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Air Drying of Ponderosa Pine Lumber in Arizona[1]

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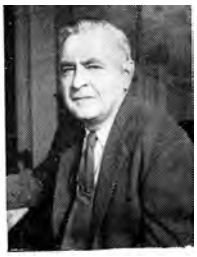

Studies of air-drying ponderosa pine in Arizona are described and results presented. The data includes the periods required to air-dry 4/4 common, 8/4 common, and 6/4 shop grades to 10 per cent moisture content; losses in grade and value during air drying and planing; and losses caused by the lack of pile roofs.

Introduction

THE CLIMATE OF ARIZONA favors rapid air drying to a relatively low moisture content. Some mills cutting ponderosa pine rely on air drying to dry all grades of lumber for planing, molding, and shipping. Other mills kiln dry select and shop grades green from the saw but air dry common.

The air-drying experiments reported herein were conducted at Flagstaff and Ariz., at plants owned by Southwest Lumber Mills, Inc. There were no dry kilns at these plants. Most of the lumber was air dried, but some upper-grade lumber was shipped to another company mill for kiln drying.

The study was conducted by the Forest Utilization Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., and the Forest Products Laboratory, Madison, Wis., in cooperation with the Southwest Lumber Mills, Inc., Phoenix, Ariz.

Objectives

Principal objectives of the study were (1) to determine the time required to air dry 4/4 and 8/4 common and 6/4 shop lumber to a moisture content of 10 per cent during the different seasons of the year; (2) to determine the minimum moisture content attainable during each season; (3) to measure drying defects and to interpret them in terms of material and dollar losses; and (4) to measure the drying defects that occurred in the boards of the two top courses of the piles, largely because pile roofs were lacking, and to interpret them in terms of material and dollar losses. Additional objectives were to determine the effect of two sticker thicknesses, 2 inches and 25/32 inch, on drying time and on defects that developed during the air drying of 8/4 common; to ascertain the relative amounts of drying defects that occurred in 4/4 and 8/4 common; and to evaluate the effect of moisture content on the amount of degrade during planing.

Experimental Work

Scope: Seventeen piles of lumber and 51 unit packages were used in the tests, which involved a total of 79,000 board-feet. There were 7 piles of 4/4 common, 6 piles of 8/4 common, and 4 piles of 6/4 shop. Nine piles were erected at Snowflake and 8 at Flagstaff.

Material: The lumber was obtained from the green chain at the Flagstaff mill and from the sorting chain at the Snowflake mill. The 4/4 and 8/4 lumber was graded as No. 3 common and better and was 12 inches wide and 8, 10, 12, 14, and 16 feet long. The 6/4 shop was random width, most of it 16 feet long. The 4/4 lumber at Snowflake was produced by resawing 8/4 boards. The 4/4 and 8/4 common lumber averaged about 80 per cent heartwood. The 6/4 shop averaged 28 per cent heartwood. The average green or initial moisture content of the common lumber was 51 per cent, that of the shop lumber 122 per cent.

Unit Packages: Unit packages 4 feet wide and 16 feet long were stacked three to a pile. In height the packages varied from 2 feet 9 inches to 4 feet 6 inches, depending on the thickness of the boards and the stickers as well as on the number of lumber courses. The packages were box piled, the edge tiers consisting of boards 16 feet long (Fig. 1). The shorter boards were placed in the two central tiers so that one end was always flush with one end of the package. The boards were piled edge to edge (Fig. 2).

Stickers were 25/32, 1-1/16, and 2⅛ inches thick, and from 2½ to 4 inches in width. Five tiers of stickers were used. At Snowflake the tiers were roughly 2, 6, 6, and 2 feet apart; at Flagstaff, about 3½, 4½, 4½, and 3½ feet. The unit packages of 4/4 common lumber at Flagstaff had extra tiers of stickers in the first four courses to provide support above the bunks of the straddle trucks and the forks of the forklift trucks (Fig. 2). The unit packages were built without sticker guides, but a measuring stick was used to position the tiers.

Lumber Piles: Most of the test piles consisted of 3 test unit packages and a dummy package consisting of lumber not in the tests. The piles of 8/4 lumber at Snowflake that were built with 2-inch stickers were the only ones that did not contain dummies. The dummy

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

This plant was dismantled in the spring of 1954.

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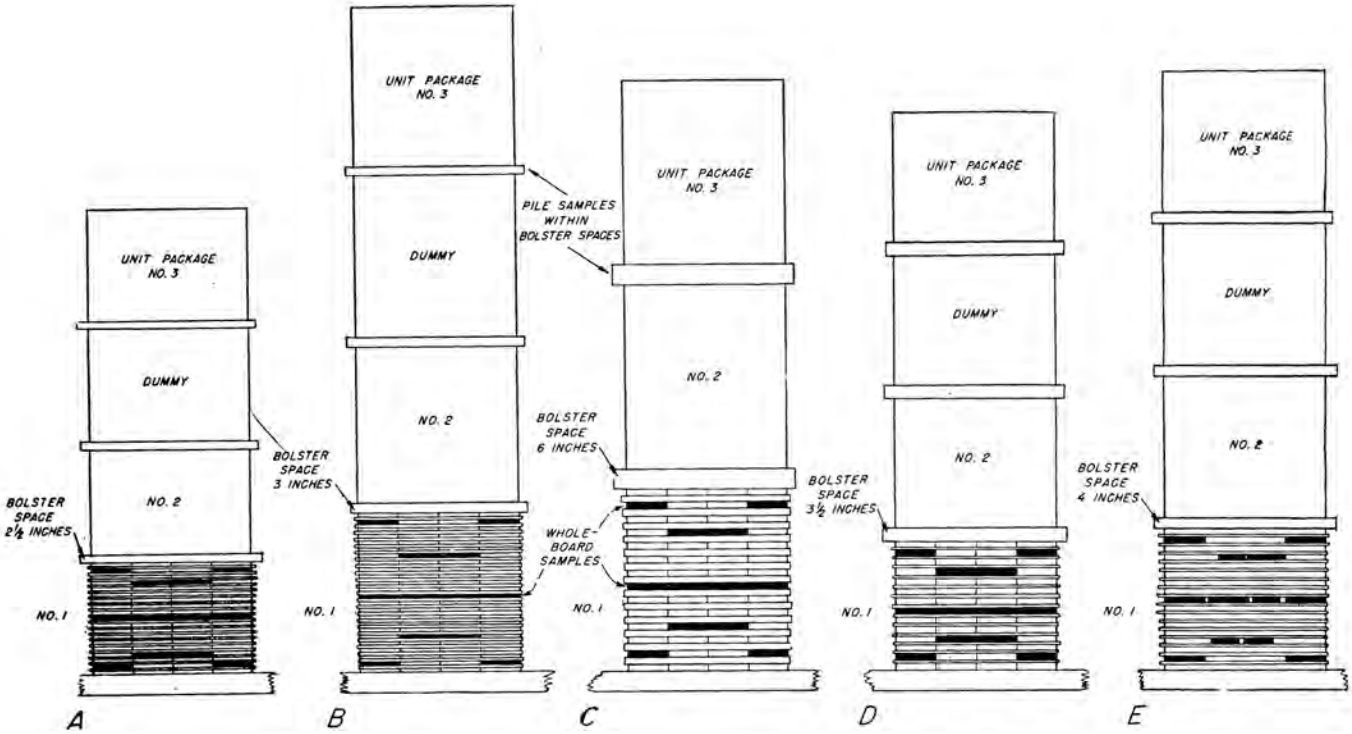

