

Estimating air-drying times of small-diameter ponderosa pine and Douglas-fir logs

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Abstract

One potential use for small-diameter ponderosa pine and Douglas-fir timber is in log form. Many potential uses of logs require some degree of drying. Even though these small diameters may be considered small in the forestry context, their size when compared to typical lumber thickness dimensions is large. These logs, however, may require uneconomically long kiln-drying time. Air-drying is a logical alternative to kiln-drying, but the variables involved make estimating air-drying times difficult. In this study, experimental air-drying time data for 4- to 8-inch- (102- to 203-mm-) diameter ponderosa pine and Douglas-fir debarked logs stacked for air-drying at four different times of the year were developed. These data were used to develop multiple linear and nonlinear regression models that relate daily moisture content (MC) loss to MC at the start of the day, average daily temperature and relative humidity, and log diameter. The model provides a way to calculate estimated air-drying times for logs stacked at any time of the year where historic weather data are available.

Dense stands of small-diameter softwood trees in the western United States are creating a fire and forest health hazard. Because it is expensive to remove small-diameter trees, value-added uses need to be found for logs and lumber from these trees. One potential outlet for small-diameter trees is use in log form, which requires some degree of drying for most uses. Even though the logs that could be cut from these trees are considered small from the forestry perspective, they are large from the kiln-drying perspective. They require long kiln-drying times, and long kiln residence times are usually uneconomical. Air-drying is one practical alternative to kiln-drying.

Air-drying times can be quite variable and difficult to predict. Time can vary from several weeks to several months or

longer depending on species, dimension, local weather conditions, and time of year when the material is stacked. This large degree of uncertainty makes it difficult to plan material flow in production and control the quality of the final product. Under-dried logs continue to dry in service and may cause shrinkage and durability problems. Over-drying results in wasted time in inven-

tory and possible development of excessive drying defects.

The general objective of this study was to correlate air-drying times of ponderosa pine and Douglas-fir logs in the 4- to 8-inch- (102- to 203-mm-) diameter range to weather conditions, log diameter, and time of year the logs are stacked for air-drying. Specifically, the goal was to develop an analytical method, based on experimental data, to estimate air-drying times of 4- to 8-inch- (102- to 203-mm-) diameter ponderosa pine and Douglas-fir logs stacked at any time of the year and at any location where historical weather data are available.

Background

Attempts have been made to estimate air-drying times for lumber. A review of some early attempts is given in Simpson and Hart (2001). Most early attempts resulted only in general ranges of estimated drying times and were not specific enough to be of much use. The first study that resulted in more specific estimated drying times was done by Denig and Wengert (1982) on 1-inch- (25-

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mm-) thick red oak and yellow-poplar lumber. Air-drying sample boards were exposed in three commercial air-drying yards for five months. The daily rate of moisture loss was related to meteorological data obtained from a regional weather station. That result was developed into the following regression relationship for estimating daily moisture content (MC) loss:

$$\Delta M = a + bM^n + cT = dH \quad [1]$$

where:

ΔM = daily MC loss,

M = MC at the beginning of the day,

T = daily average temperature,

H = daily average relative humidity (RH),

a , b , c , and d = regression coefficients, and

n = 1 for yellow-poplar and 2 for red oak.

This result allows the useful capability of estimating air-drying time for any stacking date during the year if local temperature and RH data are available.

Simpson and Hart (2000, 2001) used a different approach to develop an analytical way to estimate air-drying times of several hardwood and softwood species from local weather data and for lumber stacked on any day of the year. They also included the effect of lumber thickness on drying time. The method was based on a computer drying simulation developed by Hart (1982) and utilized experimental air-drying times for six wood species to develop parameters for the drying simulation. Once these parameters were found for each species in the geographical location for the experimental data, they could be used in the drying simulation to estimate air-drying times at other locations where historical weather data are available. The results made it possible to estimate air-drying times of the six species stacked for air-drying on any day of the year at any location where average temperature and RH data are available, and for lumber, of any thickness, dried to any final MC.

Experimental methods

The experimental material was ponderosa pine and Douglas-fir logs, ranging from about 4 to 8 inches (102 to 203 mm) in diameter, taken from the vicinity of Hayfork, California, about 40 miles

west of Redding. The general experimental scheme was to stack logs for air-drying at four different times of the year so that a variety of weather conditions were included, to monitor log MC loss, and to collect local temperature and RH data.

