

VAPOR PRESSURES GENERATED IN DRYING ENGELMANN SPRUCE WOOD

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Although researchers have conducted wood drying investigations for many years, information is lacking about the moisture vapor pressures that are created in wood during drying. That such pressures exist has long been theorized;

however, the actual pressures generated during drying have never been measured.

Inasmuch as the pressure differential between the wood interior and the atmosphere might be a prime moisture moving or drying force, a knowledge of the magnitude of vapor pressure created in the wood is essential to the understanding of the drying operation. Therefore, the purpose of our investigation was to obtain such knowledge, specifically to determine how the maximum vapor pressure is affected by variables in the drying process.

### Procedure

All the test specimens 2- by 4- by 20-inches, used in this investigation were obtained from a single Engelmann spruce butt log selected from a log deck at a Missoula sawmill. The specimens, cut from clear, knot- and defect-free wood, were stored under water until required for testing.

At the time of test, specimens selected at random from the group obtained from any one log quarter, were ripped either 0.5, 1.0, or 2.0 inches from one edge. A small chamber, 1/4- by 1/4- by 2 inches, was then routed in the center of one of the freshly exposed surfaces. The end of a teflon capillary tube and a thermocouple were placed in the chamber, figure 1. The specimen was reassembled and coated on the ends using an epoxy resin adhesive. After the adhesive had cured, 36 specimens were coated on the radial faces and 36 specimens were coated on the tangential faces using an asphalt paint.

Each specimen was placed in a frame that was suspended from a balance located on the oven top. The capillary tube was connected to a mercury manometer and the thermocouple to a potentiometer, figure 2. The specimens were then dried in a forced air circulation oven at one of the temperatures--83°, 110°, or 138° C.

A total of 108 specimens were tested; four for each combination of coating treatment, chamber depth, and drying temperature. The experimental design is shown in figure 3.

During drying the weight of the specimen and the temperature and vapor pressure of the chamber were recorded at 10-minute intervals until a maximum pressure had been obtained. After it was certain that the maximum vapor pressure had been reached, the capillary tube and thermocouple leads were disconnected, the specimen was removed from the drying oven and placed in a second oven which was maintained at 104° C. for drying to a constant weight. The oven dry weight was used to calculate the initial and intermediate moisture content percents for the specimen. In order to compute the true percent moisture content, all weights were corrected by subtracting the weight of the adhesive and coating from the initial weight; also, the weight of the frame and balance suspension wire had to be subtracted from the intermediate weights.

The vapor pressure, too, had to be corrected. This was done by using a microbarograph recorder to obtain atmospheric pressure data which were used to adjust the gage pressure readings to absolute pressure values.<sup>1</sup> Only absolute pressure values were used in the subsequent analyses.

In addition, the following data were obtained for each specimen: specific gravity (based on a sample cut from each specimen), growth ring angle, number of growth rings intercepted by the glue line, initial moisture content, time in storage before testing, presence or absence of compression wood, time to maximum pressure, and moisture content at maximum pressure. All these data were subjected to multiple regression analyses.

### Analysis of Data

After accounting for the effects of the controlled variables, regression screening indicated that the number of growth rings intercepted by the glue line provided the strongest and most consistent addition to the model. After ring number, no other uncontrolled variable contributed meaningfully to the explanation of variation in vapor pressure. The regression model finally adopted included drying temperature, chamber depth, time to maximum pressure, number of growth rings intercepted by the glue line, and each of the three coating alternatives.

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<sup>1</sup> Absolute or true pressure is the sum of the atmospheric and gage pressures.

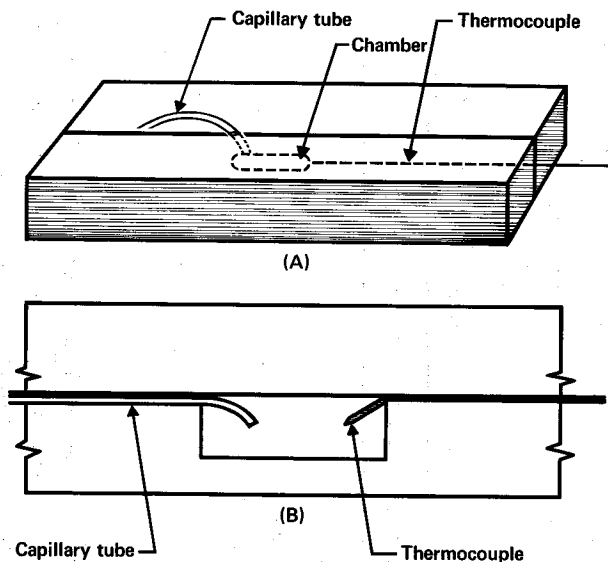


Figure 1.--Drawing of test specimen with (A) chamber, capillary tubing, and thermocouple and (B) placement of the capillary tube and thermocouple in the chamber.

