Method for interconverting drying and heating times between round and square cross sections of ponderosa pine

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Abstract

To use small-diameter trees effectively as square timbers, we need to be able to estimate the amount of time it takes for these timbers to air-dry. Since experimental data on estimating air-drying time for small-diameter logs have been developed, this study looked at a way to relate that method to square timbers. Drying times were determined for a group of round cross-section ponderosa pine logs and a group of square timbers. With regression analysis used to relate the two groups, it was shown that there is a square cross section of dimension *S* that results in the same drying time as a round cross section of diameter *D*, and the relationship between the two dimensions is $S = 0.900\ D$. This relationship allows the conversion of previously published estimates of air-drying times for ponderosa pine logs to air-drying times of square timbers. The conversion is only valid if the sapwood/heartwood ratio is not altered by the round to square conversion. An analysis of analytically calculated heating times for heat sterilization of round and square cross sections further verified the relationship, as well as showing it also is applicable to interconverting heating times between round and square cross sections when one is known but the other is not.

In a previous study, Simpson and Wang (2003, 2004) developed experimental data on air-drying times of ponderosa pine logs in the 4- to 8-inch (102- to 203-mm) diameter range. These drying times were related to ambient temperature, relative humidity (RH), and log diameter. The end result was a multiple regression equation allowing one to calculate an estimated air-drying time to any final moisture content (MC) for logs of any diameter between about 4 and 8 inches, stacked on any day of the year, at any location where historic temperature and RH data are available.

Square timbers are another potential use of small-diameter trees, and it would be useful to also have a way to estimate their drying times. It is possible to make certain assumptions that allow the drying time results for round cross sections to be expanded to include an approximation for square cross sections. The basic assumption is that there is a square timber dimension that is equivalent to a log diameter in terms of drying time. If this is true, the estimated air-drying times of square timbers can be calculated from the same regression equation developed for ponderosa pine logs (Simpson and Wang 2003,2004). If development of an equivalent square dimension is successful, it could be applied to interconvert kiln-drying as well as air-drying times between logs and square timbers.

Analytical development of equivalent square

One way to develop the equivalent square dimension is to assume an equivalent length of travel for water to leave the two wood configurations. The development of the geometry follows **Figure 1,** and we can work in just two dimensions since length is not a factor that influences results. The mean value of the distance, *a* ($a_1 \ldots a_n$), from the center of the square to the surface of the square where it intersects the circle over an octant of the circle (by symmetry, we can work with one-eighth of the circle and square) of 45 degrees is:

$$a = S/2 = r/(\phi_n - 0) \int_0^{\phi_n} \cos\phi\, d\phi$$

Since we are concerned with only one-eighth of the circle-square, $f_n = 45$ degrees = 0.785 radians. Integrating:

$$a = S/2 = 0.900r$$

and: $S = 0.900\ D$ [1]

or: $D = 1.111\ S$ [2]

The meaning of Equation **[1]** is that a log of diameter *D* will dry in the same length of time as a square timber of

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Forest Prod. J. 55(6):29-32.

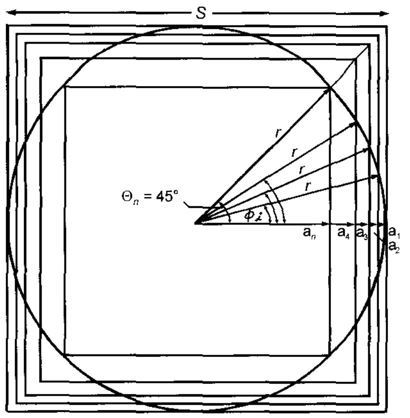

Figure 1. — Method for relating the cross-sectional dimension of a square timber to the diameter of a round cross section that is equivalent in drying time.

cross-sectional dimension S equal to 0.900 D, and conversely, for Equation **[2],** a square timber of cross-sectional dimension *S* will dry in the same time as a round log of diameter equal to 1.111 S. Equations **[1]** and **[2]** allow interconversion of estimated drying times between round and square cross sections when one or the other is known, thus eliminating the need to obtain experimental data for both cross-sectional configurations.