The four stacking dates were July 18, 2001; October 22, 2001; February 25, 2002; and May 13, 2002. For each of these dates, one stack was set up for ponderosa pine logs and one for Douglas-fir logs in Hayfork, California (Fig. 1). Each stack consisted of twenty-four 8-foot- (2.4-m-) long debarked logs whose purpose was to provide typical stack surroundings for twelve 36-inch- (0.91-m-) long, end-coated, debarked monitor log sections that were embedded in the stack. The monitor sections were removed periodically and weighed to estimate MC. For each stacking date, the logs were debarked just before stacking.

The 12 monitor log sections for each species were cut from full-length logs. A 1-inch- (25-mm-) thick moisture section was cut from each end of each monitor section, and the monitor sections were then end coated and weighed. The circumference of the monitor section was measured at each end, averaged, and later converted to diameter. The two moisture sections from each monitor section were weighed, oven-dried, and used to calculate estimates of the MC of the monitor sections as they were weighed periodically during air-drying.

The stacks were covered with plywood to protect the logs from rain and direct sun exposure. After air-drying was complete, all monitor sections were oven-dried so that exact MC could be calculated for each of the periodic weights taken during air-drying.

The weather data were monitored and recorded using a battery-powered data logger mounted near the drying stacks. The data logger was set up to measure temperature and RH every 10 minutes and to store these data along with the time and date. (With this sampling interval, the data logger can operate continuously for up to 226 days.) When air-drying was complete, the weather data were off-loaded on-site using a data shuttle (a pocket-sized device that can be used to off-load or restart the data logger) and transported to a personal computer. The temperature and RH data were then averaged over the day for data analysis.

Analytical methods

A multiple linear regression approach similar to the one used by Denig and Wengert (1982) was used and, once developed, the results are readily usable in simple user-built computer programs or in spreadsheet analyses. For this study, two regression models that are often applied in the absence of any physically based equations were investigated:

$$\Delta M = a + bM + cT + dH + eD \quad [2]$$

and

$$\Delta M = aM^b T^c H^d D^e \quad [3]$$



Figure 1. — Air-drying stacks of ponderosa pine and Douglas-fir logs in Hayfork, CA. Dark end-coated logs are logs used to monitor MC.

where:

- ΔM = daily loss of MC (%),
 M = MC at the beginning of any day during air-drying (%),
 T = average daily temperature (°F),
 H = average daily RH (%),
 D = log diameter (in.), and
 $a, b, c,$
 $d,$ and e = coefficients determined by regression.

Monitor log sections were weighed more often (every few days) early in drying, but less often (7 to 10 days) late in drying as the drying rate slowed down. For the regression analysis using Equation [2] or [3], daily moisture loss data at exact 24-hour intervals were used. It was not practical to weigh the monitor sections on this precise schedule. Therefore, daily MC values were determined by linear interpolation between the MC calculated on the days the monitor sections were weighed. The daily moisture loss, ΔM , could then be determined by subtraction of MC values between successive days. This information completed the necessary variables for the regression analysis of Equations [2] and [3].

Results

The average initial MC of ponderosa pine and Douglas-fir was 120 percent and 47 percent, respectively. The average diameter of ponderosa pine and Douglas-fir logs was 5.9 and 5.5 inches (150 and 140 mm), respectively.

Figure 2 shows MC as a function of time for ponderosa pine and Douglas-fir by stacking date. Because the diameter and initial MC of each monitor log section were different, it was not possible to construct plots that represent an average of the stacking date and species. Each plot in **Figure 2** is a representative example of one monitor section, with initial MC and diameter chosen to be near the average value for the stacking date and species. Several general observations can be made from **Figure 2**. Regardless of season of stacking date, MC decreased rapidly during the first few days. The rate of MC loss then decreased, especially for logs stacked later in the year. Logs stacked on July 18 dried the fastest, followed by those stacked on May 13. Drying of logs stacked on October 22 was greatly prolonged because the weather turned cold