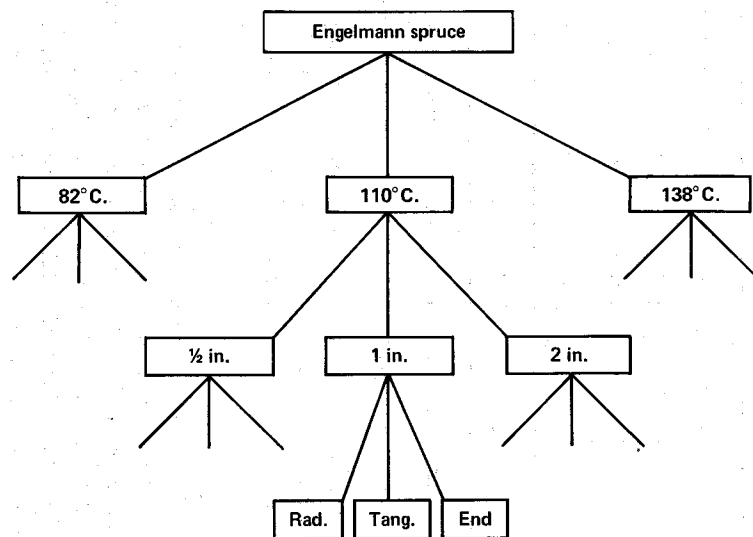


Figure 3.--Diagram showing the study's experimental design.

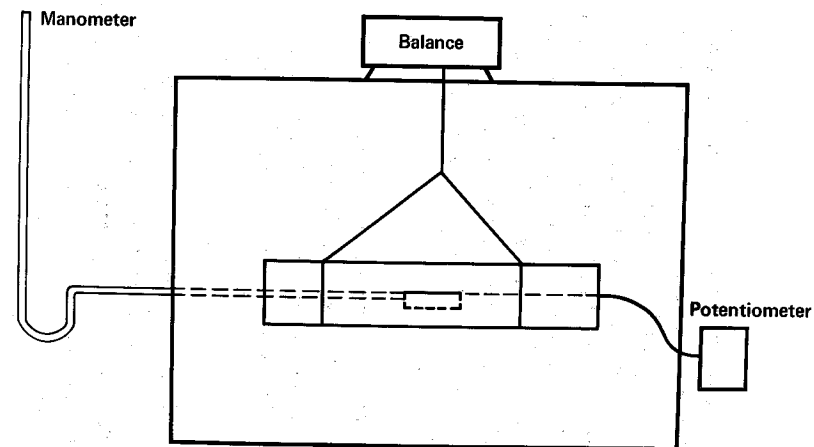


Figure 2.--Schematic showing arrangement of equipment during specimen drying.

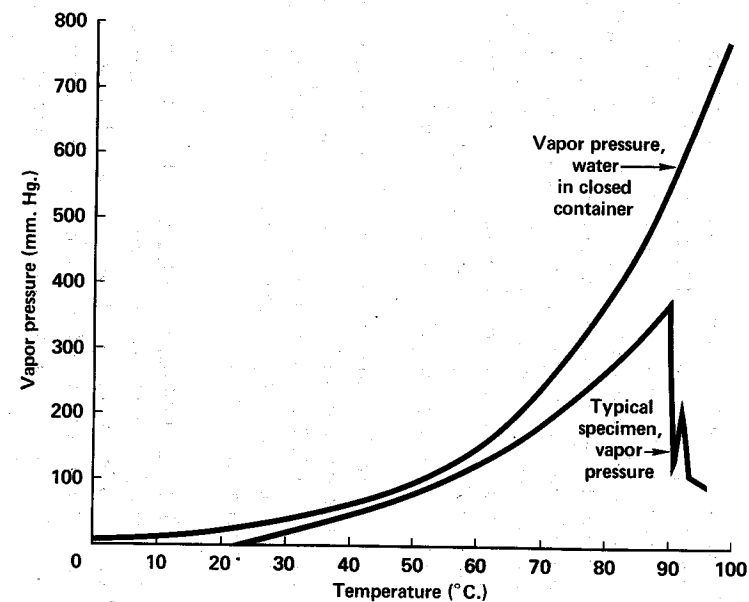


Figure 4.--A graph of the theoretical relationship of water heated in a closed container and a typical graph of experimental data.