Test of equivalent square

Experimental

The relationship between round and square cross sections was tested with the 48 ponderosa pine log sections from the air-drying study previously referenced (Simpson and Wang 2003,2004). These had been weighed periodically during the air-drying study to determine their MCs at progressive times during air-drying. They were 36 inches (0.914 m) long and varied from about 4 to 8 inches in diameter. After the air-drying study, they were ovendried for MC calculations. For this study, the sections were rehydrated in a pressure cylinder to bring them back up to MC levels near their natural green MC. After rehydration, 16 of the sections were sawn into the largest possible square timber. Three of the sections were unusable, leaving 29 sections still in the round form. After end coating, all 45 sections were dried in a controlled environment of 75°F (24°C) and 65 percent RH. The sections were weighed periodically until weights were close to stabilizing at constant levels and were then ovendried for MC calculations.

Strategy

A factor that could complicate comparison of drying times between a round cross section and the equivalent square is the heartwood-sapwood proportions. If a log contains significant heartwood, sawing an equivalent square would change the sapwood-heartwood proportion. Heartwood generally has different green MCs and drying rates than sapwood which could make drying time comparisons between a round cross section and the equivalent square invalid. However, small-diameter ponderosa pine is largely sapwood (Panshin and de Zeeuw 1980; Simpson and Wang 2003, 2004), so this effect is expected to be minimal with this species. The Douglas-fir used in the air-drying study (Simpson and Wang 2003,2004) contained significant amounts of both sapwood and heartwood so we did not attempt to test the model with Douglas-fir.

The experimental plan was to compare drying times of the 29 round log sections with drying times of the 16 square timber cross sections and determine if they could be related through Equations **[1]** and **[2].** One problem with this approach was that, since it was impossible to cut the equivalent square from the corresponding round cross section, it was necessary to use different logs for the round cross section specimens and the square cross section specimens. This means different properties, including different initial MC, which could affect drying time. One way to moderate the effect of different initial MCs was to compare normalized MCs, using the following equation:

$$E = (M - M_f)/(M_i - M_f) \qquad \textbf{[3]}$$

where M = MC at any time; M_f = final MC (taken as 12%); M_i = initial MC (range = 55% to 182%; avg. = 111%; standard deviation = 34%).

Since we could not directly compare drying times of the round cross section to the drying times of each log's equivalent square, regression analysis was used to compare regression lines of the round log cross section drying times plotted with the corresponding equivalent squares cross section dimension to the square cross section drying times plotted with the cross-sectional dimension of the squares. If these two regression lines are statistically the same, then we can infer that the model of Equations **[1]** and **[2]** is valid.

Results

Table 1 shows the dimensions and drying times of the 29 round cross-sectional logs and the 16 square cross-sectional timbers. The results of the regression analysis are shown in **Figure 2** and the Appendix. **Figure 2** shows the two regression lines and the individual data points. The solid line is the linear regression of the round log cross section drying time compared with the dimension of the equivalent square calculated by Equation **[1]** (not of the actual diameter of the log section), and the dotted line is the regression of the drying time of the square cross section compared with its cross-sectional dimension. As **Figure 2** shows, the two regression lines fall very close to one another, and as the Appendix documents, they are not different at the 0.05 statistical significance level (Glantz 2002). Therefore, two conclusions are possible: 1) that there is no difference between the two regression lines; or 2) that there are not enough observations to detect a difference at the 0.05 statistical significance level. The number of observations available could not be changed, but the results do offer evidence of the validity of Equations **[1]** and **[2]** in calculating an estimate of the drying time of either a round or square cross section from the known drying time of the other.

The equation for estimating the air-drying time of ponderosa pine logs was developed as follows (Simpson and Wang 2003,2004):

$$\Delta M = aM^b T^c H^d D^e \qquad \textbf{[4]}$$

where ΔM = daily loss of MC (%); M = MC at the start of any day during air-drying (%); T = average daily temperature (°F); H = average daily RH (%); D = log diameter (in.); a through e are regression coefficients: a = 0.00117, b = 1.38, c = 1.69, d = -0.558, e = -1.30.

The practical question that the results of this analysis can answer is, given a square timber of a certain cross-sectional dimension, how do we use Equation **[4]** to calculate an estimate of its air-drying time? We can do this by substituting Equation **[2]** ($D = 1.111S$) into Equation **[4].** As an illustration, we can refer to the first entry in **Table 1,** where the round cross section is 3.62 inches and the equivalent square is 3.26 by 3.26 inches The results of this study make it possible to estimate that a 3.62-inch log will air-dry in approximately the same time as a

Table 1. — Drying times of round and square ponderosa pine cross sections.