Fig. 1.—Diagrams of experimental piles. A: 4/4 common lumber on 25/32-inch stickers at Snowflake; B: 4/4 common lumber on 1-inch stickers at Flagstaff; C: 8/4 common lumber on 2-inch stickers at Snowflake; D: 8/4 common lumber on 25/32-inch stickers at Snowflake; E: 6/4 shop lumber on 1-inch stickers at Flagstaff.

unit packages contained lumber identical with that in the rest of the pile. The test unit packages were placed at the bottom, next above the bottom, and at the top of the pile (Fig. 1). The piles were built with forklift trucks.

The piles were placed on foundations of the fixed-beam type. The pile foundations at Snowflake consisted of two beams about 15 feet apart and about 16 inches above the ground. The foundations in the yard at Flagstaff consisted of four fixed beams placed roughly 31½, 9, and 3½ feet apart and about 1 foot above the ground. The runways between the foundations were surfaced with gravel at Snowflake (Fig. 3) and were planked at Flagstaff. At both Flagstaff, and, for the 8/4 lumber, Snowflake, central supports were provided for the piles (Fig. 3). The piles of 4/4 lumber at Snowflake had two supports over the 14-foot span between the foundation timbers.

The piles were placed 21½ feet apart in an inner row of the yard and were shielded at each end by other piles. They were not roofed.

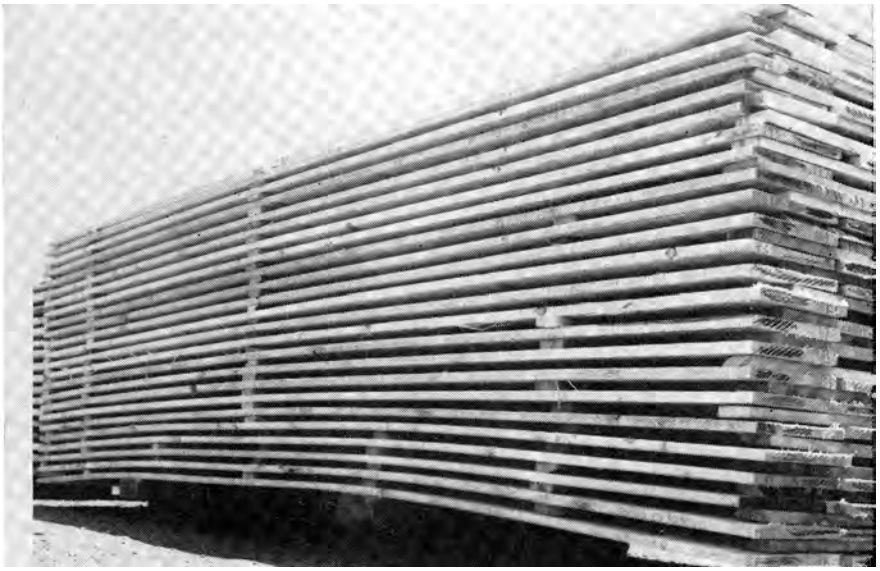

Fig. 2.—Unit package of 4/4 No. 3 common and better at Flagstaff, showing extra short tiers of stickers.

Samples : Three kinds of samples—pile, benchmark, and whole-board-were used to check rate of drying as the tests proceeded. The pile and whole-board samples were placed in the lumber pile. The benchmark samples were suspended beneath a shed roof and fully exposed to the air of the yard (Fig. 4). Pile and benchmark samples were 3½ feet long, whole-board samples 16 feet long. Sixteen pile samples were used in each pile of the first set and 8 in each pile of the other sets. They were placed on stickers in the bolster spaces just above the bottom unit package and just below the top unit package. Bolster spaces were so adjusted that the pile samples were spaced just as the boards of the pile were (Fig. 1). There were 12 whole-board samples in each unit package, or 36 for each pile. Fig. 1 shows the locations of these samples. Six benchmark samples of each kind of lumber in a set of piles were exposed in sheds (Fig. 4).

The benchmark samples supplied drying data that indicated the fastest drying that was possible under the prevalent atmospheric conditions. These data are not included in this report. They also provided data on surface checking, and supplementary data on the minimum moisture content values attainable during the different months. The pile samples provided drying time data for the atmospheric conditions within the lumber piles, and data on surface checking. The whole-board samples gave values for initial and final moisture content and data on surface and end checking. The whole-board samples also yielded data

Fig. 3.—Placing a pile sample in position between unit packages Nos. 1 and 2 while standing on the gravelled runway at Snowflake. The pile is composed of 8/4 lumber with 2-inch stickers.

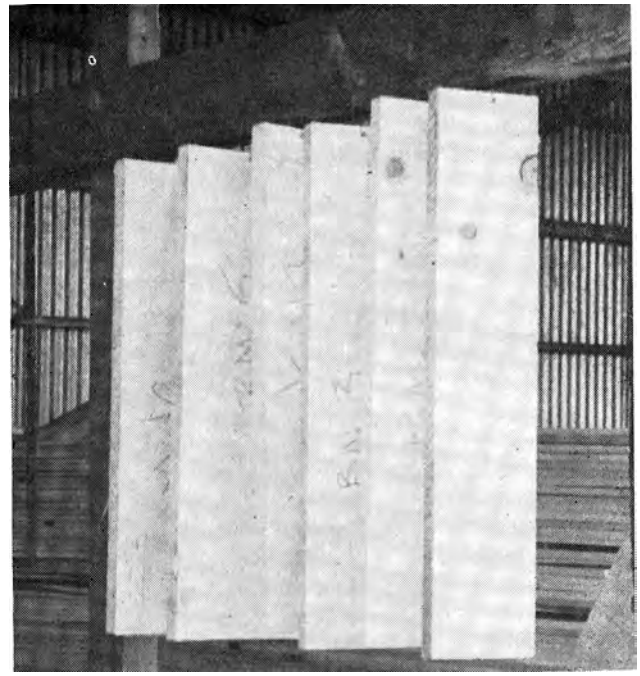

Fig. 4.—Benchmark samples of 6/4 shop lumber suspended within an open shed at Flagstaff.

on degrade, since they were graded green, air dry, and, in the case of the 4/4 lumber, after planing. Finally, the whole-board samples gave information on the percentage of heartwood and sapwood and on the character of the grain.

