Vapor Drying of Western Woods

By

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Report No. D-2
May 1954

OREGON FOREST PRODUCTS LABORATORY
State Board of Forestry and School of Forestry,
Oregon State College, Cooperating
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ACKNOWLEDGMENTS

Much of the data here presented have been developed through a cooperative agreement with the Taylor-Colquitt Company, Spartanburg, South Carolina. A vapor-drying and treating cylinder of pilot-plant size was installed at the Laboratory by the company, and was used in the work described.

Permission of the Taylor-Colquitt Company to publish the results of the work is greatly appreciated.

ABSTRACT

The vapor-drying process is described briefly and its present status in industry is discussed. Fairly extensive data on the vapor drying of 1-, 2-, and 4-inch Douglas-fir and 2-inch western hemlock lumber are presented. Exploratory work on the vapor drying of redwood, Pacific madrone, red alder and ponderosa pine is included as a matter of interest.

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INTRODUCTION

The term "vapor drying" has been used to describe the patented process of drying wood in a hydrocarbon atmosphere.[2] The temperatures employed are well above the boiling point of water, although a considerable range in temperatures can be obtained through proper selection of the drying agent and by controlling the system pressure.

This process, which is illustrated in Figure 1, consists of boiling the drying agent in a steam-heated evaporator from which the vapors pass to the drying chamber where they condense on the wood and walls of the chamber. The temperature increases rapidly above the boiling point of the water which vaporizes and, with the excess hydrocarbon vapor, passes to the condenser. The liquid condensate flows to the seperator where the two immiscible liquids separate. The excess hydrocarbon liquid flows to the condensate return tank from which it is pumped to the evaporator for re-use. The temperature of vapors entering the condenser (EVT, or effluent vapor temperature) controls the steam supply to the evaporator.

Knowledge of the amount of water removed, original moisture content, and volume of the charge permits the operator to determine when the desired average final moisture content has been reached. At the completion of the heating period, a final vacuum is used to recover most of the drying agent, plus some water. A final steaming period may be used to relieve drying

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1 A talk presented at the Annual meeting of the Western Dry Kiln Clubs, at Eureka, California, May 13-15, 1954.

2 The patents are held by the Taylor-Colquitt Company.

stresses. The continuous heating and final vacuum cycle just described is referred to as a straight cycle. An alternating heating and vacuum cycle may also be used.

Present Application

The vapor-drying process is being used commercially for drying cross ties prior to preservative treatment. The green ties are seasoned to about 40 per cent moisture content, which is sufficient for adequate preservative penetration, sterilization, and to minimize subsequent checking. For long service life, it is important that treated material in contact with the ground not open up after it is installed.

A variation of this method, the solvent-recovery process, is used to treat kiln-dried lumber. The drying agent containing a preservative is pressed into the wood, then the vapors of the drying agent are used to recover most of the liquid and part of the preservative. The resultant treated product is dry and paintable.

Application to the Drying of Lumber

The vapor-drying process, as will be shown, is a rapid method of removing water from wood because of the high temperatures used and the low EMC (equilibrium moisture content) conditions existing in the drying chamber. The drying diffusion constant, which increases with increasing temperature, appears to be higher for the vapor-drying process than would be expected. The system pressure also influences the rate of drying; at any given temperature, the drying rate appears to vary inversely as the absolute pressure.

High temperatures, above 250 degrees F, and the lowest EMC conditions (lowest absolute pressure for any temperature) generally result in more severe drying defects; high temperatures cause darkening of the wood. Vapor drying had little or no effect on the shrinkage of the wood. All vapor-drying conditions resulted in (1) casehardening, (2) steep moisture gradients, and (3) considerable variation in moisture content. These drawbacks could be overcome by equalization and conditioning periods, but it appears more advantageous to perform these last two operations in a separate chamber which would permit efficient operation of the vapor-drying unit.

