Air Seasoning of Red Oak Crossties

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A method is described that permits estimating the time required to air season green 7- by 9-inch commercial northern red oak crossties under given conditions of temperature and relative humidity. A specific application is made to the air seasoning of crossties during drying from 85 to 50 percent moisture content at each of two plants. Besides weather, other factors affecting estimates of the length of air-seasoning periods may be variations of the drying-rate factor, K, as affected by species differences in the red oak group; method of piling; and position of a pile with respect to surrounding piles and alleys. Green commercial northern red oak crossties piled by the 8-by-l method may, it is shown, real a moisture content of 50 percent in 5 months if piled in the spring, and may require twice as long if piled in the fall.

Introduction

The U. S. Forest Products Laboratory, in cooperation with the Chicago, Burlington, & Quincy Railroad Co., Galesburg, 111., and the Koppers Co., Inc., Wood Preserving Division, Orrville, Ohio, investigated the relation of air seasoning to preservative treatment of railroad crossties. The purpose of the study was to obtain data that would (1) be useful in estimating the time required to air season commercial northern red oak crossties to a moisture content suitable for pressure treatment with preservatives; (2) indicate the corresponding transverse and longitudinal moisture content gradients existing in crossties after air seasoning; and (3) permit the estimation of average moisture content from readings taken with a resistance type of electric moisture meter. Subsequent to air seasoning, records were made of the usual treating conditions, preservative retention and penetration, and specific gravity determinations.

Material

Of the 2,100 crossties used in this study 1,977 were commercial northern red oak from Ohio, Pennsylvania, New York, Illinois, and Wisconsin. The remaining 123 were commercial southern red oak from Virginia and North Carolina. All the crossties were sawed to the same nominal size, 7 by 9 inches by $8^1/_2$ feet, and contained a negligible amount of sapwood.

Procedure

In general, the crossties were received at the treating plants within a month after they were sawed. Eight borings were then taken from each crosstie: one from each of the four faces at one rail bearing and four similarly at the midsection. Each boring was cut into 3 parts, one representing the outer inch, one representing the second inch from the surface, and the remainder representing the core of the crosstie. Corresponding sections of the 8 borings were placed in tightly stoppered glass bottles, and weighed in the green and oven-dry condition to determine the moisture content, in accordance with the formula:

$$\text{Moisture content (percent)} = \frac{\text{Weight green} - \text{weight oven-dry}}{\text{Weight oven-dry}} \times 100$$

The moisture content values of the 3 sections of the 8 borings were averaged to compute the average moisture content of each crosstie. The length, width, and thickness of each crosstie were measured, and each crosstie was weighed. These data were used to compute the weights per cubic foot when green and when oven-dry.

All crossties were numbered and were piled by the 8-by-l method (fig. 1) at approximately monthly intervals during 11 to 20 consecutive months beginning in the spring of 1937. At the Chicago, Burlington & Quincy plant each pile had 100 crossties and at the Koppers Co. plant the number was 76. Each crosstie was weighed about once each month and replaced in its original position in the pile. Since the oven-dry weight had been calculated, it was possible to calculate the moisture content corresponding to each current weight.

Before the crossties were piled, nails were driven respectively $^1/_4$, $^1/_2$, 1, 2, and $3^1/_2$ inches deep into each crosstie at midlength, and, at Galesburg, at a rail bearing also. These nails served as electrodes to which the leads from an electric moisture meter were connected. The

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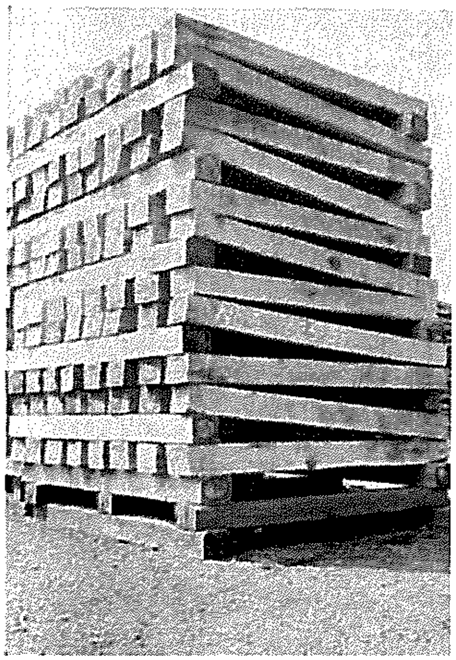

Figure 1.—Eight-by-1 method of piling red oak crossties.

moisture meter was used at intervals when the crossties were weighed. From time to time when checks occurred at the nails, the nails were removed and were driven in adjacent sec- tions where satisfactory electrical contact could be secured. The effect of poor contact is to in-crease the electrical resistance, and as a result the meter reading of moisture content would be too low. The readings later referred to in table 1 were taken during the months of June to October. Readings taken during the winter are not very reliable because the effect of low temperature is to increase the electrical resistance of a crosstie, and the relationship of electrical resistance to temperatures in a low range is not accurately known.

Maximum-and-minimum thermometers were used to determine average daily temperatures. A wood element,[4] whose calculated weight when oven-dry was 100 grams, was weighed at 8 a. m. and 5 p.m. The difference between its actual weight and the calculated 100 grams was recorded and averaged with other differences to compute the equilibrium moisture content dur- - ing a given period.

At the Orrville plant, precipitation readings were recorded daily. For the study at Gales- burg, precipitation readings recorded by the Illinois State Water Survey at Lake Bracken Station No. 2 were available.

At the end of the air-seasoning period, 1-inch sections of the crossties were used to determine the transverse moisture content distribution and specific gravity in each of 10 cross-ties from each of 12 piles at each plant. A section was cut transversely at midlength of each crosstie and was then cut into three zones. The moisture content of each zone was determined by the oven-dry method. At one plant, additional sections were cut to determine the longitudinal moisture content distribution also. These sections were cut at various positions along the length of the crosstie.

After air seasoning, the crossties were treated with a 50-50 mixture of creosote and petroleum or a 60-40 mixture of creosote and tar in accordance with the usual procedure at t he respective plants. The retention of preservative by each crosstie was determined by weighing before and after treatment, with due allowance for condensate in the preservative.

At least one boring was taken at the mid-length of each treated crosstie (with the excep-tion of the crossties in three piles at one of the plants) to determine the percentage of annual rings treated.

At Orrville the study piles were isolated from other piles and were arranged in 3 east-a nd-west rows of 4 piles each. The middle row was 4 feet from each of the other rows.

At Galesburg the rows of study piles were placed in the main yard and were spaced 4 feet from other rows of piles not included in the study. These other rows were put up and taken down at various times as a regular part of the yard operation.

Results

In figures 2 and 3 moisture content is re- lated to seasoning time for all the piles used in the study.

The curves in figures 4, A and 4, B, the mathematical basis for which is discussed in the appendix, may be used in estimiting the time required to air season 7- by 9-inch by 8½foot commercial northern red oak crossties

* U. S. Forest Products Laboratory Technical Note No. 239.