Tests and Measurements: All samples were weighed and tested for moisture content by the oven method to get moisture content values at the start, during, and at the conclusion of the air-drying experiments. Surface checks and end splits were measured in inches of length. Percentage of heartwood and the character of the grain were estimated. All lumber was tallied and graded when green and after air drying[4]. Most of the 4/4 lumber was also tallied and graded after it was planed.

Procedure: The first step in putting up a set of study piles was the selection of the material. The green lumber was then graded and representative boards were selected for the preparation of the samples. In the random-width 6/4 shop, no sample board was greater than 12 inches wide. The whole-board samples were numbered and weighed and the character of the grain, the percentage of heartwood, the grade, the total inches of surface checks on both faces, and the length of the longest end split were recorded.

The pile samples were cut from chosen boards together with 1-inch sections that were weighed, ovendried, and reweighed to determine their moisture content. The samples were end coated, numbered, weighed, and inspected as were the whole-board samples, except that they were not graded.

[4] Lumber was graded by Jack Hahn of Southwest Lumber Mills, Inc.

Each board in the piles was numbered and its exact position in the unit package recorded as the package was built.

When the pile was erected the pile samples were placed in the bolster spaces, the benchmark samples were suspended in an open shed, and the air drying was considered to have started. Then the benchmark and pile samples were weighed periodically and examined for surface checks and end splits. The sample weights gave moisture content values that were used to determine drying rates.

When the piles were taken down, the whole-board samples were weighed and a section was cut from each for the determination of moisture content by the oven method. The total length of surface checks and the length of the longest end split were measured. The whole-board samples were also graded in the air-dry condition and, if they dropped in grade, the reason for the degrade was recorded. The pile and benchmark samples were treated in the same manner except that they were not graded.

Most of the lumber from the piles of 4/4 common was planed after it was air dried. The lumber was graded after being planed and where there was a drop in grade the reason was given.

Observed Data

Climatological: Flagstaff is at an elevation of appoximately 6,900 feet; Snowflake about 80 miles away, is about 2,000 feet lower. As a consequence Snowflake is warmer and drier than Flagstaff. Temperatures at Snowflake average 7° F. above that at Flagstaff. Relative humidity at Snowflake averages almost 6 per cent lower than at Flagstaff. Total annual rainfall at Snowflake is 6 inches less than at Flagstaff. Climatological conditions affect air-drying rates, minimum moisture content values that can be attained, and development of drying defects.

Figs. 5 and 6 show the climatological data for Snowflake and Flagstaff respectively, as obtained from U. S. Weather Bureau reports. The wood equilibrium moisture content curve is based on the monthly mean temperatures and relative humidities.

The high temperatures during July and August are accompanied by moderately high relative humidity. During the time of the study, relative humidity at Snowflake was comparatively low during April, May, June, and September; the relative humidity during February was moderate. At Flagstaff, January and July are the months of high relative humidity with August, March, and December next. June is the month of lowest relative humidity, with September and May next in order. At both places, the heaviest rainfall occurs during July and August.

With relative humidity, temperature, and rainfall as criteria, the year can be divided into periods of different air-drying intensity. At Snowflake the months of April, May, and June constitute a period of rapid drying. The month of September is a secondary period of rapid drying. The months of July and August are a period of slow drying because of high relative humidity and heavy rainfall. The late fall and winter months are

characterized by generally high relative humidities and low temperatures, both of which result in slow drying. The conditions at Flagstaff are similar except that the spring period of rapid drying does not include April.

Drying Periods

Table 1 gives moisture content values lumber can be expected to attain in various months, as calculated for Flagstaff and Snowflake on the basis of mean monthly temperature and relative humidity. Lumber piled at Flagstaff can reach a moisture content of 10 per cent during February, April, May, June, August September, October, and November. Lumber piled at Snowflake can reach a moisture content of 10 per cent during all months except January, July, and December.

One-inch lumber: Piles of 1-inch No. 3 common and better were erected at Snowflake during June and October 1953 and January 1954 and at Flagstaff during July and October 1953 and January and May 1954. Since the climate of Snowflake averages both warmer and drier than that of Flagstaff, the drying periods were correspondingly shorter at Snowflake. Table 2 gives the periods required to air dry 4/4 boards to moisture content values of 10 and 15 per cent at Snowflake. The periods needed to reach 10 per cent moisture content range from **10** to 150 days.

The values in Table 2 were obtained by the use of actual and calculated[5] drying curves for the three test piles of 4/4 lumber at Snowflake and extrapolation based on climatological data. For example, the June pile never actually reached a moisture content of 10 per cent because of rains near the end of the drying period. The drying rate over the first 6 days, however, indicated that the lumber would have reached 10 per cent moisture content in 8-½ to 10 days if there had been no rain. A minimum period of 10 days was established, therefore, for air drying 4/4 common at Snowflake.

[5] The method used for calculating drying curves and periods is described in the appendix.

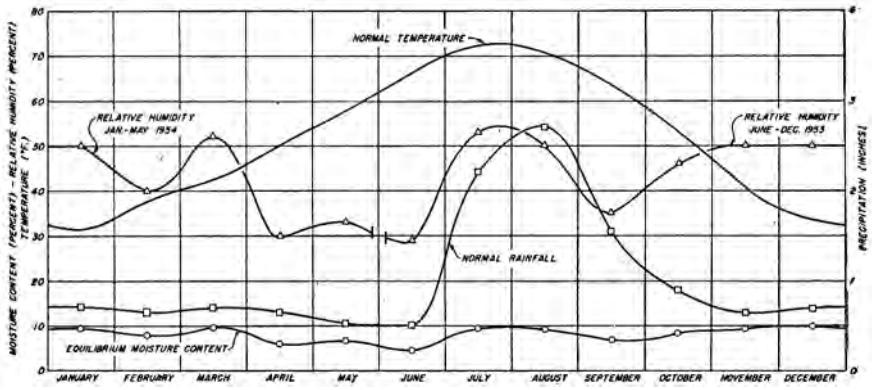

Fig. 5.—Climatological data for Snowflake, Ariz.

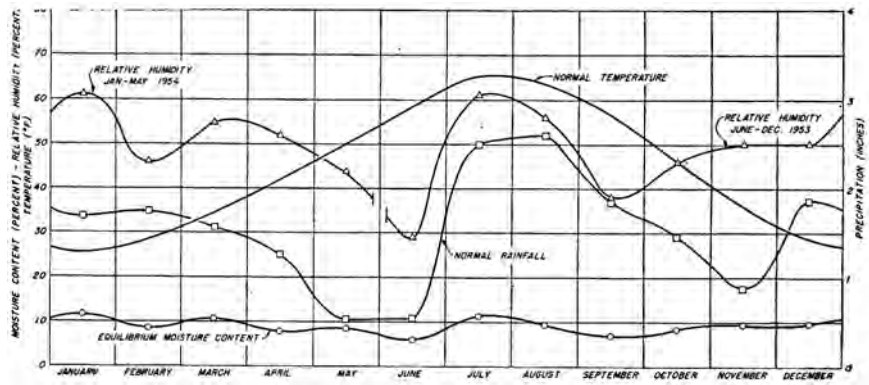

Fig. 6.—Climatological data for Flagstaff, Ariz.