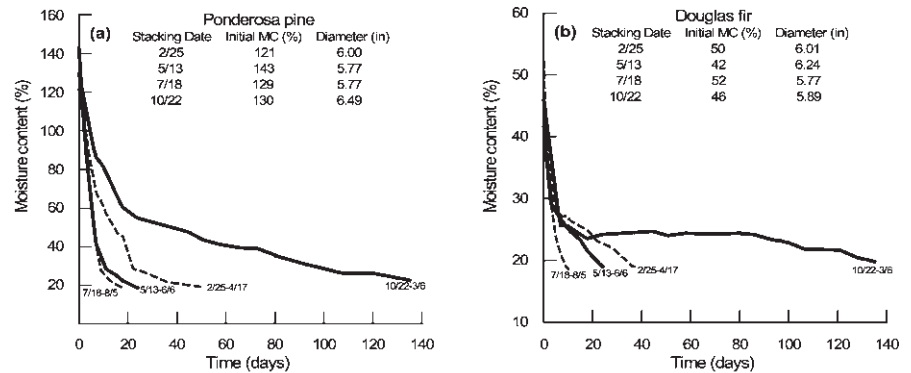


Figure 2. — MC as a function of time for (a) ponderosa pine and (b) Douglas-fir logs stacked at four different times for air-drying in Hayfork, CA. 1 in. = 25.4 mm.

and damp; the logs did not reach the air-dried MC range (19% to 25%) until March.

The experimental data were fit by multiple linear regression to Equation [2] and by multiple nonlinear regression to Equation [3]; the regression coefficients are listed in **Table 1**. The coefficient of determination, r^2 , was used as the criterion for choosing either Equation [2] or [3] as the best equation to represent the experimental data. The result was that Equation [3] was best for ponderosa pine ($r^2 = 0.786$) and Equation [2] for Douglas-fir ($r^2 = 0.723$). For ponderosa pine, the r^2 value was 0.717 with Equation [2]; for Douglas-fir, the r^2 value was 0.648 with Equation [3].

The average deviation between experimental and regression-estimated drying days was 25.5 percent for ponderosa pine and 16.1 percent for Douglas-fir. The best agreement for ponderosa pine was for the May 13 stacking date (13.4% average deviation) and for Douglas-fir the October 22 stacking date (4.5% deviation). The deviations of most concern were those for ponderosa pine stacked on October 22 (53.3%) and Douglas-fir stacked on May 13 (39.7%). These deviations were large enough to question the usefulness of the regression estimates.

Another way to evaluate the usefulness of the regression estimates is to compare the MC predicted by the regression analysis at the experimental time required to reach 20 percent MC. For example, one of the logs stacked on February 25 required 46.1 days to reach 20 percent MC, and the regression analysis predicted 48.9 days. The regression analysis also predicted that the MC would be 21.8 percent after 46.1 experimental days, a 1.8 percent deviation

Table 1. — Regression coefficients, coefficients of determination, and standard error of estimate for models of Equations [2] and [3] for air-drying ponderosa pine and Douglas-fir logs.

Coefficient ^a	Ponderosa pine ^b	Douglas-fir ^c
<i>a</i>	0.00117	-2.67
<i>b</i>	1.38	0.156
<i>c</i>	1.69	0.0262
<i>d</i>	-0.558	-0.0189
<i>e</i>	-1.30	-0.0885
r^2	0.786	0.723
StEr	1.368	0.652

^a r^2 = coefficient of determination; StEr = standard error of estimate.

^b $\Delta M = aM^bT^cH^dD^e$.

^c $\Delta M = a + bM + cT + dH + eD$.

from the experimental value of 20.0 percent after 46.1 days. The purpose of this method of comparison relates to how closely the air-dry MC needs to be estimated. It can be argued that the difference between 21.8 percent and 20.0 percent MC is insignificant from any practical standpoint. At what point a MC difference becomes significant is a matter of interpretation that is best left to the user. If the results are examined in this way, the overall error in estimated air-dry MC is 7.4 percent for ponderosa pine and 1.6 percent for Douglas-fir. Again, in this method of comparison, the results for ponderosa pine stacked on October 22 and Douglas-fir stacked on May 13 are the only poor estimates, missing the target air-dry MC by 17.9 percent and 3.6 percent, respectively. In contrast, the best result for ponderosa pine (stacked May 13) missed the target air-dry MC by 3.3 percent, and the best result for Douglas-fir (stacked February 25) missed the target air-dry MC by only

0.5 percent. There is no apparent explanation for the poor results for ponderosa pine stacked on October 22 and Douglas-fir stacked on May 13.

Application of results

Logs

The main objective of this study was to provide the basis that allows estimates of air-drying times to be calculated for any diameter (in the approximate 4- to 8-in. [102- to 203-mm] range) of debarked ponderosa pine and Douglas-fir logs stacked at any day of the year at any location where historic temperature and RH data are available. This basis is the regression coefficients of Equations [2] and [3] as listed in **Table 1** and weather data available in terms of 30- to 40-year averages from the National Climate Data Center, National Oceanic and Atmospheric Administration (2002).