DRYING OF INDIVIDUAL SPECIES

Douglas-fir

Charges of one-, 2-, and 4-inch thick Douglas-fir lumber have been dried at temperatures from 211 to 260 deg F in a xylene atmosphere. The lower temperatures were obtained by drying at reduced pressures. The results are summarized in Table 1 and the drying diffusion constants of kiln-dried and vapor-dried material are compared in Figure 2. These data indicate the following times for drying green Douglas-fir to an average final moisture content of 12 per cent:

Thickness Inches	Drying time Hours
1	4-6
2	8-14
4	30-40

Rate of drying

The drying diffusion constant which is a rough measure of the drying rate, (Figure 2) varied directly as the temperature.* Also, the vapor-drying values appeared to be considerably higher than one would expect if material were kiln-dried at these higher temperatures. The values of the vapor-drying diffusion constants may be considered as minima, for they were based on the

* Kiln Certification. Bul. ANC-21, Forest Products Laboratory, U. S. Forest Service, Madison, Wisconsin. March 1946.

total drying time (heating plus vacuum) and with the assumption that the EMC was zero. Actually, a low EMC probably does exist. The apparent increase in the vapor-drying diffusion constant with wood thickness may be more accidental than real.

Moisture gradient and shrinkage

Severe moisture gradients were present unless the material was dried to low final moisture contents. There was little or no change in the core moisture content of some of the 4-inch specimens.

Shrinkage was virtually normal for Douglas-fir at all drying temperatures. This is shown in Figure 3, in which shrinkage data for vapor-and kiln-dried 4-inch material are compared; the wood began to shrink as soon as it started to dry.

Defects

In general, surface checks were no more severe than in kiln-dried material, although vapor-dried Douglas-fir was more prone to honeycomb at higher temperatures. An alternating cycle appeared to minimize this defect, probably because of the lower average temperature that prevailed during such a cycle. Four-inch Douglas-fir timbers were found to be free of honeycomb immediately after vapor drying. Twenty-four vapor-dried and kiln-dried timbers, which were dried to 16 per cent, will be examined after storage for the development of defects.

Table 1. Results of Vapor Drying Douglas-fir in a Xylene Atmosphere.

Dimensions	Effluent vapor temperature	Type of cycle	Drying time		Moisture content				Shrinkage		Diffusion constant	Xylene retained
			Heating	Vacuum	Initial	Final	Shell	Core	Width	Thickness		
Inches	Deg F		Hours	Hours	Per cent[1]				Per cent[2]		In^2/hr	Per cent
1 x 8	221	S[3]	4.5	1.0	52	13	8	16	2.6	4.3	0.042	0.4
	237	S	3.5	1.0	46	12	4	18	3.0	4.4	.049	0.6
	248	A	3.5	1.5	55	9	6	12	3.2	4.2	.065	0.7
	251	S	3.5	1.0	43	7	6	8	3.3	6.0	.065	0.8
	260	S	3.5	1.0	44	9	5	12	3.7	5.7	.061	0.6
2 x 2	211	S	7.0	1.0	32	10	5	17	2.8	2.5	.047	1.9
2 ½ x 2 ½	224	S	10.5	0.7	29	8	--	--	--	--	0.040	--
2 x 6	230	S	8.5	0.5	27	15	6-14	26	1.4	2.0	.028	0.2
	250	S	8.5	--	20	8	5-11	13	--	--	.068	2.1
	240-260	S	9.2	0.7	21	8	7-8	11	--	--	.059	3.4
	240-260	S	10.0	1.0	38	7	6-6	9	3.4	2.7	.123	2.7
	260	S	9.0	1.0	21	6	6-6	8	--	--	.077	0.2
	260	S	10.0	1.0	35	5	5-5	6	3.7	3.2	.116	0.1
2 x 8	222	S	12.0	0.7	37	10	5-8	17	3.0	3.1	.058	0.4
	228	S	12.2	0.9	35	10	4-7	17	2.8	4.0	.060	0.9
	227	A	9.5	2.2	38	13	6-9	21	2.4	3.1	.059	0.5
	240	S	12.0	0.7	40	11	6-7	17	3.4	5.4	.067	0.3
	246	S	11.0	0.7	42	17	8-12	28	1.8	3.9	.047	0.1
	265	S	7.5	0.7	40	8	3-4	13	2.9	2.8	.145	0.4
	265	A	5.0	3.7	44	11	4-7	19	2.6	5.4	.106	0.6
	243-270	S	12.0	1.0	38	7	4-5	11	3.4	3.6	.086	0.4
4 x 8	220	S	21.6	2.0	26	12	7-16	22	2.6	2.5	.065	--
	220	S	24.0	1.0	35	16	--	--	2.3	2.7	.067	--
	240	S	22.0	2.0	29	12	6-20	24	2.3	3.4-	.076	--
Kiln-dried	(152DB[4] (137WB	-	260	--	37	16	--	--	2.6	2.7	.012	--
	(202DB (186WB	-	164	--	34	16	--	--	2.2	2.2	.016	--

[1] Based on oven-dry weight.
[2] Based on green dimensions.