The October pile was taken down in November, at which time the moisture content of the lumber was 13.6 per cent. The relative humidity during December and January corresponds to a wood equilibrium moisture content of about 10 per cent. Adding 1 per cent to this value gives 11 per cent. Consequently, the lumber in the October pile could not have reached a moisture content of 10 per cent during December or January. A moisture content of 10 per cent would probably have been reached during February or March. The maximum air-drying period of 120 to 150 days was selected on this basis.

The lumber of the January pile reached a moisture content of 8 per cent during February, or after 46 days;

Table 1.—MINIMUM MOISTURE CONTENT ATTAINABLE IN PONDEROSA PINE EXPOSED OUTDOORS DURING EACH MONTH OF THE YEAR

Month	Moisture content: Flagstaff* Per cent	Moisture content: Snowflake* Per cent
January	13	11
February	10	9
March	12	10
April	9	7
May	9	8
June	7	6
July	12	11
August	10	10
September	8	8
October	9	9
November	10	10
December	11	11

*These values were obtained by adding 1 per cent to the equilibrium moisture content values for wood corresponding to the monthly mean temperature and relative humidity.

Table 2.—PERIODS NEEDED TO AIR DRY PONDEROSA PINE TO MOISTURE CONTENT VALUES OF 10 AND 15 PER CENT AT SNOWFLAKE AND FLAGSTAFF, ARIZNORMAL

Month of pile erection	Drying period: 4/4 Common, Snowflake, 15 per cent moisture content Days	4/4 Common, Snowflake, 10 per cent moisture content Days	4/4 Common, Flagstaff, 15 per cent moisture content Days	4/4 Common, Flagstaff, 10 per cent moisture content Days	6/4 Shop at Flagstaff, 15 per cent moisture content Days	6/4 Shop at Flagstaff, 10 per cent moisture content Days	8/4 Common at Snowflake, 15 per cent moisture content Days	8/4 Common at Snowflake, 10 per cent moisture content Days
January	22	40	51	89	85	130	69	110
February	16	30	34	60	67	100	50	80
March	19	30	17	30	64	90	38	60
April	10	15	10	18	43	60	19	30
May	6	10	10	18	25	36	10	15
June	7	10	7	12	25	36	10	15
July	32	60	41	75	52	75	55	90
August	26	45	34	60	40	60	34	60
September	9	15	9	15	130	200	17	30
October	83	150*	94	170†	110	170	104	170
November	59	120*	79	140†	97	150	87	140
December	44	90*	62	110	95	140	75	120

*These values possibly can be reduced by 20 to 30 days.
†There is a possibility that these values can be reduced by 30 to 60 days.

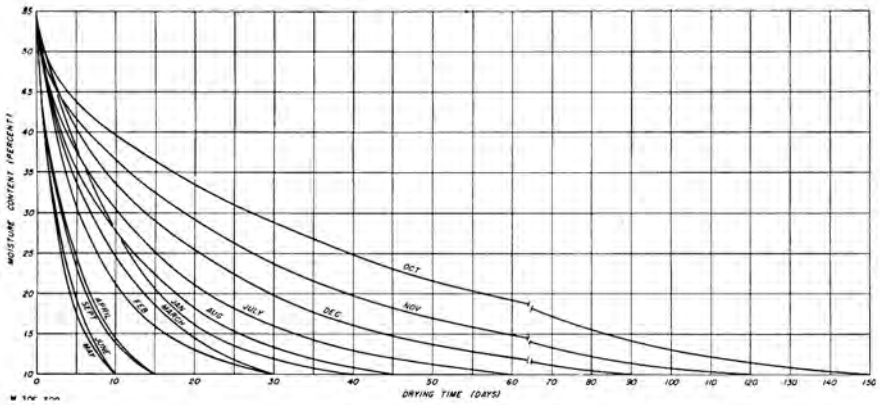

Fig. 7.—Calculated drying curves for 4/4 lumber piled at Snowflake.

it reached 10 per cent in 40 days. The air-drying periods for lumber piled during the other months were estimated and drying curves were calculated as described in the Appendix (Fig. 7).[6]

The periods given in Table 2 to air-dry lumber to a moisture content of 15 per cent were picked from calculated drying curves. Where the test piles reached a moisture content of 15 per cent in a relatively short period, but did not reach a moisture content of 10 per cent during a considerably longer period, the calculated periods for the 15 per cent moisture content figure are subject to large errors.

The periods required to air dry 4/4 No. 3 common and better at Flagstaff to a moisture content of 10 per cent range from 12 to 170 days. (Table 2). These data show that 4/4 lumber piled in October will not reach 10 per cent moisture content until the following April, 170 days later. There is, however, a possibility that 4/4 lumber piled early in October might reach 10 per cent moisture content in November or in February. The drying periods for lumber piled during the months of October to March inclusive were calculated on the basis of the attainment of 10 per cent moisture content in April.

Calculated drying curves were drawn for 4/4 No. 3 common and better piled at Flagstaff.

Shop lumber: The air drying of 6/4 shop lumber differed considerably from the air drying of 4/4 common. The higher green moisture content of the sapwood together with the added thickness, caused the drying periods to be longer. The data indicate that shop lumber can be air dried to 10 per cent in 36 to 200 days. (Table 2). The 36-day period applies to shop lumber piled during May and June and dried before the July showers come. The relatively dry month of September is not long enough to reduce the moisture content to 10 per cent. Lumber piled during July and August reaches 10 per cent during September. Occasionally 6/4 shop piled in September might reach 10 per cent in October or November if weather conditions were particularly favorable to drying.

Two-inch lumber: It took from 15 to 170 days to air dry 8/4 lumber to a moisture content of 10 per cent at Snowflake. Data indicate that lumber piled during May and the first half of June will reach 10 per cent in 15 days (Table 2). Lumber piled in April and September requires 30 days. Lumber piled in July and August reaches a moisture content of 10 per cent during September. Lumber piled during October does not each 10 per cent until the following April.

The effect of rain on drying periods varies. Rain falling near the start of a drying period has less effect than one falling near the end. Rain has more effect on a short period than on a long one. For example, a rainstorm occurring on the day a pile is erected has no measurable effect if the drying period is a long one, but a 10-day drying period may be lengthened by a day. Rain during the last day of a drying period when the lumber is near or at 10 per cent moisture content will prolong the period several days.

