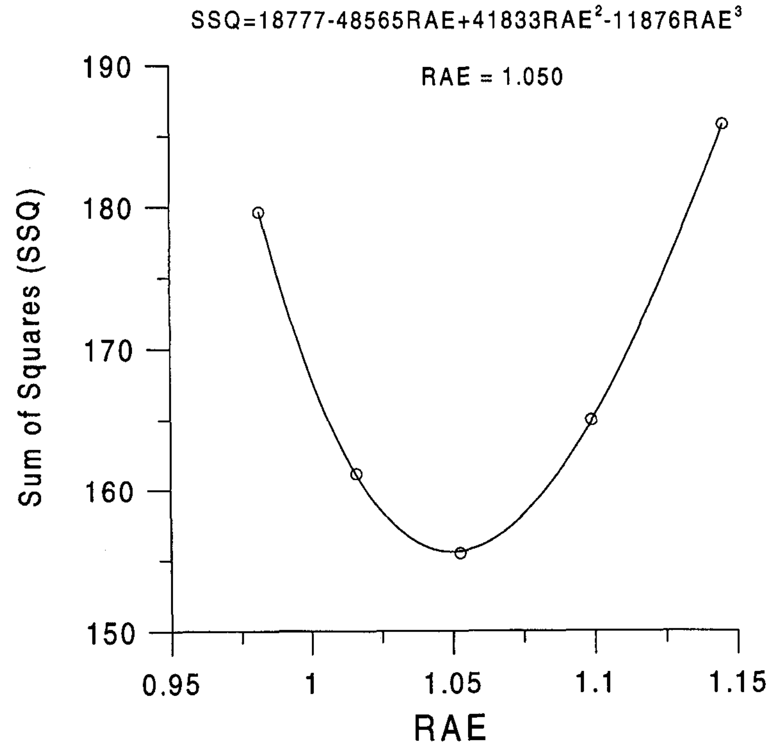

Figure 2.- Example graph of sum of squared deviations between experimental and simulated air-drying times vs. RAE for determining optimum value of RAE at optimum value of *D*.

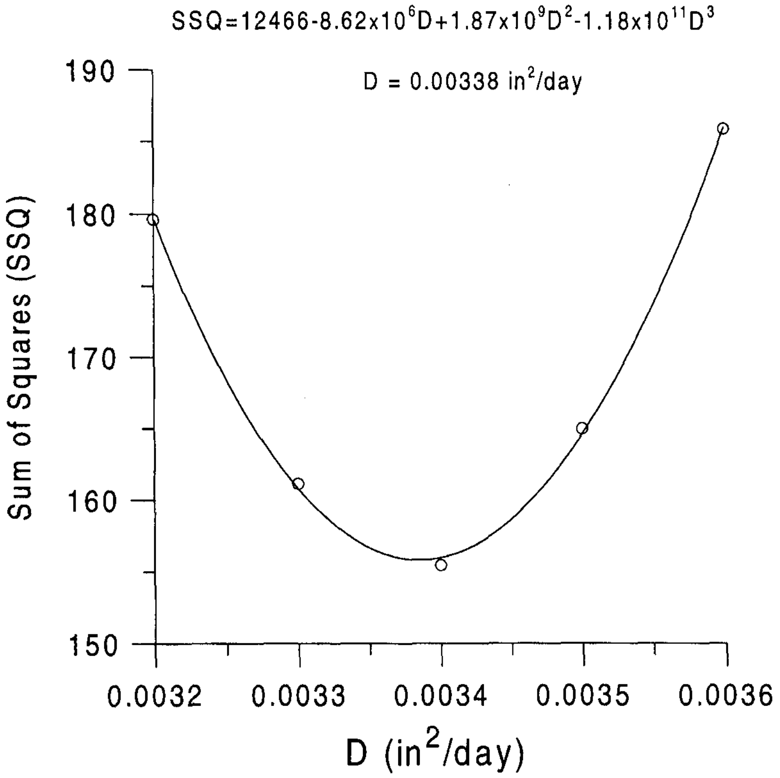

Figure 3.- Example graph of sum of squared deviations between experimental and simulated air-drying times vs. *D* for determining optimum value of *D* at optimum value of RAE.

merely requires the assumption that drying rate is proportional to the moisture gradient. No assumptions are made of the mechanism of drying, and a more correct term would be an internal moisture transfer coefficient instead of a diffusion coefficient. Another rationale is that drying may be controlled by, and therefore can be characterized by, diffusion through surface fibers that are below the fiber saturation point rather than by capillary movement in the interior where MC is above the fiber saturation point. As early as 1940, Hougen and others (4) stated that diffusion analysis is successful for calculating the average MC of wood at any time during drying from above the fiber saturation point, but that it cannot accurately calculate MC gradients. This issue is discussed further in Simpson and Liu (23).