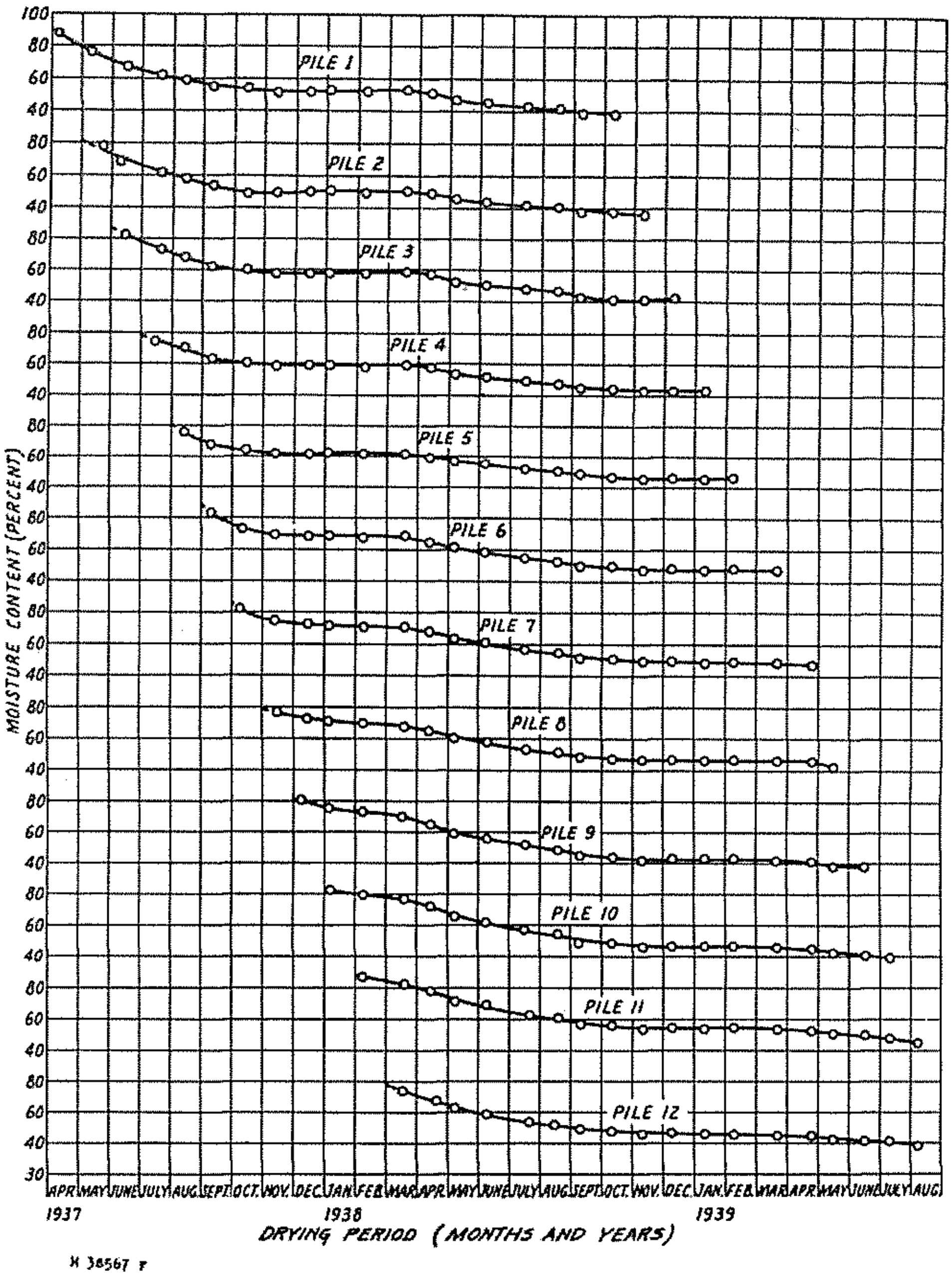

Figure 2.—Moisture-time curves for 12 piles of 7- by 9-inch by $8^1/_2$-foot commercial red oak crossties in air-seasoning investigation at Orrville, Ohio; 8-by-1 method of piling.

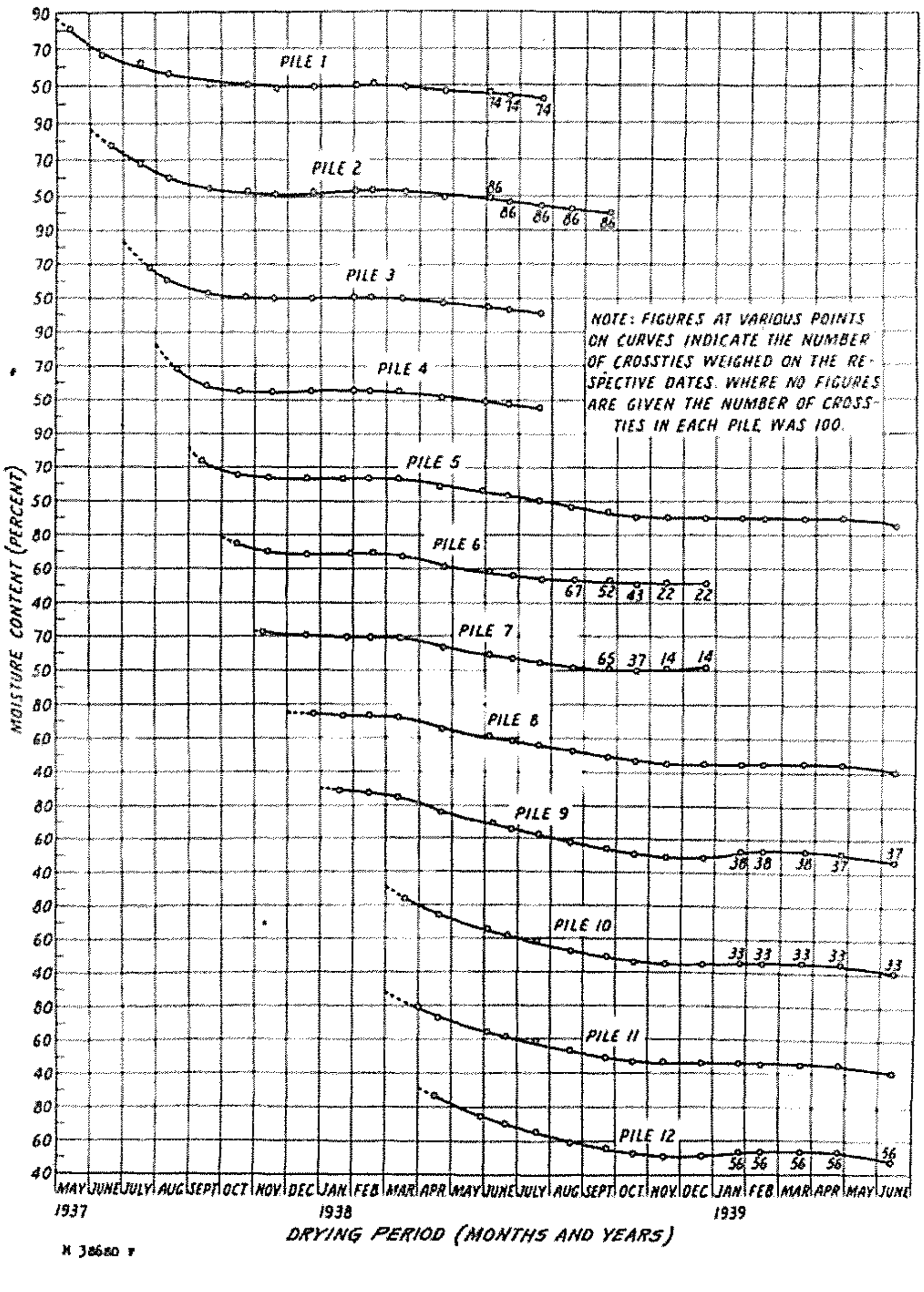

Figure 3.—Moisture-time curves for 12 piles of 7- by 9-inch by 8l/2-foot commercial northern red oak cross ties in air-seasoning investigation at Galesburg, 111.; 8-by-l method of piling.