[3] S - Straight cycle.
A - Alternating cycle.

[4] DB - Dry-bulb temperature.
WB - Wet-bulb temperature.

Western Hemlock

The vapor-drying data on 2-inch vertical-grain western hemlock (Table 2) were obtained by Cyril Lansell during a study of EMC conditions existing in a xylene-water vapor atmosphere. The study was carried out in a small chamber using 4-foot samples from two timbers and recirculating part of the effluent vapors during drying. Two 2-inch green and one ½-inch air dried hemlock samples were included in each charge.

Equilibrium moisture content

The ½-inch thick sample was used to measure the EMC of the system. As shown in Table 2 and in Figure 4, a small but definite EMC did exist for each set of drying conditions. These values, which ranged from 0.7 to 6 per cent, correspond to theoretical values of 0.5 to 10 per cent. The higher EMC values were associated with lower temperatures at each pressure level.

Drying rate

The drying diffusion constant (Figure 4) varied directly as the temperature and inversely as the absolute pressure. The lowest absolute pressure for any given temperature produced fastest drying. These data indicate that it is possible to dry western hemlock at 225 to 250 deg F from 50 to 18 per cent moisture content within 25-35 hours.

Effect of drying conditions on the wood

Shrinkage values for both kiln-dried and vapor-dried samples were similar and normal for the species.

Those drying conditions producing low EMC conditions most frequently caused honeycombing. At any given temperature, an increase in humidity appeared to control this drying defect.

Residual stresses, tending to slight core tension, were present at the completion of drying, but severe case hardening developed upon standing.

The highest temperature, 265 deg F, caused a darkening of the lumber throughout its thickness.

Table 2. Results of Vapor Drying 2-inch Western Hemlock in a Xylene Atmosphere.

Charge	Absolute pressure[1]	Temp.	Observed EMC	Wood temperature differential	Drying time	Average moisture content		Average shrinkage		Retention of xylene	Average diffusion constant
						Initial	Final	Width	Thickness		
	Mm Hg	Deg F	Per cent	Deg F	Hours	Per Cent[2]		Per cent[3]		Per cent	In^2/hr
39	1200	290	0.7	45	12.0	47	9	2.1	5.8	0.4	0.098
38	1200	265	2.2	8	21.5	44	15	2.5	5.2	—	.031
37	1200	240	2.8	4	31.5	48	23	1.5	4.2	0.6	.013
24	760	240	2.1	11	23.0	62	21	2.1	4.5	0.5	.030
36	600	245	1.4	16	23.0	49	15	2.4	4.5	0.1	.032
35	600	225	2.3	7	33.0	52	19	1.7	4.0	0.0	.021
34	600	205	4.4	4	48.0	55	19	1.6	3.5	1.6	.025
26	300	210	2.0	12	28.5	42	12	2.2	4.5	0.7	.031
27	300	190	2.6	6	56.5	40	12	2.5	4.0	1.2	.015
28	300	170	5.7	4	82.7	46	18	1.6	3.7	2.1	.009
29	150	170	3.6	6	33.5	46	20	1.5	3.7	0.3	.015
30	150	155	3.9	4	75.5	50	20	1.5	4.5	1.3	.008
31	150	140	6.0	-	114.5	46	19	1.4	3.7	1.4	.006
32	75	140	4.4	4	66.2	40	18	1.7	4.2	0.2	.009
45	760	240-265	—	--	15.0	57	21	2.1	4.5	0.2	.037
Average											
44	Kiln-	(DB 170				48	17	1.9	4.3		
		(WB 115	2.5	5	47.5	38	18	1.6	4.2	--	.009
43	dried	(DB 140									
		(WB 92	3.0	-	85.0	40	17	1.9	4.7	--	.006
Average						39	17	1.7	4.4		

1 1200 = 8, and 760 = 0 psi gauge; 600 = 6, 300 = 18, 150 = 24, and 75 = 27 inches mercury gauge (vacuum).
2 Based on oven-dry weight.
3 Based on green dimensions.