ADAPTATION OF HART SIMULATION FOR AIR-DRYING ANALYSIS

Another question was how to apply the simulation to arrive at a method to estimate air-drying times for the six study species stacked on any day of the year at any location where temperature, RH, and wind speed data are available. To make the simulated drying times agree with the experimental drying times, it was necessary to determine the values of *D* and RAE that would result in agreement. Because these values are not known, a logical approach was to determine them by least squares analysis. The basic strategy was to find the best combination of *D* and RAE for each study species. To extract the most from the data sets, the best combination was judged to be that which minimized the sum of the squared deviations between the experimental drying times (4 drying times for northern red oak, sugar maple, ponderosa pine; 5 for Douglas-fir; 12 for yellow-poplar) and the corresponding calculated simulation drying times. The following procedure was applied to each species.

The first step was to select a reasonable value for *D*. Next, the simulation was run for a series of RAE values. *D* was defined to apply at 50°F (10°C) to represent the approximate midpoint of the range of air-drying temperatures. The sum of the squared deviations was plotted against the RAE values **(Fig. 1).** The optimum value of RAE for this selected trial *D* value occurred where the sum of squared deviations was a minimum value. The minimum was determined by fitting the curve with a third-degree polynomial, differentiating the polynomial, and solving for the value of RAE at the minimum. The simulation was then run with this trial *D* value and the optimized RAE value, and a new sum of squared deviations was calculated and saved for further use. The result was the best RAE for this particular trial value of *D*.

At this point, we did not know whether the value of *D* we had selected was the best value for minimizing the sum of the squared deviations. To determine the best value, we selected several additional *D* values and for each value repeated the previously described procedure. This resulted in a series of *D* values, each with its own optimized value of RAE, and a series of sum of squared deviations. The next step was to make two graphs: one graph showing the sum of squared deviations vs. RAE **(Fig. 2)** and the other showing the sum of squared deviations vs. *D* **(Fig. 3).** For each graph, we used the previously described procedure to find the RAE and *D* value where the sum of squared deviations was minimum. The end result was the optimized combination of *D* and RAE for each species.

Several other inputs to the simulation were required. None of the references for the air-drying experiments stated actual lumber thickness, only the nominal dimensions of 4/4 and 6/4 lumber.[1] Board width was taken as 6 inches (152 mm). Stickers were assumed to be 0.75 inch (19 mm) thick.

COMPARISON OF EXPERIMENTAL AND SIMULATED DRYING TIMES

The optimized values of *D* and RAE are shown in **Table 1. Table 2** compares experimental and simulated air-drying times to 20 percent MC, except for yellow-poplar, whose final MC depended

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[1] For lumber, 4/4, 5/4, and 6/4 designate nominal thicknesses of 1, 11/4, 11/2, and 2 inches. Actual thicknesses were assumed to be as tabulated in Lunstrum (7): 1.16 inches (29 mm) for 4/4 hardwoods; 1.00 inch (25 mm) for 4/4 western softwoods; and 1.688 inches (43 mm) for 6/4 western softwoods.

on stacking date **(Table 3).** MC of green lumber was 77 percent for northern red oak, 67 percent for sugar maple, 56 percent for American beech, 80 percent for yellow-poplar, 135 percent for ponderosa pine, and 36 percent for Douglas-fir.

Whether the agreement between experimental and simulation air-drying times is good or bad is not clear-cut. Some data were exact to the day and others within a few days, but some data differed markedly. The largest deviation was Douglas-fir, with an error of 17 days (35 vs. 52 days). An important factor to consider in judging the estimates is the slow approach to final MC. During this slow approach, a small change in MC takes a relatively long time. For example, American beech stacked in Philadelphia on February 8 was estimated by the simulation to reach 20 percent MC in 76 days **(Table 2).** However, the estimated air-drying times to 19 and 21 percent MC were 81 and 72 days, respectively. A 2 percent range of final MC over this 9-day period does not seem to have large practical significance. It does not seem very important if lumber MC is 19, 20, or 21 percent at the end of some stated time period.