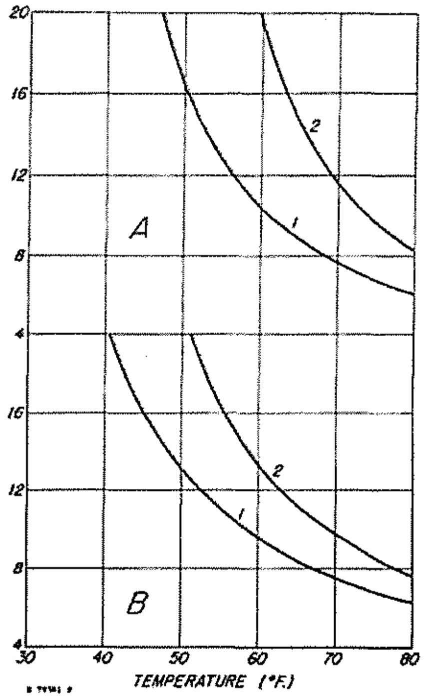

Figure 4.—A, Time-temperature curves for 7- by 9-inch by 8 ½-foot commercial northern red oak crossties at Galesburg, 111.; curve 1 relates to piles with an average drying rate, and curve 2 relates to piles with slowest drying rate. B, Time-temperature curves for 7- by 9-inch by 8 ½-foot commercial red oak crossties at Orrville, Ohio; curve 1 relates to piles with an average drying rate, and curve 2 relates to piles with slowest drying rate.

under certain conditions involving given initial and final moisture content values, equilibrium moisture content values, and corresponding outdoor temperatures. Curves marked 1 in figures 4, A and 4, B are applicable to piles with average drying rate; curves marked 2 in the same figures are applicable to piles with slowest drying rate. The procedure indicated may be readily modified to apply to other initial and final moisture content values of commercial northern red oak crossties, temperature, and relative humidity. The relationship of relative humidity and equilibrium moisture content at various temperatures is shown in figure 5.

In table 1, computed average moisture content values for the piles at Orrville are compared with the moisture meter readings taken with electrodes that penetrated ½ inch below

Table 1.—Calculated Average Moisture Content of Crosstie Piles at Orrville, Ohio and Moisture-Meter Readings Taken at a Depth of ½ Inch in 7- by 9-Inch Commercial Red Oak Railroad Crossties

Pile Number	Average moisture content Percent	Moisture meter reading Percent
1	45.5	18.2
2	49.1	20.8
3	50.4	19.5
4	48.7	21.3
5	50.4	20.8
6	49.8	20.3
7	51.0	19.3
8	48.1	19.2
9	48.4	20.7
10	48.9	193
11	49.5	19. G
12	48.3	18.9

the surface of each crosstie having a calculated moisture content of 45 to 51 percent.

The midsection average and transverse moisture content distribution and specific gravity values for 120 crossties air seasoned at each plant are shown in tables 2 and 3. The transverse and longitudinal moisture distribution values obtained at one plant are shown in figure 6.

In table 4 are listed the crossties that received satisfactory treatment when at a moisture content of approximately 50 percent. In 93 percent of these crossties 100 percent of the annual rings of the borings showed penetration by the preservatives, and 7 percent showed penetration in 91 to 97 percent of the annual rings.

Table 5 shows the air-seasoning periods that were required by 7- by 9-inch by 8½-foot commercial red oak crossties when piled during different months at Galesburg, 111. and at Orrville, Ohio. The table is based on the same data used in drawing the curves in figures 2 and 3.

The average moisture content values, treating conditions, retentions, and percentages of rings of borings penetrated are shown in tables 6 and 7. The computations to determine the percentage of rings penetrated were made in accordance with AWPA recommended practice.[5]

According to AWPA Specification T6-48 (Revised): "Standard Specification for the Preservative Treatment of Ties by Pressure Processes," 65 percent of the rings must be treated if the ties are to be accepted.

As previously mentioned, the daily weights of a wood element at each plant were used to

[5]R2-48 (Revised): Standard Instructions for the Inspection of Preservative Treatment of Wood, paragraph 3.413.

Table 2.—Transverse Moisture Distribution, Average Moisture Content, and Specific Gravity Based on 10 Sections Cut From 10 Crossties From Each Pile at Galesburg, Ill., After an Average Seasoning Period of 14.5 Months

Pile	Moisture content Outer inch Percent	Next inch Percent	Core Percent	Whole section Percent	Specific gravity[1]
1	26.5	46.4	63.2	42.2	0.593
2	25.4	42.2	62.0	38.9	.600
3	26.9	46.7	68.9	43.3	.605
4	28.0	46.7	68.9	44.9	.596
5	22.9	37.9	49.7	33.6	.588
6	30.8	52.1	64.0	45.5	.632
7	31.0	51.5	64.6	46.2	.629
8	24.6	42.8	46.7	36.0	.614
9	28.4	48.4	66.8	43.6	.570
1	28.0	47.3	63.7	42.0	.594
11	22.1	41.2	50.6	34.8	.605
12	27.0	46.0	67.6	42.0	.594
Av	26.8	46.1	61.2	41.1	.602

[1]Based on volume when green and weight when oven-dry.

Table 3.—Transverse Moisture Distribution, Average Moisture Content, and Specific Gravity Based on 10 Sections Cut From 10 Crossties From Each Pile at Orrville, Ohio, After an Average Seasoning Period of 18.0 Months

Pile Number	Moisture Outer inch Percent	Next inch Percent	Core Percent	Whole section Percent	Specific[1] gravity
1	22.5	39.1	48.4	34.2	0.570
2	21.7	38.3	48.6	33.0	.578
3	24.8	41.0	47.8	36 2	.568
4	24.8	42.0	50.0	36.3	.612
5	26.0	44.4	51.3	38.0	.588
6	29.5	56.2	71.0	48.0	.562
7	31.2	52.3	73.5	42.4	.548
8	25.2	46.7	55.4	37.0	.584
9	28.2	42 3	51. 1	37.5	.569
10	26.4	45.7	63.6	41.0	.543
11	24.9	51.2	61.8	42.4	.580
12	25.5	49.0	61.9	36.3	.591
Av	25.9	45.7	57.0	38.5	.574

[1] Baaed on volume when green and weight when oven-dry.

determine equilibrium moisture content values. The relationship of equilibrium moisture content values to relative humidities at various temperatures is shown in figure 5. The relative humidities corresponding to equilibrium moisture content values recorded at Orrville were compared with the relative humidities determined by the Weather Bureau Office at Colum-

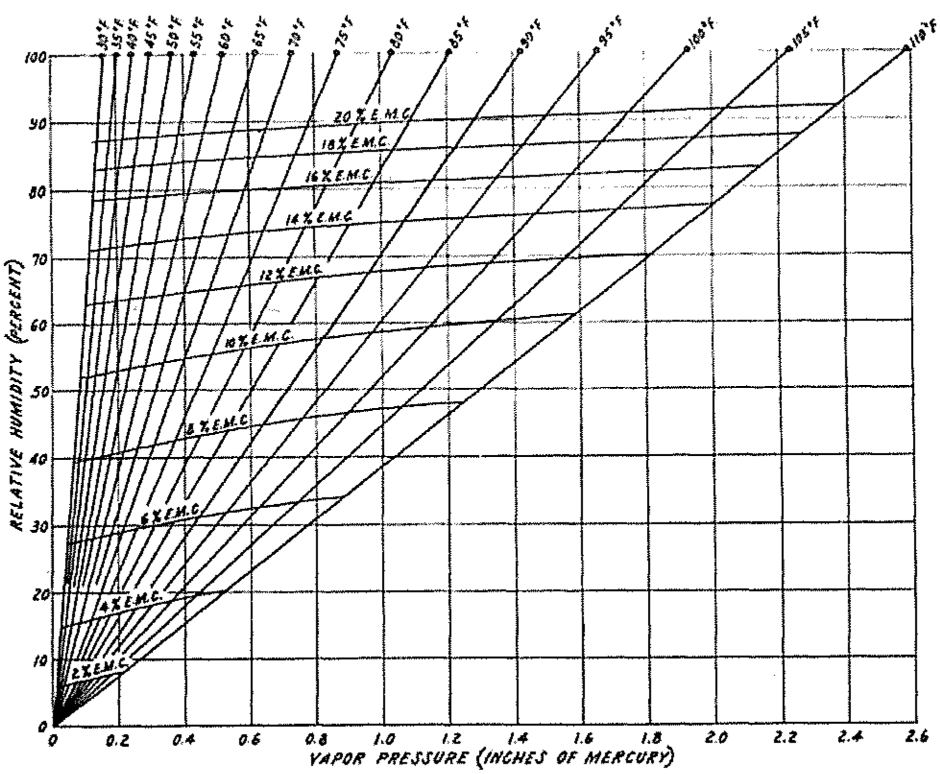

Figure 5.—Equilibrium moisture content as a function of temperature, relative humidity, and partial vapor pressure.