Surface Checking

Lumber that surface checks severely during air drying is seriously downgraded. For this reason, checking was critically observed. Total length of surface checks was measured in inches on both faces of a 16-foot board. Total checking in the 3—½—foot pile and benchmark samples was adjusted to a 16-foot board length.

Table 3 gives the amount of surface checking for the benchmark, pile, and whole-board samples of all test piles. The benchmark samples generally surface checked more than the pile or whole-board samples, presumably because they were completely exposed. The 8/4 No. 3 common and better lumber surface checked more than the 4/4 No. 3 common and better or the 6/4 shop. The 4/4 lumber surface checked least.

One-inch lumber : The surface checking of the whole-board samples indicates that 4/4 lumber piled during May or June tends to surface check more than that piled in October or January. These data are not entirely consistent but they indicate that 4/4 lumber checks most under severe drying conditions. The 4/4 lumber piled at Snowflake surface checked somewhat more than that piled at Flagstaff.

Shop lumber: Using the surface checking of the whole-board samples as a basis, the 6/4 shop lumber piled during May checked most. During May the weather was hot and dry. The lumber piled in January surface checked more than that piled in July

[6] Similar calculated curves were drawn for the 4/4 and 6/4 lumber piled at Flagstaff, and the 8/4 lumber piled at Snowflake.

Table 3.—SURFACE CHECKING OF AIR-DRIED PONDEROSA PINE AT SNOWFLAKE **AND FLAGSTAFF, ARIZ.**

Location	Lumber thickness and grade	Type of sample	Total surface checking during air drying			
			June–July 1953 Inches	October 1953 Inches	January 1954 Inches	May 1954 Inches
Snowflake	4/4, No. 3 Common and Better	Benchmark	65	48	48	---
	4/4, No. 3 Common and Better	Pile	16	12	13	---
	4/4, No. 3 Common and Better	Whole-board	19	2	8	---
Flagstaff	4/4, No. 3 Common and Better	Benchmark	24	92	26	133
	4/4, No. 3 Common and Better	Pile	6	46	0	141
	4/4, No. 3 Common and Better	Whole-board	4	9	7	15
Snowflake	8/4, No. 3 Common and Better (2-inch stickers)	Benchmark	202	81	158	---
	8/4, No. 3 Common and Better (2-inch stickers)	Pile	207	73	141	---
	8/4, No. 3 Common and Better (2-inch stickers)	Whole-board	145	83	113	---
Snowflake	8/4, No. 3 Common and Better (25/32-inch stickers)	Pile	168	121	117	---
	8/4, No. 3 Common and Better (25/32-inch stickers)	Whole-board	180	73	88	---
Flagstaff	6/4 Shop	Benchmark	219	101	153	260
	6/4 Shop	Pile	57	53	139	159
	6/4 Shop	Whole-board	7	55	140	176

and October, probably because the temperature during January averaged below freezing and consequently the large amount of water in the shop lumber was frozen. The small amount of surface checking in the July pile may have been due to the showers and mild drying conditions that came shortly after the pile was erected.

Two-inch lumber: The whole-board samples of the June piles surface checked considerably more than those of the other piles. The lumber in the June piles dried to a moisture of 18 per cent, and had surface checked severely before the July showers came. In the October and January piles, the lumber dried under milder conditions, particularly during the early part of the air-drying period. The 8/4 common lumber contained less water than the 6/4 shop and consequently did not surface check because of freezing.

One group of piles of 8/4 lumber was made with 25/32-inch and the other with 2-inch stickers. The average amount of surface checking in the three piles of each group was the same. The thinner stickers were used to permit the piling of more lumber in a unit package of given size and to retard drying by reducing air circulation. Some temporary retarding effect was evident, but apparently not enough to reduce surface checking.

Degrade During Air Drying

Drying defects, such as surface checking, end splitting, warping, staining, and the checking and loosening of knots, affect the grade of lumber adversely. Drying defects hence may cause dollar losses and sometimes material losses. For example, board may drop to No. 5 common, for which there is no market; or an end trim may be required.

Table 4 gives the dollar losses due to drying degrade, per thousand board-feet, and in percentage of green value for the lumber of all test piles. Prices on which calculated value losses are based are given in the Appendix. The losses in per cent of the green value are the best figures for comparisons among the different piles.

The losses during air drying increase with the thickness of the lumber. Piles made in January 1954 sustained the heaviest losses. The losses for the 4/4 lumber air dried at Snowflake were greater than those for the 4/4 lumber air dried at Flagstaff.

The losses in value for the piles of 8/4 lumber piler with 25/32-inch stickers were slightly less than those for the piles with 2-inch stickers.

Surface checking was the chief air-drying defect. Loose and. checked knots, warp, and shake also contributed to degrade and loss in value. Considering all the piles, the correlation between the surface checking of the 36 whole-board samples (Table 3) and losses in value is not close. The total length of the surface checks is not a direct measure of their effect on degrade. A few wide and deep surface checks are more likely to cause a drop in grade than many narrow and shallow ones.

To get data on common lumber only, the data for losses due to air-drying defects were analyzed after eliminating the comparatively few boards that were of considerably higher green grade than the general grade level of the pile. This analysis was limited to Nos. 2, 3, and 4 common in the 4/4 and 8/4 lumber and Nos. 1, 2, and 3 shop in the shop lumber. In addition, the boards in the top two courses of the pile were eliminated. Table 5 gives the resulting figures.

The losses per thousand board-feet and in per cent of green value are less in Table 5 than those in Table 4 except in three instances. However, the conclusions reached are generally unchanged.

The boards in the two top courses of the unroofed piles developed more severe drying defects than those lower down in the piles. Table 6 gives net losses in value and net losses in terms of percentage of the green value for the boards in the two upper courses. The general average losses per pile were: 4/4, $1.15; 6/4, $3.94; and 8/4, $5.39. The general average losses in percentage were 4/4, 10.2; 6/4, 16.6; and 8/4, 19.2.

The losses were heaviest in the January piles except for the 4/4 piles at Flagstaff. The May pile showed the heaviest loss for the piles of 6/4 shop. For all piles, the average loss of the

Table 4.-LOSS IN VALUE OF PONDEROSA PINE DURING AIR DRYING AT SNOWFLAKE AND FLAGSTAFF, ARIZ.