One way to characterize the agreement is the percentage of difference between experimental and simulated air-drying times. These values are 4.3 percent for northern red oak, 8.7 percent for sugar maple, 12.6 percent for American beech, 14.7 percent for yellow-poplar (although the "experimental" times were from a regression), 22.2 percent for Douglas-fir, and 24.1 percent for ponderosa pine. Thus, the overall agreement was within 15 percent, which does seem close enough to consider this method a useful tool for estimating air-drying times.

EXTENSION OF SIMULATIONS TO OTHER LOCATIONS

One of the main objectives of our study was to develop a method to estimate the air-drying time of the six study species at any location and stacked at any time of the year. We were able to do this with the *D* and RAE values in **Table 1** and historic weather data for any location. An example for northern red oak is shown in **Table 4.** In this example, the thickness of the lumber is nominal 4/4 inches (actual 1.125 inches, standard 19

TABLE I. - Optimized values for diffusion coefficient D and relative activation energy RAE. [a]

Species	in.^{2}/day × 10^{-3}	m^2/s × 10^{-11}	RAE
Northern red oak	2.93	2.18	0.780
American beech	3.38	2.52	1.050
Sugar maple	5.83	4.35	0.860
Yellow-poplar	10.02	7.61	1.421
Ponderosa pine	39.39	29.40	1.509
Douglas-fir	1.85	1.38	3.245

[a] *D* is defined at 50°F (10°C); it is reported in units of square inches per day as required by the simulation.

TABLE 2. - Comparison of simulated and experimental air-drying times to 20 percent MC for various species and locations. [a]

								Drying time	
Species and size	Location[b]	Ref.	Stack date	Dry-bulb	RH	Wet-bulb	Air velocity	Exp./int.	Simulation
				(°F)	(%)	(°F)	(ft./min.)	------- (days)	-------
Northern red oak 414	Madison	16	Jan. 19	20.4	73.8	18.5	231	115	125
			May 15	59.3	67.4	53.2	215	65	66
			July 28	72.1	70.7	65.5	178	72	69
			Oct. 22	44.4	70.9	40.4	220	188	183
Sugar maple 4/4	Upper Michigan	15	Jan. 20	13.4	82.0	12.4	250	94	110
			May 20	55.0	72.5	50.3	233	39	39
			July 15	64.3	73.6	59.0	207	42	31
			Oct. 28	38.0	78.5	35.5	257	170	160
American beech 4/4	Philadelphia	14	Feb. 8	32.7	63.4	28.9	239	68	76
			May 1	60.3	62.6	53.1	216	33	38
			Aug. 1	75.8	67.3	67.9	177	35	28
			Nov. 5	48.1	67.2	43.1	209	112	108
Ponderosa pine 614	Flagstaff	10-13, 17-18	Jan. 20	26.0	59.7	22.5	145	58	57
			May 28	53.5	37.1	42.5	156	10	16
			July 1	63.0	50.5	52.9	136	26	17
			Oct. 15	46.0	46.0	38.1	128	38	38
Douglas-fir 414	Seattle-Tacoma	5, 17	Jan. 17	40.3	78.8	37.6	210	90	96
			Mar. 17	43.3	60.2	37.9	211	35	52
			June 8	59.1	57.0	51.0	192	27	17
			Aug. 7	61.2	62.1	53.8	180	18	16

[a] Temperature and RH values are for the date halfway between listed stacking dates and represent average conditions during that drying period. Comparison was made by least squares optimization of Hart's computer drying simulation (3); $T_C = [T_F - 32]/1.8$; 1 ft./min. = 5.08 × 10^{-3} m/s.

[b] Madison, Wisconsin; Amara, Michigan; Philadelphia, Pennsylvania; Flagstaff, Arizona; Seattle-Tacoma, Washington.

mm) and the width 6 inches (152 mm). Initial MC is 80 percent, which is typical for northern red oak. The location is Asheville, North Carolina, and the temperature, RH, and air velocity are 30-year average data from the National Climate Data Center, National Oceanic and Atmospheric Administration (9). Stacking dates are the 1st and 15th days of each month. A more concise and inclusive way to show drying time estimates is graphically, as in **Figure 4** for nominal

TABLE 3. — Comparison of simulated air-drying times to various final MCs with data from air-drying 4/4 yellow-poplar in Roanoke, Virginia.[a]