Redwood

During the vapor drying of western hemlock, Cyril Lansell dried 4 charges of 1- by 6-inch by 4-foot vertical-grain redwood boards in xylene vapors at temperatures from 150 to 250 deg F, and a charge of matched material was kiln-dried at 180 deg F. These data are summarized in Table 3.

Results

The best-appearing boards were those dried at 150 deg F and there was virtually no difference in the drying time between 150 deg F (26 in. vac) and 180 deg F (20 in. vac). Collapse and internal checks developed in boards dried at 250 deg F. The lower temperatures eliminated honeycombing and reduced greatly the amount of collapse. A steep moisture gradient existed in the boards which were dried from 101-222 to 10-40 per cent moisture content.

The estimated times needed to dry from 140 to 10 per cent moisture content under the drying conditions used are listed below:

Temperature	Vacuum	Theoretical EMC	Drying time
Deg F	In.Hg	Per cent	Hours
250	0	1.3	14
180	20	4.5	89
180 DB-130 WB	Kiln	3.0	105
150	26	3.0	88

Table 3. Results of Vapor Drying one-inch Redwood in a Xylene Atmoshpere.

Charge	Temp	Vacuum	Drying time	Specific gravity	Moisture content				Shrinkage		Xylene retained
					Initial	Final	Shell	Core	Width	Thickness	
	Deg F	In.Hg	Hours	OD/G[1]	Per cent[2]				Per cent[3]		Per cent
18	250	0	7	—	—	40	—	—	—	—	—
19	150	26	58	0.42	147	18	9	38	1.6	4.0	0.9
				.41	139	30	15	58	1.6	4.0	0.7
20	180	20	72	.37	101	19	14	27	2.8	3.0	0.0
				.32	217	14	12	21	2.3	6.0	0.5
				.34	209	30	16	50	2.3	6.0	1.0
				.33	222	26	16	47	2.3	6.0	0.0
25[4]	180	20	67	.42	129	28	8	59	1.6	3.3	1.1
				.34	193	10	7	14	6.4	4.4	2.1
Kiln dried[4]	180DB[5] 130WB	—	67	.42	117	34	15	52	1.5	2.2	—
				.34	190	15	9	22	4.2	4.4	—

1 Oven-dry weight, green volume.
2 Based on oven-dry weight.
3 Based on green dimensions.
4 Matched lumber.
5 DB - dry bulb temperature.
WB - wet-bulb temperature.

Pacific Madrone, Red Alder, and Ponderosa Pine

The following information on the vapor drying of 1-inch lumber of these species was obtained from a few exploratory charges. The madrone and pine were dried in a 12 $\frac{1}{2}$-inch cylinder and the alder in a 36-inch cylinder. The results are summarized in Table 4.

Pacific madrone

Madrone was dried at 210 deg F using an alternating cycle from 95 to 12 per cent in 15 hours. The material was in very good condition at the completion of drying. All of the boards contained a dark red stain at varying depths below the surface which gave a streaked appearance to the surfaced stock. The accumulation of extractives at the evaporating surface within the wood undoubtedly was responsible for this stain.

Red alder

Red alder was dried from 100 to 12 per cent moisture content in 16 hours at 225 deg F. and in 6.5 hours at 250 deg F. Seasoning defects were not severe. The surfaced wood was very light in color, except for those boards that contained a grayish-brown stain which had not surfaced off. This stain was concentrated at the edges of the stickers and at varying depths below the surface.

Ponderosa pine

Ponderosa pine was dried from green to about 6 per cent moisture content in 7 - 9 hours at 250 deg F. The alternating cycle was more rapid than the straight cycle, and left much less xylene in the wood. The xylene content was high in the sapwood and low in the heartwood.

The boards were in good condition, but there was considerable variation in moisture content and the stock was casehardened. Equalizing and conditioning periods would be required to produce a more uniform moisture content and to relieve casehardening. A brown stain was present in the dried boards.