Location	Lumber thickness and grade	Loss: Per thousand board feet: June–July 1953 Dollars	October 1953 Dollars	January 1954 Dollars	May 1954 Dollars	Loss: Per cent of green value: June–July 1953	October 1953	January 1954	May 1954	Major cause of degrade and loss
Snowflake	4/4, No. 3 Common and Better	2.03	1.77	7.23	-----	2.4	1.7	7.5	----	Surface checks, June–July and January; loose knots, October
Flagstaff	4/4, No. 3 Common and Better	1.86	1.21	3.14	2.50	2.3	1.4	3.4	3.0	Surface checks, June–July and October; cross checks, checked knots and warp, January; shake and loose knots, May
Flagstaff	6/4 Shop	5.29	7.77	26.09	16.37	4.0	6.3	16.6	12.2	Surface checks, October and January; surface checks and warp, June–July and May
Snowflake	8/4, No. 3 Common and Better (2-inch stickers)	15.36	5.66	16.73	-----	16.2	6.1	17.6	----	Surface checks all piles
Snowflake	8/4, No. 3 Common and Better (25/32-inch stickers)	11.86	7.52	13.06	-----	13.1	8.2	14.5	----	Surface checks all piles

Table 5.-LOSS OF GRADE AND VALUE DURING AIR DRYING OF PONDEROSA PINE AT SNOWFLAKE AND FLAGSTAFF, ARIZ., IN PILES ERECTED DURING JUNE-JULY AND OCTOBER 1953 AND JANUARY AND MAY 1954, INCLUDING ONLY NOS. 2, 3, AND 4 COMMON IN 4/4 AND 8/4, AND NOS. 1, 2, AND 3 SHOP, AND ELIMINATING THE TWO UPPER LUMBER COURSES OF EACH PILE.

Location	Lumber thickness and grade	Loss per pile: Total: June–July 1953 Dollars	October 1953 Dollars	January 1954 Dollars	May 1954 Dollars	Per thousand board measure: June–July 1953 Dollars	October 1953 Dollars	January 1954 Dollars	May 1954 Dollars	Per cent of green value: June–July 1953	October 1953	January 1954	May 1954
Snowflake	4/4, No. 3 Common and Better	4.85	5.47	13.78	-----	1.46	1.96	4.39	-----	1.7	2.2	4.9	----
Flagstaff	4/4, No. 3 Common and Better	5.98	4.20	13.82	10.43	1.38	1.04	3.38	2.46	1.7	1.3	3.8	3.0
Flagstaff	6/4 Shop	11.15	31.04	22.82	27.89	3.70	8.92	12.81	8.99	3.4	8.2	10.8	7.8
Snowflake	8/4, No. 3 Common and Better (2-inch stickers)	70.44	17.88	64.74	-----	14.64	3.88	13.47	-----	15.5	4.4	14.7	----
Snowflake	8/4, No. 3 Common and Better (25/32-inch stickers)	52.38	26.25	49.00	-----	11.14	5.37	10.26	-----	12.4	6.1	11.5	----

Table 6.-LOSS IN VALUE OF BOARDS IN THE TWO UPPER COURSES OF THE PILES FROM EXPOSURE TO SUNSHINE AND WETTING DURING AIR DRYING OF PONDEROSA PINE AT SNOWFLAKE AND FLAGSTAFF, ARIZ., IN PILES ERECTED DURING JUNE-JULY AND OCTOBER 1953 AND JANUARY AND MAY 1954

Location	Lumber thickness and grade	Loss							
		Value				Per cent of green value			
		June–July 1953 Dollars	October 1953 Dollars	January 1954 Dollars	May 1954 Dollars	June–July 1953	October 1953	January 1954	May 1954
Snowflake	4/4, No. 3 Common and Better	1.78	0*	2.83	----	16.0	0*	23.9	----
Flagstaff	4/4, No. 3 Common and Better	2.05	.82	.28	0.32	19.0	6.9	2.7	3.0
Flagstaff	6/4 Shop	2.48	1.54	5.71	6.04	13.9	9.1	19.0	24.4
Snowflake	8/4, No. 3 Common and Better (2-inch stickers)	.25	3.11	4.27	----	1.1	10.5	16.8	----
Snowflake	8/4, No. 3 Common and Better (25/32-inch stickers)	2.89	8.56	13.06	----	12.6	25.4	48.7	----

*These values are less than those for the bulk of the pile.

Table 7.-LOSS IN VALUE DURING THE PLANING OF 4/4 LUMBER AIR DRIED AT SNOWFLAKE AND FLAGSTAFF, ARIZ., IN PILES ERECTED DURING JUNE-JULY AND OCTOBER 1953 AND JANUARY AND MAY 1954

Location	Loss								Moisture content when planed			
	Value per thousand board measure				Per cent of green value							
	June–July 1953 Dollars	October 1953 Dollars	January 1954 Dollars	May 1954 Dollars	June–July 1953	October 1953	January 1954	May 1954	June–July 1953 Per cent	October 1953 Per cent	January 1954 Per cent	May 1954 Per cent
Snowflake	1.92 (2.03)*	3.12 (1.77)	---- ----	---- ----	2.2 (2.4)	3.0 (1.7)	---- ----	---- ----	11.5	13.5	----	----
Flagstaff	1.25 (1.86)	.80 (1.21)	9.64 (3.14)	4.29 (2.50)	1.5 (2.3)	1.0 (1.4)	10.6 (3.4)	5.2 (3.0)	13.0	15.0†	10.1	10.6

*Values in parentheses are losses that occurred during air drying.
†This lumber was wetted by rain and snow when the pile was taken down.

top course was $2.81 while that of the next course was $0.74. The difference was due to the greater surface checking of the boards in the top course.

Degrade During Planing

Table 7 gives the losses that occurred during planing in values per thousand board-feet, and in percentage of green value, together with the average moisture content of the lumber at the time of planing. It also gives the losses that occurred during air drying from green to rough-dry condition. If all piles are considered, the average degrade is greater during planing than during air drying. Of the 6 piles, however, 3 degraded more during planing and 3 degraded more during air drying.

The heavy planing degrade in the January and May piles at Flagstaff caused the average loss to be greater during planing than during air drying. The planing losses at Snowflake were greater than those at Flagstaff. However, the lumber of the June-July and October piles at Snowflake was planed at a lower moisture content than that at Flagstaff.

That moisture content plays an important part in loss during planing is evidenced by the data for the four piles at Flagstaff. Planing 4/4 com mon lumber at a moisture content of about 10 per cent results in heavy degrade, approximately $10 per thousand board-feet. The October pile of 4/4 lumber that was wetted by snow and rain at the time it was taken down was planed with a loss of only $0.80 per thousand board-feet. The average moisture content of this lumber was 15 per cent. After planing, the average was presumably lower because much of the surface moisture was removed.

Summary

1. Four-quarter comm on boards, piled in Arizona, can be air dried to 15 per cent moisture content in 6 to 94 days or to 10 per cent moisture content in 10 to 170 days.
2. Eight-quarter common boards, piled in Arizona, can be air dried to 15 per cent moisture content in 10 to 104 days or to 10 per cent moisture content in 15 to 170 days.
3. Six-quarter shop, piled in Arizona, can be air dried to 15 per cent moisture content in 25 to 130 days or to 10 per cent moisture content in 36 to 200 days.
4. Air drying defects, principally surface checks, cause degrade and loss in value. The average loss per thousand board-feet was $2.82 for 4/4, $11.70 for 8/4, and $13.80 for 6/4 shop grades.
5. The loss per pile resulting from the lack of a pile roof was $1.15 for 4/4, $5.36 for 8/4, and $3.94 for 6/4 shop.
6. The average loss per thousand boardfeet due to planing of 4/4 boards was $3.50.
7. 4/4 boards planed at about 10 per cent moisture content dropped in value $9.64 per thousand board-feet, compared to $0.80 for lumber planed at 15 per cent moisture content.