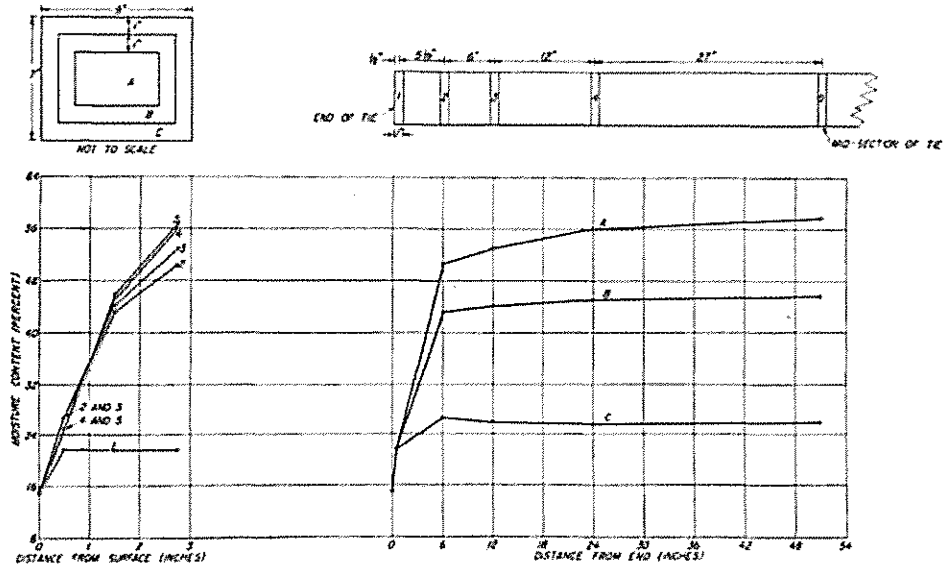

Figure 6.—Transverse and longitudinal moisture content distribution based on 120 commercial red oak crossties 7 by 9 inches by 8½ feet in size, after air seasoning for 18 months at Orrville, Ohio. Curves at lower left numbered according to moisture section cut from ties as shown at upper right; curves at lower right lettered according to thickness zones as shown in upper left.

Table 4.—Commercial Northern Red Oak Crossties With Preservative Retentions of About 8 Pounds or More When Treated at a Moisture Content of About 50 Percent

Number of crosstie	Moisture content Percent	Retention of preservative Pounds per cubic foot	Number of crosstie	Moisture content Percent	Retention of preservative Pounds per cubic ft.
1E1	48.7	9.52	9G1	50.0	9.61
1D11	50.8	8.86	9A2	48.7	10.11
			9D4	48.9	8.16
2F5	49.0	11.60	9G5	51.0	8.61
			9C9	48.7	9.78
			9D1	49.8	9.64
3S6	49.4	11.27	9C2	49.3	8.89
3D5	49.7	10.79	9A4	49.5	8.16
3S8	49.6	9.66	9B4	49.3	10.24
3F9	48.7	10.69	9H5	49.3	10.26
			9E7	48.8	12.18
4F3	49.0	8.58	9H7	49.8	9.90
4G3	49.3	7.73	9B8	50.0	8.77
4A8	49.8	8.45	9G8	49.8	9.08
4S6	50.5	7.90	9B9	49.1	8.80
4C5	49.8	7.72	9D9	49.3	8.72
4A7	49.3	7.97			
4B8	49.7	7.94	10B1	48.8	8.40
4S10	51.2	8.89	10S5.	50.0	10. 85
4B10	50.6	9.18	10S10	51.0	8.60
4D11	50.9	8.40	10F9	50.2	8.18
6D2	50.5	8.29	11G9	48.6	8.07
6E3	51.1	9.02			
6F4	50.5	8.21	12S2	49.2	9.68
6S6	51.5	9.12	12B3	49.0	8.79
6B7	51.5	8.56	12B4	48.8	11.18
6D7	49.3	7.94	12C5	49.4	9.74
6E9	50.2	7.94	12B8	48.8	7.83
6E10	51.2	8.62	12E9	48.7	8.50
			12S11	48.7	9.25
7E7	49.5	7.63	12D4	48.7	8.61
7H7	50.3	7.94	12E4	48.8	11.33
7B2.	51.2	8.92	12F5	49.7	8.16
7S5	49.9	7.77	12G5	49.5	8.62
			12D8	48.8	8.66
8D8	49.6	8.20	12A10	49.3	8.40
8S10	50.8	8.14	12E11	48.7	8.57

bus, Ohio. Likewise, the monthly average temperatures at the two locations were compared. The results are plotted in figures 7, B and 8. Similarly figures 7, A and 9 show the relationship of relative humidities and temperatures at Galesburg and Peoria, Ill. These graphs indicate that the Weather Bureau records of temperature and relative humidity would be very useful in estimating air-seasoning periods at the two treating plants provided rainfall is not excessive. It is probable that better estimates of air-seasoning periods could be made if rain-tight covers were provided for the piles.

Table 5.—Air-Seasoning Periods That Were Required by 7- by 9-Inch by 8 1/2-Foot Commercial Red Oak Crossties[1] to Attain an Average Moisture Content of About 50 Percent at Orrville, Ohio and Galesburg, Ill.

	Piled at Orrville, Ohio				Piled at Galesburg, Ill			
		Average moisture content		Air-seasoning		Average moisture content		Air-seasoning
Pile Number	Date erected	Initial Percen	Attained Percent	period Months	Date erected	Initial Percent	Attained Percent	period Months
1-----------------	April 7, 1937	87.5	51.7	7.3	May 13, 1937	81.0	50.6	4.3
2-----------------	May 22, 1937	78.0	49.1	4.8	June 19, 1937	78.1	51.6	5.1
3-----------------	June 14, 1937	82.2	50.4	11.9	July 24, 1937	68.4	50.1	3.9
4-----------------	July 14, 1937	74.6	51.4	10.9	Aug. 19, 1937	68.1	49.9	9.5
5-----------------	Aug. 13, 1937	76.2	50.4	12.3	Sept. 12, 1937	73.8	50.1	10.3
[2]-----------------	Sept. 10, 1937	83.3	49.8	12.1	Oct. 14, 1937	75.0	53.9	9.3
7-----------------	Oct. 13, 1937	82.5	50.5	12.1	Nov. 8, 1937	72.9	51.3	9.5
8-----------------	Nov. 15, 1937	76.3	51.5	9.2	Dec. 24, 1937	74.8	49.6	9.1
9-----------------	Dec. 7, 1937	80.3	48.4	8.5	Jan. 17, 1938	89.1	50.5	9.1
10-----------------	Jan. 6, 1938	82.3	48.9	8.2	March 17, 1938	84.0	49.7	6.3
[3]11-----------------	Feb. 7, 1938	86.7	49.5	16.5	March 29, 1938	79.1	49.4	5.9
12-----------------	March 17, 1938	73.3	48.3	5.9	April 15, 1938	86.2	51.1	7.1

[1] All crossties were commercial northern red oak except as otherwise noted.
[2]Sixty-one percent of the crossties in pile 6 at Orrville were from Windsor, N. C.
[3]All crossties in pile 11 at Orrville were from Norfolk, Va.