Stacking date	M_f	Dry-bulb	RH	Wet-bulb	Air velocity (ft./min,)	Drying time Regression	 Simulation
						- - - - - - (days)	- - - - - -
Jan. 1	19	35.5	61.9	31.2	203	70	56
Feb. 1	19	36.6	60.0	32.0	210	40	44
Mar. 1	18	44.5	59.2	38.8	218	30	33
Apr. 1	16	53.4	59.0	46.5	214	20	27
May 1	17	62.0	64.7	55.1	182	20	20
Jun. 1	16	69.7	67.7	62.6	155	20	17
Jul. 1	15	74.6	69.2	67.3	145	20	17
Aug. 1	17	74.9	71.0	68.1	137	20	15
Sep. 1	19	69.5	72.7	63.6	133	20	18
Oct. 1	19	59.3	69.3	53.6	146	30	26
Nov. 1	21	49.8	65.0	44.3	173	30	35
Dec. 1	23	40.6	63.3	35.9	189	40	45

[a] Temperature and RH values are for the date halfway between listed stacking dates and represent average conditions during that drying period. Simulated data were derived by least squares optimization of Hart's computer drying simulation (3). Experimental drying times were derived from Denig's regression analysis (1). M_f = final MCs.

TABLE 4. - Estimated air-drying times of nominal 1-inch- (standard 19-mm-) thick northern red oak to various MCs in Asheville, North Carolina, using 30-year average weather data.[a]

Stacking date	Dry-bulb (°F)	RH (%)	Wet-bulb (°F)	Air velocity (ft./min.)	Drying time to various MCs 30%	 25%	 20%
					- - - - - - - - (days)	- - - - - - - -	- - - - - - - -
Jan. 1	36.7	72.0	33.5	207	74	91	114
Jan. 15	36.5	71.3	33.2	211	69	84	107
Feb. 1	38.0	69.8	34.4	210	63	78	101
Feb. 15	40.9	69.0	36.9	208	58	72	95
Mar. 1	45.3	69.0	40.9	206	53	67	89
Mar. 15	49.4	68.5	44.5	202	49	62	84
Apr. 1	53.3	67.5	47.9	195	45	58	80
Apr. 15	57.2	68.9	51.6	183	42	55	76
May 1	61.1	72.7	55.9	165	40	52	73
May 15	64.6	75.2	59.6	150	38	50	71
June 1	67.8	76.4	62.8	138	36	48	70
June. 15	70.3	77.5	65.4	131	35	47	70
July 1	72.0	78.5	67.2	129	35	47	71
July 15	72.6	79.3	68.0	126	35	48	74
Aug. 1	72.2	79.8	67.7	121	37	51	76
Aug. 15	70.6	80.0	66.2	121	39	54	82
Sep. 1	67.7	80.0	63.5	124	43	59	91
Sep. 15	63.7	78.8	59.5	131	47	66	105
Oct. 1	58.5	76.3	54.2	142	53	76	119
Oct. 15	53.8	74.3	49.5	156	60	87	126
Nov. 1	49.6	72.8	45.4	172	69	94	126
Nov. 15	45.5	72.0	41.5	184	75	98	128
Dec. 1	41.5	72.0	37.9	192	77	98	125
Dec. 15	38.6	72.0	35.2	200	77	95	120

[a] Temperature and RH values are for the date halfway between listed dates and represent average conditions during drying (9).

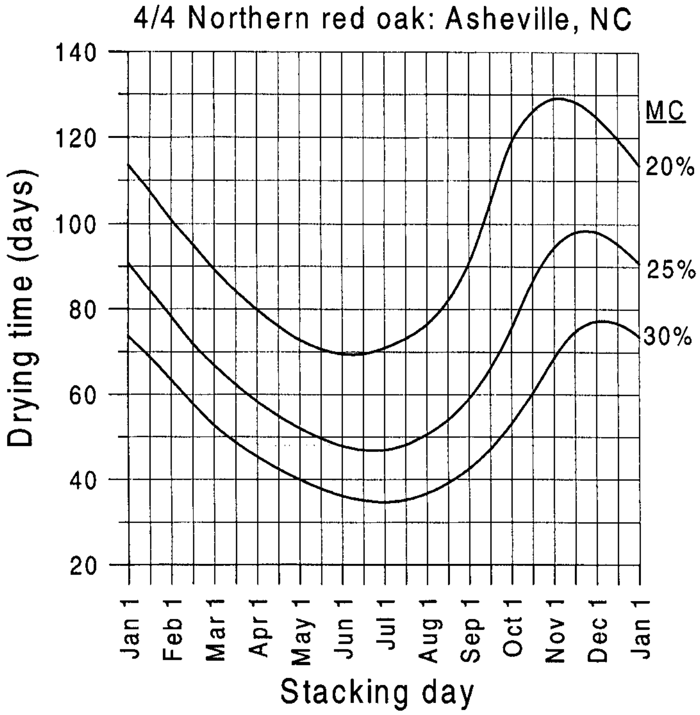

Figure 4. - Estimated air-drying times for 4/4 (nominal 1-inch- [standard 19-mm-] thick) northern red oak lumber to 30, 25, and 20 percent MC in Asheville, North Carolina, using 30-year average weather data (9).