Table 4. Results of Vapor Drying One-inch Madrone, Red Alder, and Ponderosa Pine Lumber.

Charge	Cycle	EVT[1]	Drying time	Moisture content				Shrinkage		Xylene retained
				Initial	Final	Shell	Core	Width	Thickness	
		Deg F	Hours	Per cent[2]				Per cent		Per cent
Pacific madrone										
1	A[4]	210	13	95	11					
2	A	210	17	97	12					
Red alder										
1	S	226	16	100	12					
2	S	226	10	100	23					
3	S	250	6.5	100	12					
Ponderosa pine										
1 charge	S	212	7	82	16	7	22	2.6	3.6	8.4
4 charges	S	254	9	102	4	3	5	3.3	3.9	12.5
4 charges	A	252	7	119	6	4	11	2.7	4.4	1.5

1 Effluent vapor temperature.
2 Based on oven-dry weight.
3 Based on green dimensions.
4 A -- Alternating cycle.
S -- Straight cycle.

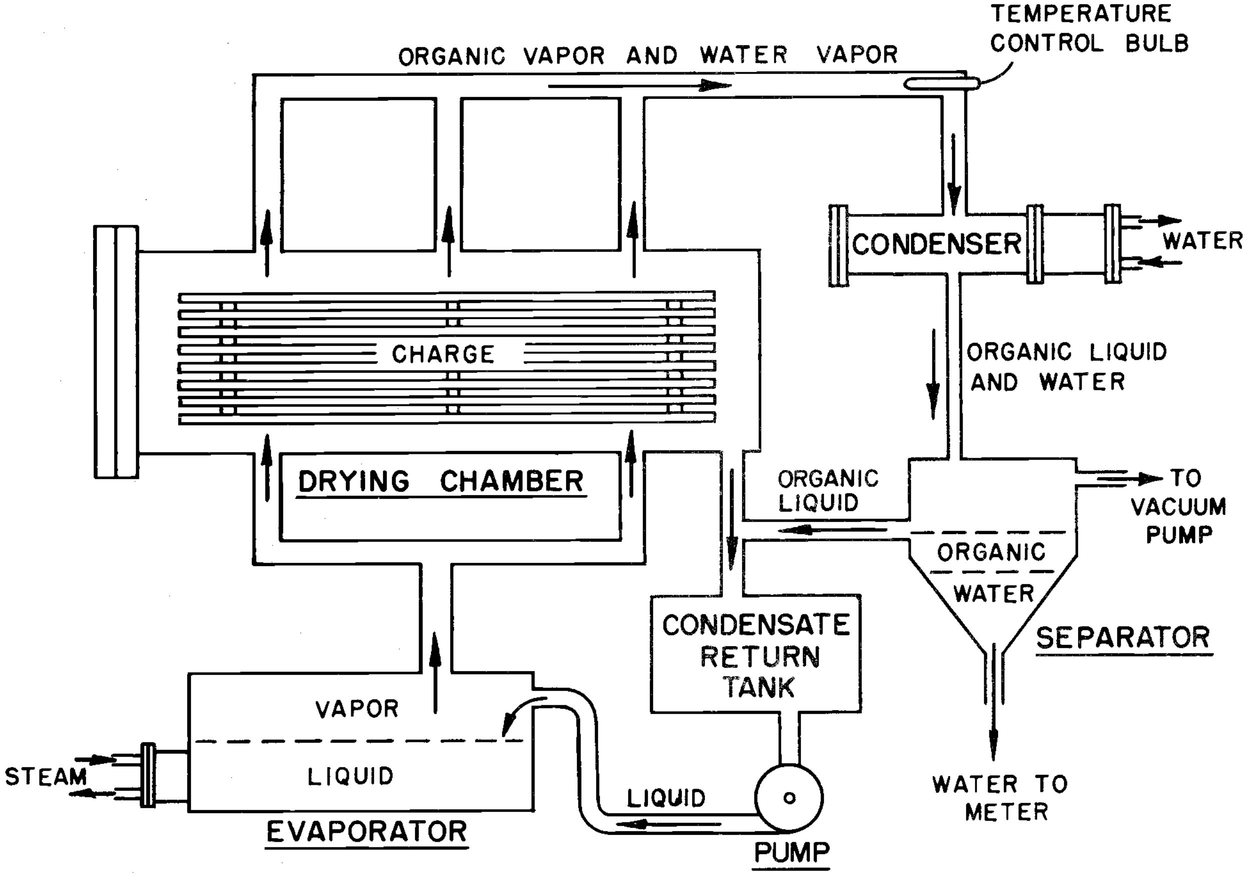

FIGURE I. FLOW DIAGRAM OF VAPOR-DRYING PROCESS

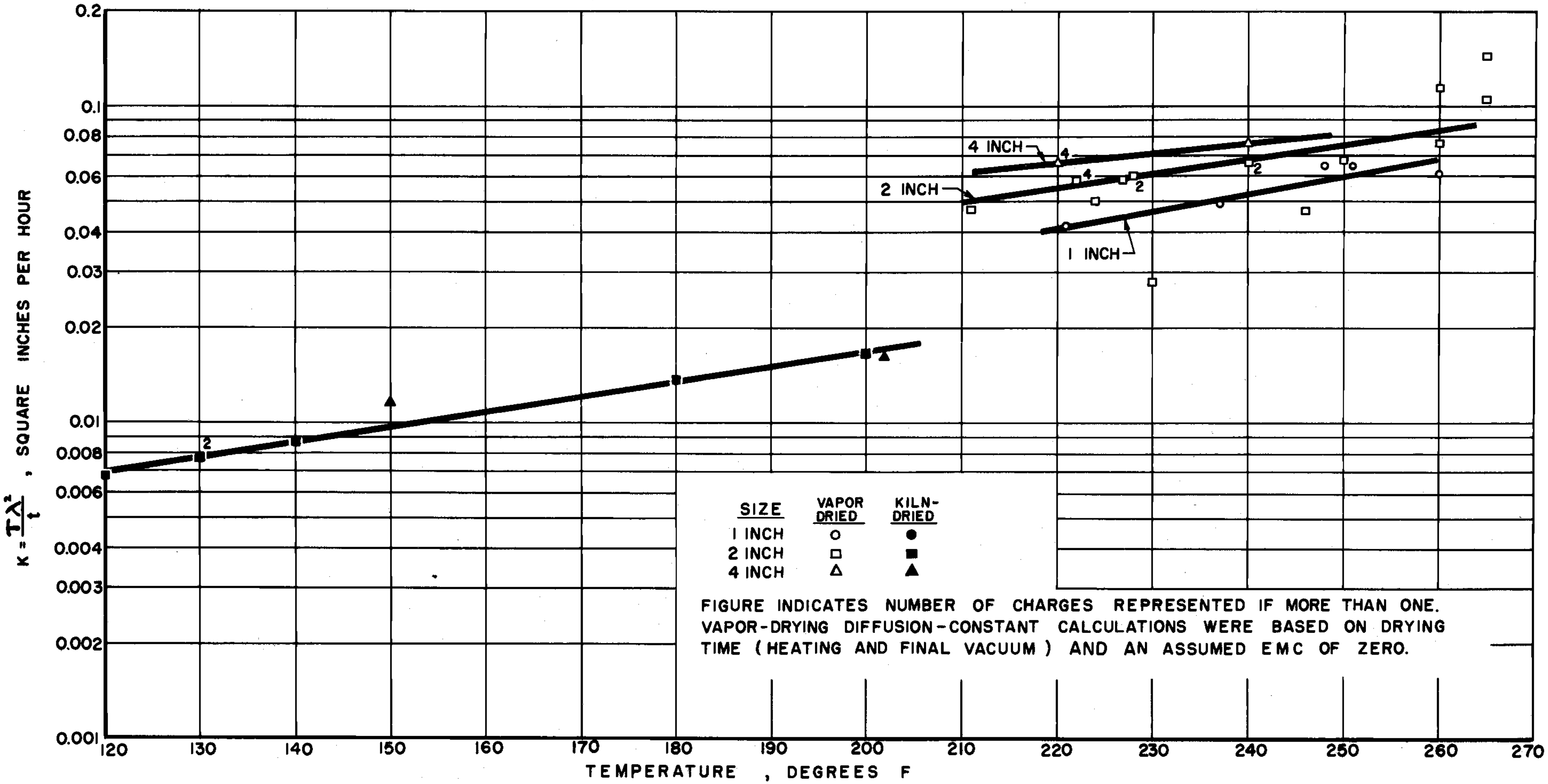

FIGURE 2. TEMPERATURE AND DRYING—DIFFUSION—CONSTANT RELATIONSHIP FOR DOUGLAS-FIR LUMBER.