Appendix

Because it was impossible to maintain an individual at the sites of the experiments to collect current data during the entire air-drying periods, pertinent data were often lacking. Adequate data were obtained during the first week to 10 days of each experiment, but for the rest of the period the data were obtained at irregular intervals. When the test piles were dismantled, the final moisture content was usually higher or lower than the goal of 10 per cent. Since the object was to determine drying periods necessary to attain a moisture content of 10 per cent, interpolation and extrapolation were necessary.

There were only two instances where the lumber actually reached a moisture content of 10 per cent according to the moisture content determinations on the pile and wholeboard samples. In some instances there was reason to surmise that the samples may have reached a moisture content of 10 per cent prior to the time that the pile was dismantled. The lumber of all piles exeept two actually reached a moisture content of 15 per cent.

Following is a description of the method used for calculating drying curves and thereby determining drying periods.

Calculated Drying Curves: Sherwoody developed a theory applicable to the drying of water from porous

[7] Sherwood, T. K. 1929. Ind. Eng. **Chem.** 21, 12.

solids by evaporation in air. Newman[8] developed equations and tables giving the relation between the amount of evaporable moisture, *E*, and a function of time. The function of time is expressed by $T = \frac{kO}{a^2}$ where *k* is the diffusivity constant, O is time, and a is the distance through which the moisture must travel to the surface.

Newman's tables were applied to the drying of wood, and a chart (Fig. 8) was constructed with the vertical axis so adjusted that a drying curve of a piece of wood would plot a straight line. The heavy diagonal line drawn on the chart has coordinated equal to the values in the E—T table.

It is well known that a drying piece of wood follows this law only approximately. If the initial green moisture content and the time required to rea- ch a certain moisture content are known, the entire drying curve for a piece of wood, or for the average of a number of pieces, can be plotted. An obviously eroneous assumption must be made, however, that temperature and relative humidity are constant throughout the drying period. Because they vary, the best that actually can be done is to use monthly mean values and the coresponding wood equilibrium moisture content values. For long air-drying periods, the equilibrium moisture content was selected that agreed with the mean temperature and relative humidity of the last 2 months of each period.

The following example illustrates the application of the method. A pile of 4/4 No. 3 common and better lumber was erected at Snowflake June 26 and taken down July 6, 1953. On the sixth day the samples averaged 13.6 per cent. On the ninth and tenth days 0.28 inch of rain fell. When the pile was taken down the 16 pile samples averaged 11.1 per cent moisture content. Since the month of June at Snowflake is generally the month of lowest mean relative humidity and moderately hot, it was hoped to obtain the shortest drying period for the 4/4 lumber from this test pile. The question is, therefore, how long would the drying period have been that was required to bring the moisture content to 10 per cent if rain had not fallen on the last 2 days?

Initial average moisture content of 16 samples	60.1 per cent
Assumed equilibrium moisture content	7.0 per cent
Total evaporable moisture	53.1 per cent
Moisture content after 6 days of drying	13.6 per cent
Loss in moisture content in 6 days	60.1—13.6 = 46.5 per cent
Evaporable moisture after 6 days of drying	$1 - \frac{46.5}{53.1} = 0.124$

[8] Newman, Albert B. 1932. Cooper Union Bulletin. The drying of porous solids: diffusion calculations, diffusion, and surface emission equations.

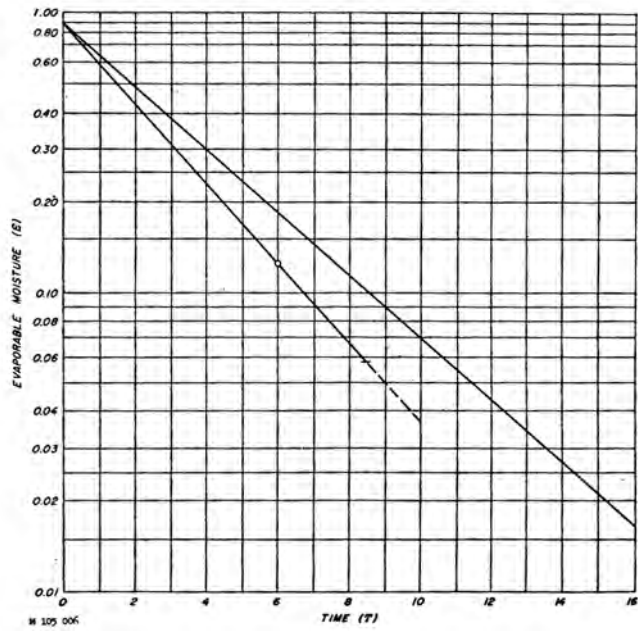

Fig. 8.—Chart for calculating drying curves.

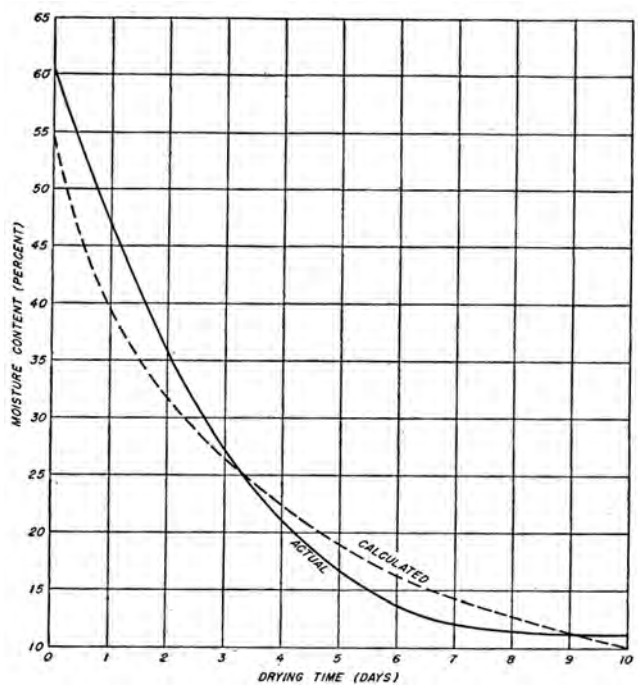

Fig. 9.—Actual and caluulated drying curves for 4/4 lumber piled at Snowflake, June 1953.

The value of E is 0.124 after 6 days. The value of E at 10 per cent moisture content is:

$$1 - \frac{60.1 - 10.0}{53.1} = 0.057$$

When 0.124 E is plotted against 6 T in Fig. 8 and a straight line is drawn through the origin, an intersection of 0.057 E occurs at about 8.5 T. On this basis the time required to reach a moisture content of 10 per cent becomes 8-½ days. The drying time was therefore conservatively estimated to be 10 days.