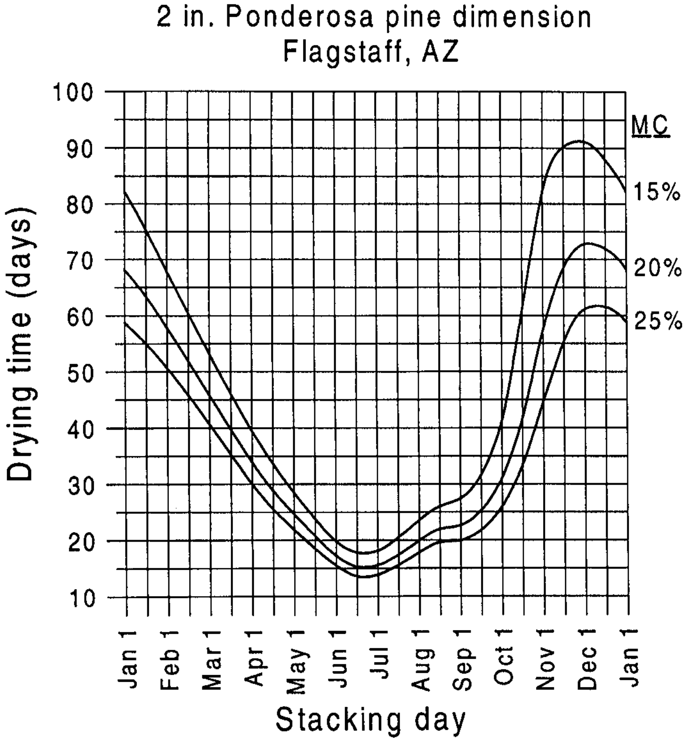

Figure 5. - Estimated air-drying times for nominal 2-inch- (standard 38-mm-) thick ponderosa pine dimension lumber to 25, 20, and 15 percent MC in Flagstaff, Arizona, using 30-year average weather data (9).

4/4 (standard 19-mm-) lumber. The continuous curves were drawn from the 24 data points in each set using commercial spline-smoothing software; the curves allow easy interpolation between the 15-day increments of starting dates listed in **Table 4.** A similar curve for nominal 2-inch- (standard 38-mm-) thick ponderosa pine dimension lumber, air-dried in Flagstaff, Arizona, is shown in **Figure 5.** Actual thickness is 1.70 inches (43 mm) to correspond to the approximate green thickness of softwood dimension lumber intended for construction use. In **Figure 5,** the stacking dates from July to mid-September show the effects of the mid-summer rainy season on drying time. In late August and early September, the rainy season abates and RH decreases; the jog in the curves after mid-August reflects a slightly faster drying rate because of the lower RH.

A series of graphs like **Figures 4** and **5** was developed for 4/4, 5/4, 6/4, and 8/4 hardwoods (actual thicknesses of 1.125, 1.375, 1.688, and 2.188 in. [29, 35, 43, and 56 mm], respectively) in various locations throughout their growing range. Similar graphs were developed for 4/4, 5/4, nominal 2-inch dimension, and 8/4 softwoods (actual thicknesses of 1.00, 1.25, 1.70, and 2.125 in. [25, 32, 43, and 54 mm], respectively). Because of space limitations, these graphs are not presented here and have been published elsewhere (22). A total of 64 combinations of locations and the 6 species are included.

A prominent feature in Figures 4 and 5 and the other graphs (22) is the occurrence of a critical stacking date in the late summer or early fall, depending somewhat on location, beyond which air-drying time quickly lengthens because the lumber does not reach a low MC before winter. For example, in **Figure 4** and **Table 4,** if 414 northern red oak is stacked to air-dry in Asheville, North Carolina, on August 1, it will take about 76 days to reach 20 percent MC; if stacking is delayed until October 1, 119 days are required. The height of the late summer and early autumn rise in drying time increases as stacking location moves northward.

CONCLUSION

The drying simulation developed by Hart (3) is a useful tool for solving drying problems. This was demonstrated by using the simulation to estimate air-drying times to any final MC for northern red oak, sugar maple, American beech, yellow-poplar, ponderosa pine, and Douglas-fir lumber stacked at any time of the year at any location where average monthly temperature, RH, and wind speed are available.

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