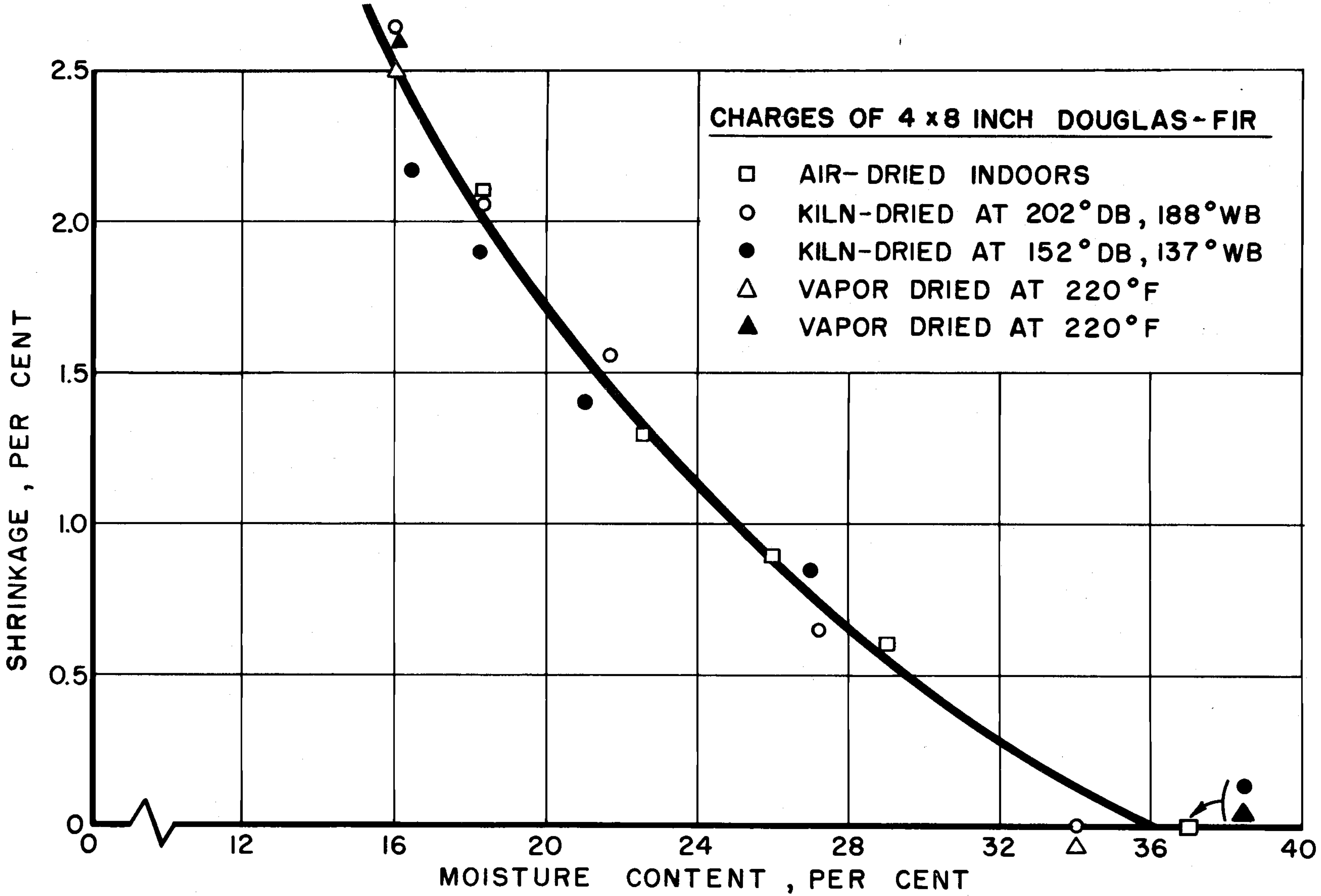

FIGURE 3. SHRINKAGE AND MOISTURE-CONTENT RELATIONSHIPS.