Round cross section diameter *D*	Equivalent square 0.900*D*	Drying time of round to *E*=0.100	Square cross section dimension *S*	Equivalent round 1.111*S*	Drying time of square to *E* = 0.100
-------- (in.) --------		(days)	-------- (in.) --------		(days)
3.62	3.26	26.2	3.14	3.49	27.0
3.80	3.42	30.6	3.22	3.58	30.5
3.98	3.58	43.1	3.55	3.94	28.2
4.05	3.65	47.0	3.63	4.03	48.3
4.21	3.79	49.5	3.70	4.11	41.8
4.22	3.80	47.8	3.84	4.27	50.8
4.25	3.83	42.7	4.09	4.54	53.3
4.33	3.90	42.7	4.23	4.70	62.5
4.37	3.93	44.8	4.34	4.82	63.0
4.42	3.98	40.2	4.50	5.00	56.2
4.62	4.15	66.3	4.66	5.18	49.3
4.68	4.21	55.2	4.81	5.34	72.0
4.79	4.31	42.3	5.08	5.64	67.0
4.91	4.42	47.7	5.16	5.73	42.2
5.00	4.50	50.7	5.92	6.58	57.9
5.51	4.96	53.8	5.97	6.63	75.0
5.58	5.02	59.9			
5.63	5.07	49.5			
5.83	5.25	57.1			
5.93	5.34	59.5			
6.07	5.46	59.8			
6.16	5.54	57.6			
6.27	5.64	90.0			
6.43	5.79	65.2			
6.48	5.83	57.3			
6.61	5.95	63.4			
7.18	6.46	100.0			
7.28	6.55	71.0			
8.69	7.82				

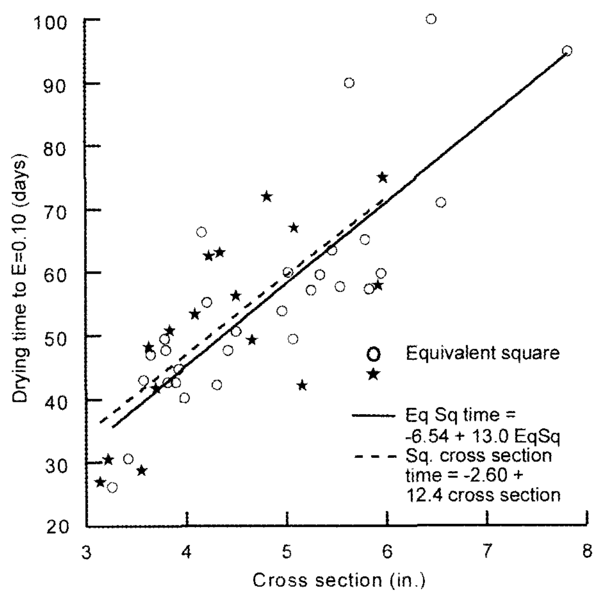

Figure 2. — Regressions of drying times to the dimensions of equivalent squares of ponderosa pine round cross sections and to the drying time of square cross sections.

3.26- by 3.26-inch square timber. So by substituting Equation **[2]** into Equation **[4],** we have an estimate of the time to air-dry a 3.26- by 3.26-inch square as well as a 3.62-inch-diameter log.

Simpson and Wang (2003) show a series of graphs, for several geographical locations, with curves of estimated air-drying time compared with the day of the year the logs are stacked for 4-, 6-, and 8-inch- (102-, 152-, and 203-mm-) diameter logs air-dried from 120 to 20 percent MC. **Figure 3** shows an example of one of these graphs (ponderosa pine; Boise, Idaho) modified to include the corresponding equivalent squares.

Heat sterilization times

To prevent the transfer of insects and fungi between countries in international trade, wood and wood products in various configurations are sterilized. This practice is becoming more routine. Heat treatment is one of the common ways to do this, but one practical problem is obtaining estimates of the time necessary to heat various wood configurations, including both round and square cross sections, to the target temperature required to kill the insect or fungus. Simpson (2001) has provided an analytical method to obtain these heating time estimates, in steam, for both round and rectangular cross sections. These estimates utilize heat flow equations that are based on the same mathematical theory as moisture movement, and because of this, they also offer a way to further test the validity of Equations **[1]** and **[2].** Boundary conditions of immediate surface equilibrium in drying and heating are assumed to be similar. The heating times for round cross sections of diameters (*D*) were calculated using the corresponding equations in a previous study (Simpson 2001), and then the equations for rectangular cross sections were used to calculate the square cross section dimension (*S*) that would result in the same heating time as the round cross section. If Equations **[1]** and **[2]** are valid, then the ratio of the round cross-sectional diameter to the square cross-sectional dimension resulting in equal drying times should be approximately 1.11. The results of these calculations, which are independent of diameter, showed the *D/S* ratio to be 1.09. For example, a log 6 inches in diameter, heated at 160°F (71°C), initially at 70°F (21°C), 120 percent MC, and specific gravity 0.38 (typical of ponderosa pine), will require 167