A calculated drying curve can be drawn by working with the E and T values of the straight line and applying them to the green moisture content and to the assumed equilibrium moisture content. For example the calculated moisture content after 4 days of drying, with E equal to 0.23, is approximately: moisture content = 0.23 (53.1) + 7.0 = 19.2 per cent.

The calculated drying curve shown in Fig. 9 was not derived from this straight line; it was drawn on the basis of the average green moisture content of all of the samples of 4/4 lumber at Snowflake, rather than the average green moisture content of the 16 samples of the June pile, and an equilibrium moisture content of 5.0 per cent. In addition, this second curve was drawn on the basis of the attainment of 10 per cent moisture content in 10 days instead of 8-1/2.

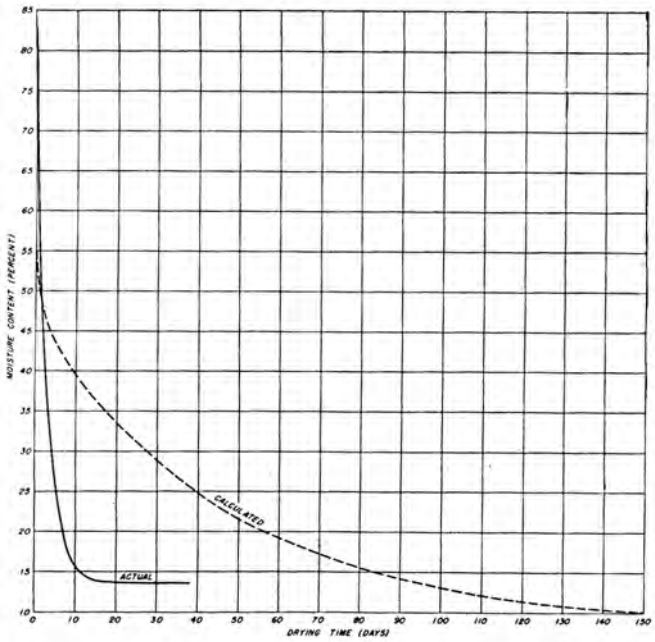

Fig. 10.—Actual and calculated drying curves for 4/4 lumber piled at Snowflake, October 1953.

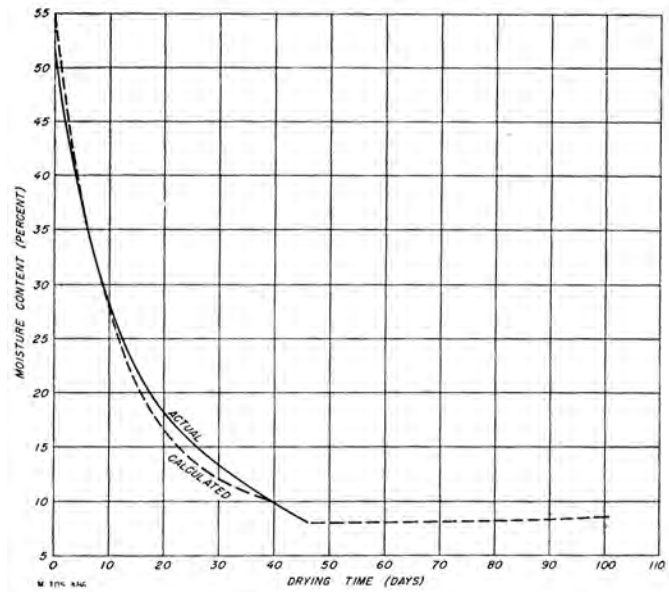

Fig. 11.---Actual and calculated drying curves for 4/4 lumber piled at Snowflake, January 1954.

Figs. 10 and 11 show how the actual and the calculated drying curves compare. Where the weather was nearly constant during the drying period, the actual and calculated drying curves nearly coincide. This is illustrated by the pairs of curves in Figs. 9 and 11. Where the weather underwent drastic changes during the drying period, the curves are separated widely (Fig. 12) .

This pile was dismantled during November after 38 days of drying. When the pile was taken down, the average moisture content was 13.6 per cent. If these values are used, 13.6 per cent moisture content in 38 days, then the calculated time to reach 10 per cent would be considerably shorter than the 150 days shown. The relative humidity was too high during November, December, and January, however, to permit the lumber to reach 10 per cent moisture content. Consequently, it was assumed that the lumber reached a moisture content of 10 per cent in March, or in 150 days. Using these values, the calculated drying curve was derived.

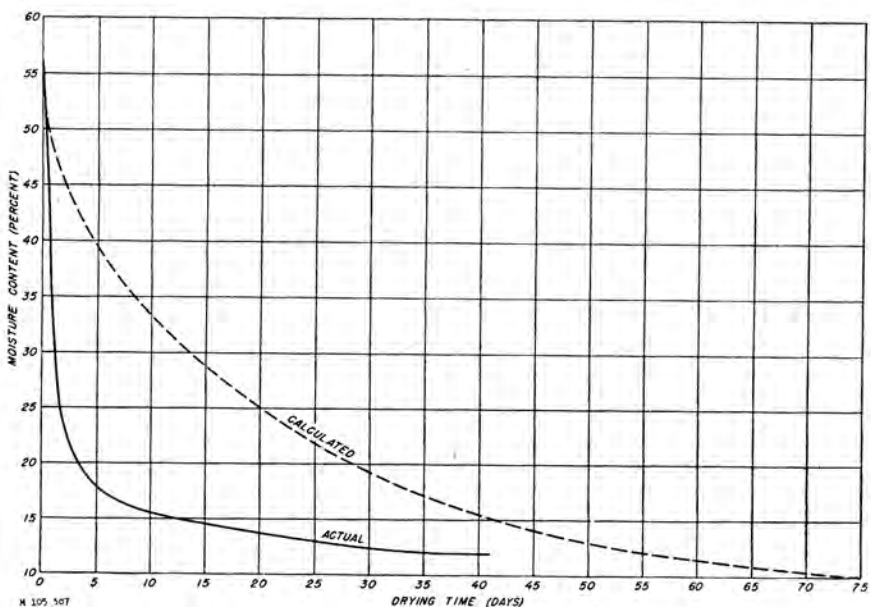

Fig. 12.—Actual and calculated drying curves for 4/4 lumber piled at Flagstaff, July 1953.

Lumber Prices Used

The following lumber prices were taken from American Lumberman, July 1953. The prices of grades that were not listed are estimated by the authors.

Grade	Price per M.B.M.
C and better	$255
D	205
3 Clear	190
1 Shop	142
2 Shop	110
3 Shop	90
Molding	150
2 Common and Better	128
3 Common	84
4 Common	64
Box	75
4 Common 6/4	75
5 Common	0