Table 6.—Final Average Moisture Content Values, Treating Conditions, and Preservative Retention and Penetration in 7- by 9-Inch Commercial Northern Red Oak Crossties at Galesburg, Illinois

	Number of Cross-ties	Moisture content	Pressures: Initial air	Pressures: Maxim Treat-ing	Treating temperature	Pressure period	Retention: Maximum	Retention: Minimum	Retention: Average	Penetration: Number of borings	Penetration: Annual rings penetrat
		Percent	Lb. sq. in.	Lb. per sq. in	°F.	Hours	Lb. per cu. ft.	Lb. per cu. ft.	Lb. per cu. ft.		Percent
1.---	64	42.3	20	175	200	5	12.37	4.25	9.37	64	99.4
2----	76	40.0	20	175	190-200	5	12.50	7.07	10.30	75	99.8
3----	90	41.9	20	175	200	5	12.13	4.11	9.50	89	99.4
4----	90	45.4	20	175	200	5	12.75	1.84	7.50	87	93.5
5----	90	35.1	20	175	196-203	6.2	13.47	2.71	10.51	89	97.5
6----	90	48.7	20	175	178-200	5-10.5	9.34	2.00	5.90	90	93.1
7----	90	48.2	20	175	178-202	5-10.5	9.61	2.30	6.21	84	92.5
8----	90	40.3	20	175	196-203	6.2	10.05	3.28	6.83	89	96.2
9----	89	46.6	20	175	178-203	6.2-10.5	13.56	6.70	9.15	89	99.1
10---	90	43.2	20	175	178-203	6.2-10.5	11.43	5.68	8.73	88	100
11---	90	40.9	20	175	196-203	6.2	10.07	2.19	7.22	90	95.9
12--	90	46.8	20	175	178-203	6.2-10.5	12.24	5.99	9.03	88	98.9

Table 7.—Final Average Moisture Content Values, Treating Conditions, and Preservative Retention and Penetration in 7- by 9-Inch Commercial Red Oak Crossties[1] at Orrville, Ohio

Pile No.	Number of cross-ties	Moisture content	Pressures: Initial air	Pressures: Maximum treat ing	Treating temperature	Pressure period[2]	Retention: Maximum	Retention: Minimum	Retention: Average	Penetration: Number of borings	Penetration: Annual rins penetrated
		Percent	Lb. sq. in.	Lb. per sq.in.	°F.	Hours	Lb. per cu. ft.	Lb. per cu. ft.	Lb. per cu. ft.		Percent
1 --	67	38.8	60	200	210	6	12.04	2.82	8.83	48	95.6
2---	73	36.1	50	200	210	51/2	11.91	3.52	8.43	41	84.2
3---	76	42.5	60	200	200	41/	10.22	2.97	7.10	---------	------------
4---	75	43.5	60	200	210	53/4	11.72	1.93	7.50	---------	------------
5---	74	46.3	55	200	210	6	9.29	4.71	6.87	---------	------------
6---	[3]76	47.8	45	200	210	6	18.04	3.03	7.66	---------	------------
7---	55	47.7	55	200	210	51/2	9.95	5.30	7.49.	30	96.0
8---	75	42.7	55	200	210	51/2	13.18	3.86	7.06	25	84.8
9---	76	38.1	70	200	210	41/2	9.14	2.87	6.43	24	95.1
10--	76	39.1	60	200	210	51/2	12.47	3.05	8.13	22	95.5
11--	[4]76	44.7	60	200	210	51/2	8.58	2.40	5.73	32	88.5
12--	76	35.3	60	200	210	51/2	9.97	2.85	7.30	34	90.2

[1]All crossties were commercial northern red oak except as otherwise noted.
[2]Followed by final vacuum of 22 to 24 inches of mercury for approximately 1 hour.
[3]Forty-seven crossties from Windsor, N. C. [4] All crossties from Norfolk, Va.

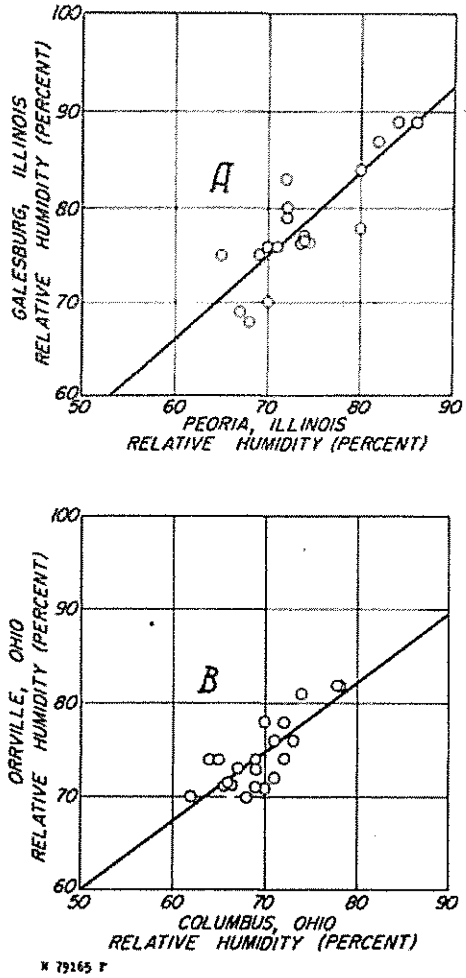

Figure 7.—Relative humidity at different locations: A, relationship of relative humidity at Peoria, 111., to that at Galesburg, 111.; B, relationship of relative humidity at Columbus, Ohio, to that at Orrville, Ohio.

Discussion of Results

Figures 2 and 3 clearly show the marked retarding effect of winter weather on the air seasoning of commercial red oak crossties. Little or no drying occurred under such conditions when the moisture content was below about 70 percent. The minimum average for a pile after 18 months' seasoning was about 35 percent.

The data in table 1 indicate that electric moisture meter readings taken at a depth of $^1/_2$ inch are a fair indication of average moisture content when the crossties have died to 50 percent or less. When the readings were 21 percent or less, the average moisture content was 50 percent or less.

Figure 6 indicates that after 18 months' air seasoning the transverse moisture content varies from 15 percent at the surface to 57 percent in the core at the midsection of a 7- by 9-inch red oak crosstie. Figure 6 shows also that in the outer 2 inches of the cross section, comprising 16 percent of the cross-sectional area, the end-

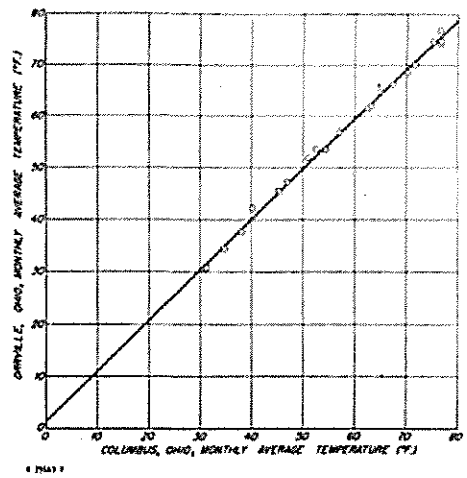

Figure 8.—Relationship of temperature at Columbus, Ohio, to that at Orrville, Ohio.

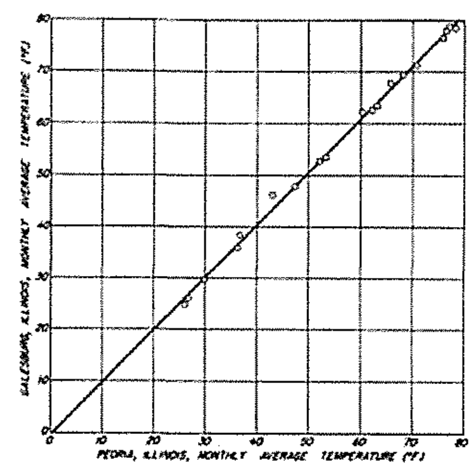

Figure 9.—Relationship of temperature at Peoria, 111., to that at Galesburg, 111.

drying effect extends inward only about 6 inches, while in the core it extends inward about 24 inches.

To the extent to which moisture content, rather than wood structure, is a controlling factor in treatment, table 4 indicates that 7- by 9-inch commercial northern red oak crossties at a moisture content of 50 percent can be satisfactorily treated with a 50-50 mixture of creosote and petroleum.

Figures 7, 8, and 9 indicate that Weather Bureau records of temperature and relative humidity should be very useful in estimating air-seasoning periods provided that precipitation is not excessive or that the crossties are protected from precipitation. Referring to figure 7, A, for example, a relative humidity of 70 percent at Peoria corresponds to 75 percent at Galesburg. It is evident from figure 9 that a temperature of 70° F. at Peoria corresponds to a temperature of 71° F. at Galesburg. In figure 5 the equilibrium moisture content corresponding to 71° F. and 75 percent relative humidity is 15 percent. Figure 4, A is based on original and final moisture content values of 85 and 50 percent, respectively, and an equilibrium moisture content of 15.1 percent (Appendix). Referring to curve 1 in figure 4, A the average drying time would be about iy$_2$ months, unless winter months were a part of the air-seasoning period, in which case the period would be extended 3 or 4 months when the average temperature is 71° F.