Figure 3 shows estimated air-drying times at various locations for ponderosa pine (Boise, ID and Flagstaff, AZ) and Douglas-fir (Redding, CA and Spokane, WA). The graphs show estimated air-drying times of 4-, 6-, and 8-inch- (102-, 152-, and 203-mm-) diameter logs to 20 percent MC for logs stacked on any day of the year. Data for other locations are reported in Simpson and Wang (2003).

The graphs in **Figure 3** assume an initial MC of 120 percent for ponderosa pine and 47 percent for Douglas-fir. Initial MC does have some effect on air-drying time, as illustrated in **Figure 4** for 6-inch- (152-mm-) diameter ponderosa pine in Flagstaff for initial MC of 80 percent, 120 percent, and 160 percent. As expected, the higher the initial MC the more time required for ponderosa pine to air-dry to 20 percent MC. Initial MC had a minimal effect on air-drying time of Douglas-fir, primarily because green Douglas-fir MC is low and does not vary over a wide range.

Another factor that affects air-drying time is target final MC. This study focused on 20 percent as the target final MC, but other values could also be of interest. The effect of target final MC is illustrated in **Figure 5** for 6-inch- (152-mm-) diameter Douglas-fir stacked in Redding and air-dried to 20 percent, 22.5 percent, and 25 percent final MC. The effect of target final MC was quite large; a small increase in MC, from 20 percent to 22.5 percent, resulted in a large reduction in predicted air-drying time.

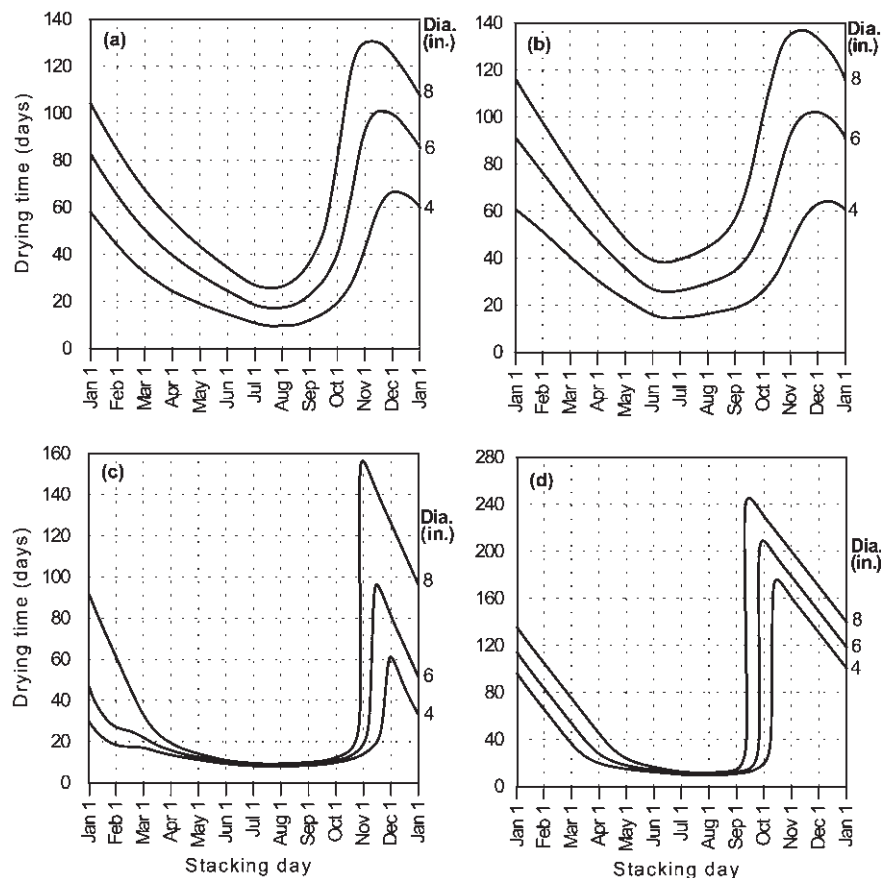


Figure 3. — Estimated air-drying times to 20 percent MC of 4-, 6-, and 8-inch-diameter ponderosa pine (MC = 120%) and Douglas-fir (MC = 47%) logs stacked on any day of the year at selected locations within their growing range. (a) Ponderosa pine, Boise, ID; (b) Ponderosa pine, Flagstaff, AZ; (c) Douglas-fir, Redding, CA; and (d) Douglas-fir, Spokane, WA.