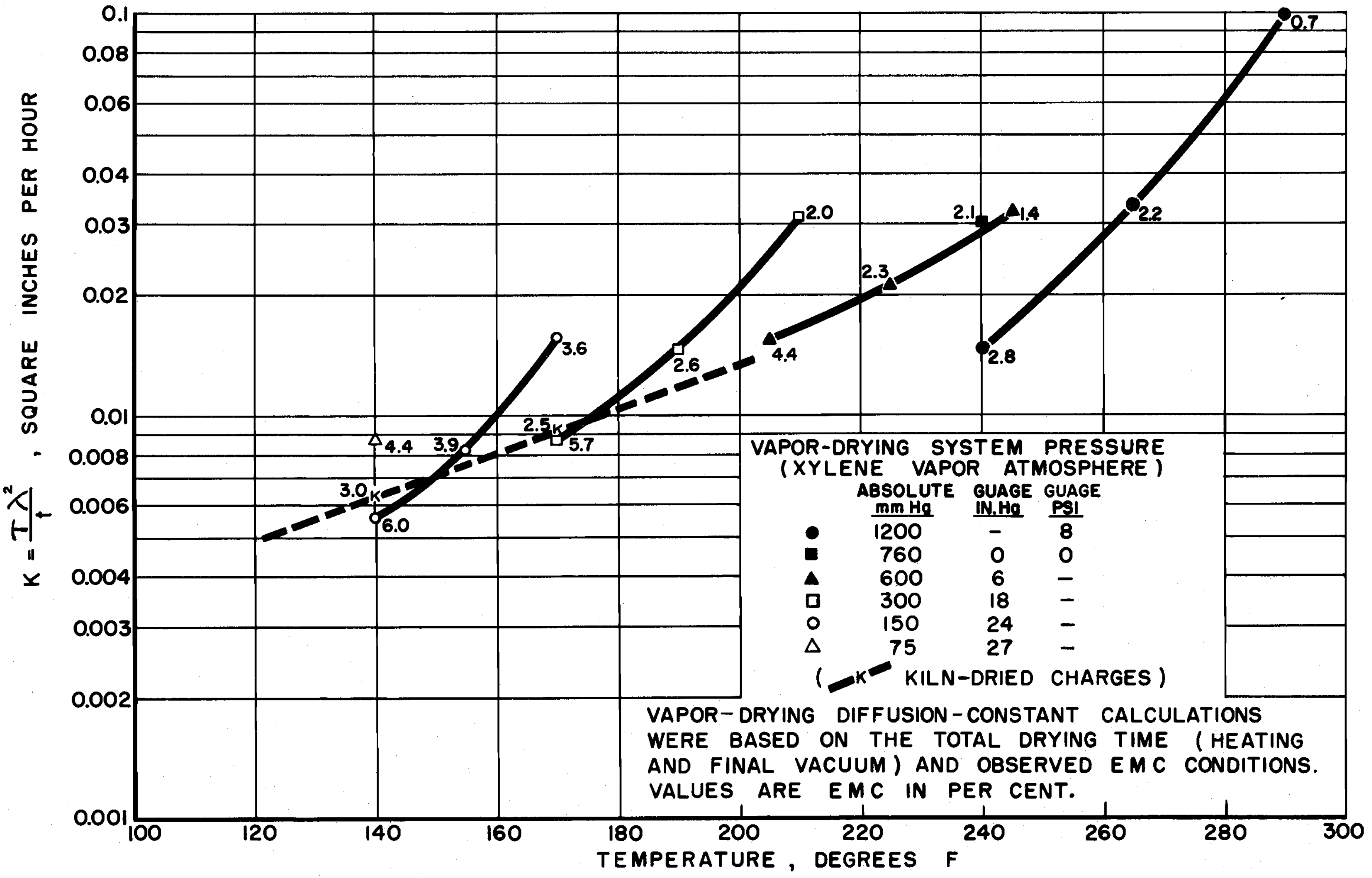

FIGURE 4. TEMPERATURE, PRESSURE AND DRYING-DIFFUSION-CONSTANT RELATIONSHIPS FOR 2-INCH WESTERN HEMLOCK LUMBER.