Aside from weather effects and inherent differences in drying-rate factors of various species in the red oak group, differences in air-seasoning periods required by the different piles may be attributed to differences in location of piles with respect to surrounding piles and alleys. For example, it is to be expected that piles closely spaced in the middle of a row would dry more slowly than piles next to a wide alley, where air circulation would be more rapid. The effect of pile location cannot be accurately gaged because the spaces around the piles varied from time to time.

A comparison of the last line of data in table 2 with that in table 3 indicates that the principal effect of seasoning 7- by 9-inch commercial northern red oak crossties for 18 months instead of 14.5 months is to reduce the moisture content of the core about 4 percent, with but little effect upon the rest of the cross section, comprising 76 percent of the total cross section.

Table 5 indicates that the time required to air season the crossties at Galesburg varied from 4.3 months when they were piled in May to 10.3 months when piled in September.

Corresponding air-seasoning periods for crossties at Orrville were 4.8 and 12.1 months (table 5). It is interesting to note that the time required for Pile 11 at Orrville, which was commercial southern red oak, was 16.5 months, or twice as long as that for Pile 10 at Orrville, which was commercial northern red oak.

There were wide differences both in retention and in penetration in individual crossties (tables 6 and 7). These differences, however, are not necessarily related to moisture content of the wood but may result from wood structural differences. For example, air permeability tests[6] made on sections cut from two crossties showed the permeability in one crosstie to be 40 times that in the other. The retention of preservative in the crosstie with smaller per-meability was 3-66 pounds per cubic foot, while the corresponding figure for the other crosstie was 7.18 pounds per cubic foot. The moisture content of the low-permeability crosstie was 42.5 percent and its specific gravity (based on oven-dry weight and volume when green) 0.567, while the corresponding data for the other crosstie were 47.5 percent and 0.586. In other words, the crosstie with the higher moisture content and higher specific gravity was much more permeable than the other crosstie. Examination of the sections tested showed that the tyloses were much more abundant in the low-permeability crosstie than in the other crosstie and indicated the importance of the effect of tyloses on retention of preservative.

Summary and Conclusions

1. A method is described that permits an estimate to be made of the time required to air season green 7- by 9-inch commercial northern red oak railroad crossties under given conditions of temperature and relative humidity. A specific application is made to the air seasoning of crossties during drying from 85 to 50 per-

[8] Variation in the Porosity of Twelve Species of Oak: Southern Lumberman, March 15, 1942, pp. 31 to 33.

cent moisture content. Besides weather, other factors affecting estimates of the length of air-seasoning periods may be variations of the drying-rate factor, K, as influenced by species differences in the red oak group, method of piling, and position of a pile with respect to surrounding piles and alleys.

2. Commercial northern red oak crossties piled by the 8-by-1 method may reach a moisture content of 50 percent in 5 months if piled in the spring and may require twice as long if piled in the fall.

3. A method of estimating moisture content distribution is described and an application is made to 7- by 9-inch crossties after 14.5 and 18.0 months' air seasoning.

4. In the outer 2 inches, representing 76 percent of the volume of a 7- by 9-inch red oak crosstie, the end-drying effect after 18 months extends inward only about 6 inches. In the core the effect may extend inward 2 feet.

5. The data taken with a resistance type of electrical moisture meter at one plant indicate that, when readings taken at a depth of y_2 inch are 21 percent or less, the average moisture content is 50 percent or less.

6. A considerable number of crossties were treated at a moisture content of about 50 percent, and were, according to AWPA requirements, treated satisfactorily with respect to retention and penetration.

7. Normally, commercial red oak used for crossties has open pores. Sometimes, however, the wood may sporadically develop tyloses that interfere more or less with treatment. Consequently, treatment in such crossties may be unsatisfactory even though they are dried to an average moisture content of 50 percent.

Appendix

In 1925 the U. S. Forest Products Laboratory suggested that there might be an analogy between the calculations for heat conduction and moisture movement in wood.[7] The pertinent equations for diffusion are as follows.

Newton's law of diffusion in an infinite sheet may be expressed by the Fourier equation:

$$\frac{dm}{dt} = K\frac{d^2m}{dX^2} \text{ -----------------------------------(1)}$$

In this equation, dm = differential concentration; $= \frac{d^2m}{dx^2} =$ change in concentration with respect to differential distance x from the surface; dt = differential time; and K is the diffusion constant. The equation expresses the fact that the change of concentration with respect to time is proportional to the slope of the concentration gradient. The solution of this equation is:

$$\Delta = \frac{4}{\pi}\left[e^{-\left(\frac{\pi}{2}\right)^2 T}\sin\frac{X\pi}{2R} + \frac{1}{3}e^{-9\left(\frac{\pi}{2}\right)^2 T}\sin\frac{3X\pi}{2R} + \frac{1}{5}e^{-25\left(\frac{\pi}{2}\right)^2 T}\sin\frac{5X\pi}{2R} + \ldots\ldots\right] \text{-----(1)}$$

In this equation A = free liquid concentration per unit volume initial free liquid concentration per unit volume' x = distance from surface, R = half slab thickness, T = RB _ , ® = time, and K = R^2 diffusion constant. The integration of equation 2 is as follows:

$$E = \frac{8}{\pi^2}\left[e^{-\left(\frac{\pi}{2}\right)^2 T} + \frac{1}{9}e^{-9\left(\frac{\pi}{2}\right)^2 T} + \frac{1}{25}e^{-25\left(\frac{\pi}{2}\right)^2 T} + \ldots\ldots\right] \text{----------------(3)}$$

and expresses the degree to which the specimen has been dried.

The theory upon which these equations are based involves a number of assumptions: (1) the validity of Newton's law of diffusion; (2) the constancy of the diffusion constant; (3) a uniform moisture distribution when the drying begins; (4) that the effective moisture movement is normal to the surface; (5) that the surface fibers attain a moisture content that is in equilibrium with the surrounding atmosphere as soon as drying begins; (6) that the thickness of the specimen does not change; and (7) that the temperature and relative humidity remain constant during the drying process.

Even though the conditions underlying the mathematical theory are seldom if ever met in practice, methods are available that have proved helpful in estimating the time required to dry various materials.

[7] Tuttle, Fordyce. A Mathematical Theory of the Drying of 'Wood. Franklin Inst. Journal 200:609-614, illus. 1925.

Table 8.—Actual and Calculated Average Transverse Moisture Distribution Values for 120 Crossties at Each of Two Treating Plants After Air-Seasoning Periods Shown

Treating plant location	Average air-seasoning period	Moisture content distribution					
		Actual			Calculated		
		Outer inch	Next inch	Core	Outer inch	Next inch	Core
	Months	Percent	Percent	Percent	Percent	Percent	Percent
Galesburg, Ill.	14.5	26.8	46.1	61.2	25.0	42.5	57.5
Orrville, Ohio	18.0	25.9	45.7	57.0	23.8	41.7	55.7

The solution of such equations by ordinary methods is too complicated for practical use. In 1929, however, Sherwood[8] devised methods of simplifying the calculations by means of graphs.

Figure 10 is based on Sherwood's curves for the calculation of moisture distribution, and figure 11 is useful in calculating the degree to which drying has progressed.

Referring to figure 10, the abscissas are average values of evaporable moisture, E, which is equal to

$$\frac{\text{Present moisture content} - \text{equilibrium moisture content}}{\text{Original moisture content} - \text{equilibrium moisture content}}$$

For example, suppose that a crosstie has dried from an initial moisture content of 85 percent to 50 percent and that the equilibrium moisture content during the drying was 15 percent. Then

$$E=\frac{50-15}{85-15}=0.50$$

The ordinates are individual values of E at different zones of a section corresponding to average values of E for the entire section. For example, when the average value of E is 0.60, the corresponding value at 50 percent of the drying thickness is about 0.70.