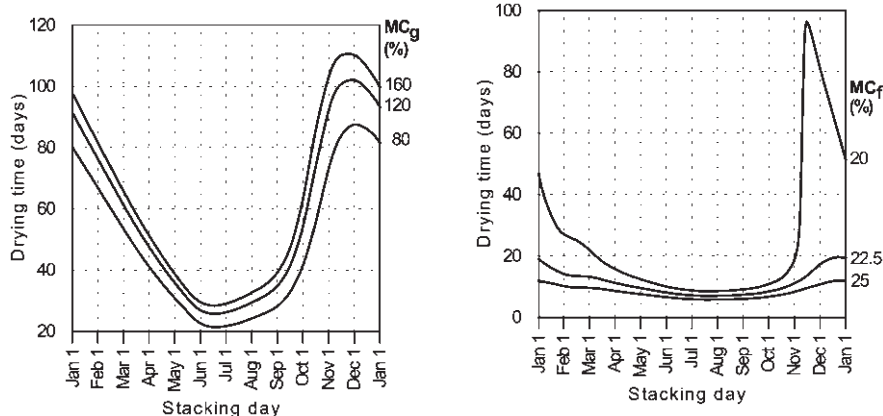


Figure 4. — Effect of initial MC (MC_i) on estimated air-drying time to 20 percent MC of 6-inch-diameter ponderosa pine in Flagstaff, AZ.

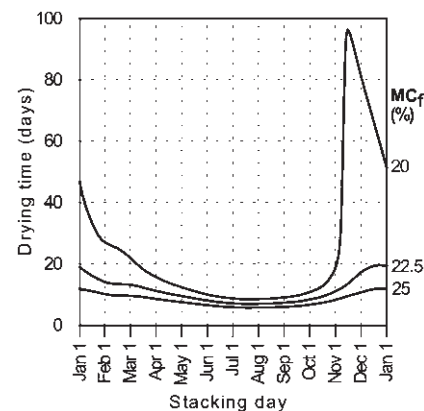


Figure 5. — Effect of target final MC (MC_f) on estimated air-drying time of 6-inch-diameter Douglas-fir, initial MC 47 percent, air-dried in Redding, CA.

Note that the air-drying times shown in **Figures 3 through 5** are only rough estimates. The imprecision of the estimates is the result of several factors. Because of the natural variability of wood

(including initial MC), possible experimental error, and weaknesses in the experimental design (more replicate monitor logs and a more systematic and representative distribution of log diameters

might have improved results), the regression estimates are subject to error. Another factor is the variability in weather. The estimates are based on average weather data; in any given year, weather can have some degree of deviation from the average. Nevertheless, the estimated times can serve as somewhat useful guidelines for anticipating drying times. One observation supported by most of the plots, especially for the more northern locations, is that there is a time in late summer or early fall beyond which air-drying time is greatly extended because cold, humid winter weather greatly slows drying and prevents log MC from dropping below about 25 percent. The benefits of modest temperature increases and RH decreases provided by simple, low-temperature dryers are discussed in Simpson and Wang (2003).

Another factor to be considered is the approach to final air-drying MC. Near the end of air-drying, the drying rate becomes quite slow (**Fig. 2**), and a decrease in MC of only a few percent may take many days. This is especially true for logs stacked in late summer to early

fall. For example, if 20 days are required to dry logs to 22.5 percent MC and another 30 days to dry to 20 percent MC, then some thought should be given to when air drying is considered finished – either as low enough for the final product (22.5% MC may be just as good as 20%) or as the end of a practical air-drying period and time to consider kiln-drying for lower MC.

Conclusions

The application of regression analysis to experimental air-drying data for ponderosa pine and Douglas-fir logs resulted in a method for estimating air drying times of 4- to 8-inch- (102- to 203-mm-) diameter logs stacked any day of the year at any location where historic weather data are available. The resulting regression models relate daily MC loss to MC at the start of the day, average daily temperature and RH, and log diameter. The model can readily be used in spreadsheet analyses or in user-built computer programs. Examples of drying time estimates are given for several locations within the growing range of ponderosa pine and Douglas-fir.

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