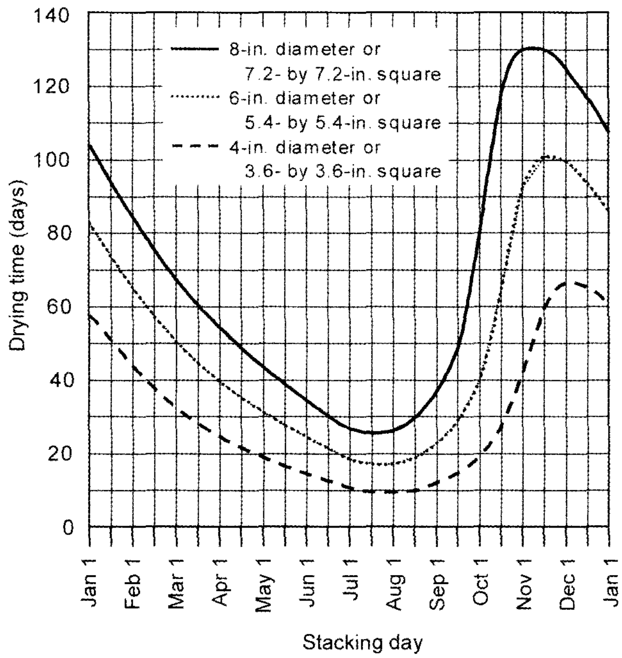

Figure 3. — Estimated air-drying times for ponderosa pine from 120 to 20 percent MC of 4-, 6-, and 8-inch- (102-, 152-, and 203-mm;) diameter logs and 3.6-, 5.4-, and 7.2-inch (91-, 137-, and 183-mm) squares stacked on any day of the year in Boise, Idaho.

minutes for the center to reach 133°F (56°C). The square cross-sectional dimension that will heat in the same time is 5.52 inches (140 mm), so the *D/S* ratio is 1.09. This agreement is further evidence that Equations **[1]** and **[2]** offer a good estimation method for interconverting round and square drying times as well as heating times.

Conclusions

The statistical analysis of the experimental drying times of round and square cross-sectional logs and timbers shows that there is a square timber cross-sectional dimension that is equivalent to a log diameter in terms of equal drying times, allowing the interconversion of drying times between round and square cross sections when one is known but not the other. The validity of the interconversion method is further reinforced by an analysis of heating times as calculated by established heat flow equations applied to round and square cross-sectional dimensions.

Literature cited

Glantz, S.A. 2002. Primer of Biostatistics. McGraw-Hill, New York.

Panshin, A.J. and C. de Zeeuw. 1980. Textbook of Wood Technology. 4h ed. McGraw-Hill Book Co., New York.

Simpson, W.T. 2001. Heating times for round and rectangular cross sections of wood in steam. Gen. Tech. Rept. FPL-GTR-130. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

__________ and X. Wang. 2003. Estimating air drying times of small-diameter ponderosa pine and Douglas-fir logs. Res. Pap. FPL-RP-613. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

__________ and __________. 200_. Using regression analysis to estimate air-drying times of small-diameter ponderosa pine and Douglas-fir logs. Forest Prod. J. (in press).

Appendix

This Appendix shows statistical test results for the coincidence of the two regression lines of **Figure 2** (Glantz 2002).

Pooled estimate of the variance around the two regression lines:

$$s^2_{y.x,p} = 95.138$$

Variance around regression fit to single line including both data sets:

$$s^2_{y.x,c} = 91.321$$

Improvement in fit obtained by fitting the two data sets with separate regressions compared with fitting them with a single regression:

$$s^2_{y.x,imp} = 26.161$$

Compute F for test of significance (with 16 + 29 – 4 degrees of freedom):

$F = s^2_{y.x,imp}/s^2_{y.x,p} = 0.275$, $F_{.05} = 2.4$ so the two data sets are not from populations with different regression lines.