An application of the use of figure 10 is shown in table 8. In this table the actual moisture distribution values are taken respectively from the last line of data in table 2 and from the last line of data in table 3. The curves in figure 10 are based on a drying thickness which is one-half the thickness of the piece. For the

[8] Sherwood, T. K. The Drying of Solids—I. Indus. and Engin. Chem. 21:12-16, illus. 1929.

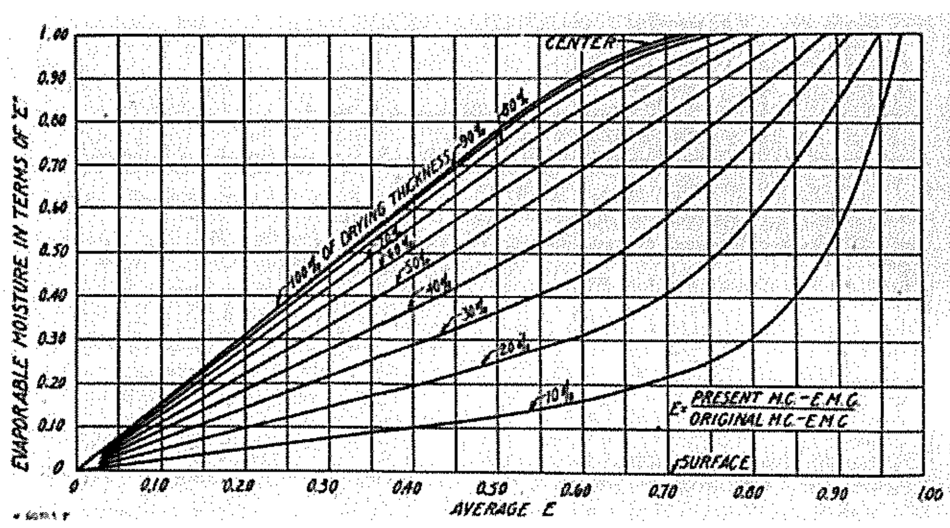

Figure 10.—Moisture-distribution curves for wood with individual values of E for different distances below surface plotted against average values of E.

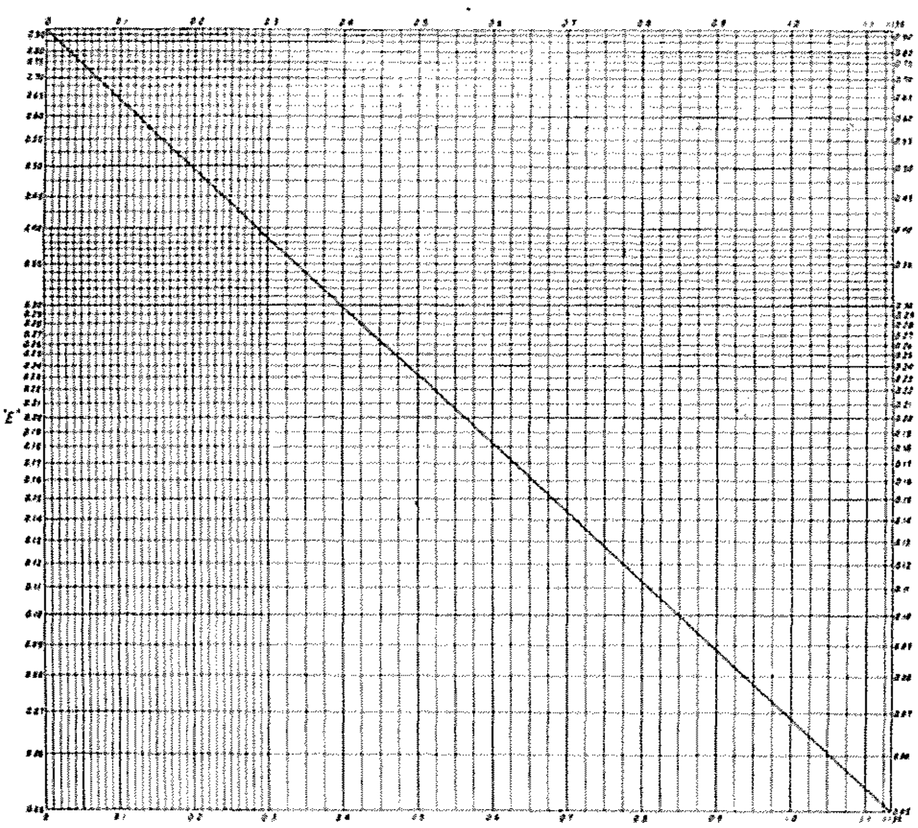

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Figure 11.—Relationship of E and T.

120 crossties at Galesburg, the drying thickness is 3.5 inches. For the outer inch the average depth is 0.5 inch. Hence, as referred to in figure 10, the percentage of drying thickness is

$\frac{0.5}{3.5} \times 100 = 14$ percent. Similarly, the percentages for the next inch and for the core are, respectively, 43 and 79. The average value of E, evaporable moisture for these crossties, is computed to be 0.45. With these percentages and this value of E, and with corresponding data for Orrville, the moisture distribution values shown in table 8 were computed and are in fair agreement with the actual values.

In figure 11 the ordinates are average values of E for the entire section. The abscissas in figure 11 are designated by T, which is equal to $\frac{K\Theta}{R^2}$. In this fraction K is the drying-rate factor,[9] Θ is time, and R is half the thickness of an infinite slab of material. The K value for a slab of given thickness and infinite width is ordinarily used in drying problems. Its magnitude is one-half the K calculated for a square with equivalent drying characteristics, and the K for an equivalent square is used in these calculations.

To apply this factor to the drying of a shape of material such as a crosstie, it is desirable to

0 The drying-rate factor is the percentage of moisture per day flowing transversely with respect to the fiber direction when the moisture gradient is 1 percent per inch in the direction of flow.

recall that, lor example, a stick 1 inch square will dry faster than a 1- by 8-inch board, other factors being equal, because in the former the ratio of surface to volume is greater than in the case of the board. Consequently, use is made of the concept of equivalent square, which can be expressed mathematically as follows:

$$2R = \sqrt{\frac{2a^2b^2}{a^2 + b^2}}$$

in which 2R is the side of a square with equivalent drying characteristics, a is the width, and b is the thickness of the material being dried. In the case of a 7- bv 9-inch crosstie:

$$2R = \sqrt{\frac{2 \times 7^2 \times 9^2}{7^2 + 9^2}} = 7.81 \text{ inches}$$

whence R = 3.91 and R^2 = 15.3 square inches.[10] Referring to figure 11, it is noted that

[10] The values of R^2 for the crossties at the two plants were based on the actual average dimensions of the cross sections rather than on the nominal dimensions, and were 16.02 and 15.50 for Galesburg and Orrville, respectively.

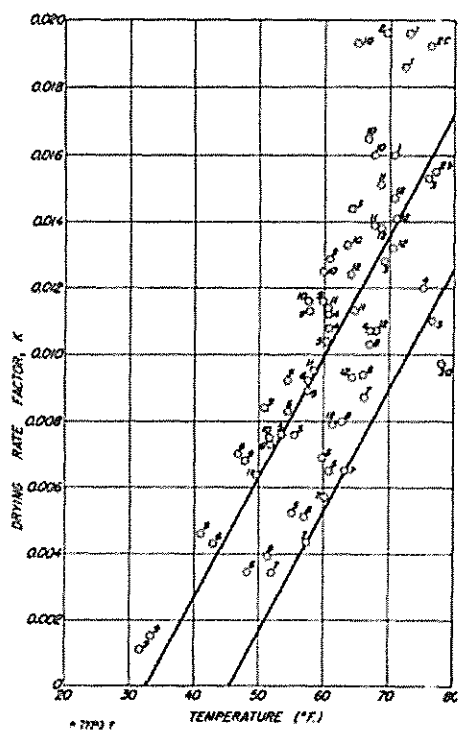

Figure 12.—Relationship of drying-rate factor K and temperature for 7- by 9-inch commercial northern red oak crossties at Galesburg, I11.

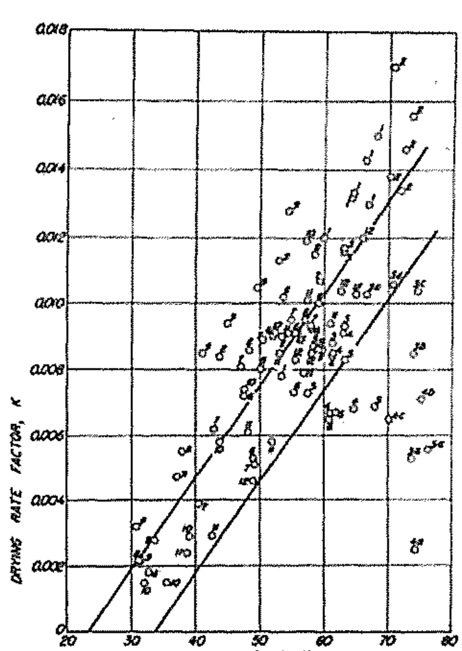

Figure 13.—Relationship of drying-rate factor K and temperature for 7- by 9-inch commercial red oak crossties at Orrville, Ohio.

when E = 0.50, T = 0.196. Substituting in the equation $T = \frac{K0}{R^2}$, $0.196 = \frac{K0}{15.3}$. The symbol 0, time, is determined experimentally. The factor K can then be computed and is related to temperature during the drying process.

By this procedure the points plotted in figures 12 and 13 were determined. The left-hand line in each figure is the straight line of best fit as computed by the method of least squares. The right-hand line in each case applies to piles with slowest drying rate. The point numbers relate to pile numbers; points with the same numbers correspond to different stages of drying of the same pile. In making the calculations, the months of December to March were omitted because, when the moisture content was below about 70 percent during these months, practically no drying occurred. In fact, in some cases, the moisture content increased slightly during those months.

With the relationship of K to temperature established from the experimental work, the data may be used to estimate the time required to air season commercial northern red oak crossties. Suppose that it is desired to compute the drying time required to dry the crossties from 85 to 50 percent corresponding to an equilibrium moisture content of 15.0 percent at various temperatures. Referring to the preceding discussion and figure 11, it is noted that for these conditions T = 0.196, and that according to figure 13, for a monthly average temperature of 70° F. during the drying period, K is

0.013 at Orrville. The equation $T = \frac{K\theta}{R^2}$ can be rewritten as $\theta = \frac{TR^2}{K}$. Substituting these values of T and K in this equation

$$\theta = \frac{0.196 \times 15.3}{0.013} = 231 \text{ days; or 7.7 months.}$$

Values of © computed in this manner are plotted against temperatures in figure 4. Curve 1 in figure 4, A is based on the left-hand line in figure 13. Likewise curve 1 in figure 4, B is based on the left-hand line in figure 14. These curves are based on the respective actual values of 15.1 percent and 14.2 percent equilibrium moisture content and actual values of R^2 of 16.02 square inches for Galesburg and 15.50 square inches for Orrville. The computations were made without considering the cold months, during which little or no drying occurred below 70 percent moisture content. Consequently, if in the example given above the air seasoning includes the winter months, 3 to 4 months should be added to the calculated period of 7.7 months.

Certain of the points on the right-hand side of figure 13 appear erratic and were not included in calculating the line of best fit. Rain appears to have been at least one of the factors affecting the positions of these points. For example, during the 5 days immediately preceding the weighing of the crossties for the determination of point 4a, the precipitation was 3.20 inches during 4 days, and the total number of rainy days since the preceding weighing was 15. The corresponding data for 4b were 0.15 inch in 1 day, and 8 rainy days. Similar data for point 3a are 1.28 inches in 5 days, and 19 rainy days; for 3b, 3.20 inches during 3 days and 10 rainy days; for 3c, no rain for 4 days, 0.154 inch in 1 day, and 8 rainy days; for 3d, 0.43 inch in 3 days, and 7 rainy days; and for 3e, about 0.1 inch in preceding 18 days. It thus appears that rain may have a marked effect on the drying-rate factor, and the indication is that rain-tight pile covers would be advantageous.

The corresponding data for point 2a in figure 12 are 2.48 inches in 2 days, and 6 rainy days in all; for point 2b, 0.11 inch in 2 days and 8 rainy days; and for point 2c, 0.03 inch in 1 day and 9 rainy days. Point la, as well as point 2a, was not included in calculating the line of best fit. Point la corresponds to the weighing when pile 1 was not near any other pile; that is, during the first stage of air seasoning when drying was abnormally rapid.

Figure 12 indicates that the drying rate factor varies greatly with temperature. This figure affords a basis for estimating the relative seasoning values of the months of the year. Thus in table 9 the monthly normal temperatures at Peoria, Ill., are tabulated together with K values as related to these temperatures in figure 12. Since the drying-rate factor in this case is maximum in July, this calendar month is rated as one seasoning month, and the other calendar months are rated in proportion to the corresponding K values as something less than one full seasoning month. The ratings are listed in the fourth column of table 9- At Galesburg, Ill., 7- by 9-inch by $8^1/_2$-foot commercial northern red oak crossties were seasoned from a moisture content of 81 percent in May to about 50 percent during the following October. This period is equivalent to about $4^1/_2$ seasoning months.

Table 9.—Monthly Normal Temperatures at Peoria, Ill., K Values, and Seasoning Months

Month	Temperature ° F.	K	Seasoning months
January---------------	23.1	0	0.0
February---------------	25.9	0	.0
March----------------	37.0	0.0017	.1
April-------------------	50.9	.0066	.4
May-------------------	61.7	.0105	.7
June-------------------	70.9	.0139	.9
July-------------------	75.4	.0156	1.0
August---------------	72.5	.0145	.9
September-----------	64.3	.0116	.7
October--------------	52.0	.0070	.4
November-----------	37.5	.0018	.1
December-------------	28.1	0	.0
Total---------------	---------------	--------	6.2

SESSION CHAIRMAN BESCHER: Are there any comments ?

J. S. PENNEY: Mr. Chairman, I think this is a very interesting and enlightening study. I would like to ask two questions. The first is in connection with piles 11 and 12 at Orrville. Pile 11, with 16$1/_2$ months seasoning took 5.73 pounds per cubic foot average with an 881/2 percent ring penetration, while Pile 12, with 5.9 months seasoning took 7.30 pounds per cubic foot and 90.2 percent ring penetration. I would like to ask if you have any explana- tion for the difference.

J. S. MATHEWSON: Pile 11 was southern red oak which apparently seasons more slowly and takes treatment less readily than the northern red oak.

MR. PENNEY: I have one more question. Do you feel this study is sufficiently conclusive to use the recommendations here as a yardstick in determining whether ties are sufficiently seasoned to treat, or not ?

MR. MATHEWSON: I think so, particularly if you do not consider that you could use the curves directly for any plant in the country; but if you will follow the method set up, I think you can do it. In other words, this is one specific application for these data; for other moisture content values and other weather conditions you would have to make some modification, but following the same general system. Does that answer your question ?

MR. PENNEY: Yes.

P. D. BRENTLINGER: I had the same ques- tion in mind that Mr. Penney had. You can't apply this formula all over the United States, because this is for purely northern red oak, and you can't say that southern red oak, moved anywhere, is going to season in five months. We users might be confronted with that problem. If we don't mark up a schedule when some- body thinks it should be marked up, somebody goes back to this paper and gets that formula out, figures it out and they say it ought to be 4.7 months. If the experiments had been based on all the kinds of ties we use the story would be different. I just want to bring to your atten-tion that this applies to northern red oak only.

SESSION CHAIRMAN BESCHER: Mr. Mathewson, we wish to thank you for presenting this paper.

We next have the subject "Treated Wood for Farm Homes and Barns", by Mr. B. G. Perkins, of the Doane Agricultural Service, St. Louis. Mr. Perkins' talk will be illustrated with slides.