## Results and Discussion

As the specimens dried, both vapor pressure and temperature inside the chamber gradually increased. However, the vapor pressure increased to a maximum after which there was usually a decrease, whereas the temperature continued to increase. In the early stages of drying, the vapor pressure within the chamber closely approximated the theoretical pressure of saturated water vapor in a closed air-tight container. As drying progressed, there was increased deviation between the vapor pressure within the chamber and the theoretical vapor pressure in a closed container. This deviation is explained by comparing the wood's vapor pressure to the pressure inside a leaky boiler: when wood is being heated, the vapor pressure is increasing although continually leaking. This pressure increases until the leakage exceeds the generation. The maximum vapor pressure attained in the chamber is dependent on the availability of moisture to replace that which is lost as well as the rate of leakage. A typical graph of the experimental data obtained for one specimen and a graph of the vapor pressure in a closed container are shown in figure 4.

Regression models developed in the analysis are shown in figures 5, 6, and 7. These models show the effect of chamber depth and drying temperature on the maximum vapor pressure obtained. The study data used in the analysis are summarized in Table 1. The maximum vapor pressure recorded for any of the specimens was 1,534 mm. of mercury for a specimen dried at 138° C. and the lowest maximum vapor pressure recorded was 782 mm. of mercury for a specimen dried at 83° C.

Time to maximum pressure. --The time to maximum pressure decreased as the drying temperature increased. Inasmuch as pressure and temperature are so closely related, this result is in accord with expectation. As the chamber depth was increased from 0.5 to 1.0 and 2.0 inches, the time required to attain maximum pressure increased. However, the time required to attain maximum pressures at chamber depths of 1.0 and 2.0 inches is practically the same because heat penetrates to the chamber from the faces, a relatively uniform distance of about 0.84 inches.

Table 1. Maximum absolute vapor pressure by study variables (in millimeters of mercury).

Log quarter number	Maximum absolute vapor pressure sums									
	Log 1 quarter	Coating treatment <sup>2</sup> 3			Depth (inches) <sup>2</sup>			Temperature (°C.) <sup>2</sup>		
		Coating treatment		3	Depth (inches)		2.0	Temperature (°C.)		138
		1	2		0.5	1.0		83	110	
1	29,390	9,471	10,560	9,359	9,686	9,499	10,205	7,628	10,717	11,045
2	29,006	9,433	10,230	9,343	9,611	9,706	9,689	8,315	11,213	9,478
3	25,881	7,625	9,787	8,469	8,344	8,934	8,603	7,944	9,175	8,762
4	26,439	9,053	8,743	8,643	8,428	8,439	9,572	8,450	9,679	8,310
Sum	110,716	35,572	39,320	35,814	36,069	36,578	38,069	32,337	40,784	37,595

<sup>1</sup> Each value is the sum of the absolute vapor pressure in 27 test specimens.

<sup>2</sup> Each value is the sum of the absolute vapor pressure in 9 test specimens.

<sup>3</sup> Treatment 1 = coated on the radial faces with asphalt paint;  
Treatment 2 = coated on the tangential faces with asphalt paint;  
Treatment 3 = coated on the ends only with epoxy resin adhesive.

The effect of coating treatment was to determine the difference between radial and tangential maximum vapor pressure times, because all specimens were end coated to simulate the center of a long board. In general, the specimens coated on the radial surfaces required the least amount of time to attain maximum pressure (Table 2). There was very little difference in the times to maximum pressure between the tangential and end-coated-only specimens. This may have been due to the difficulty in obtaining an intact coating on the surfaces of the specimens. The coatings were soft when the specimens were placed in the oven; in this stage, pinholes and small voids in the coating may have

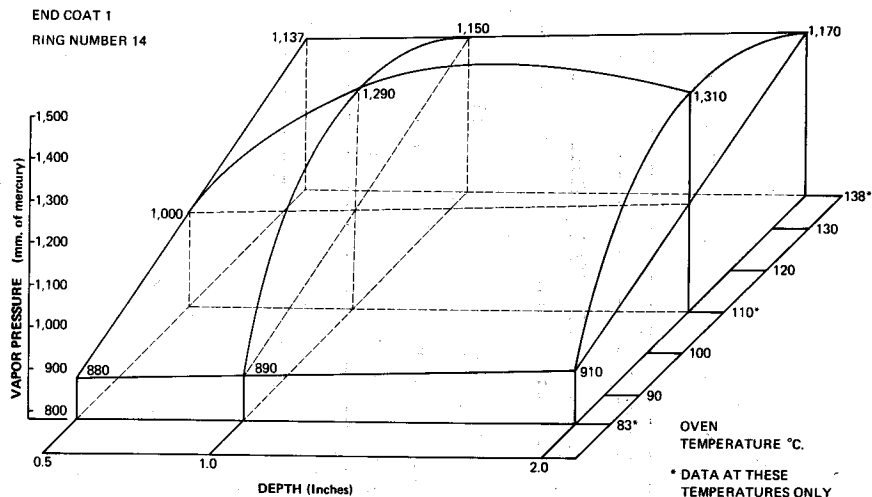


Figure 5.--Model for coating treatment 1 (radial faces and ends) showing the interrelationship between absolute vapor pressure, chamber depth, and oven temperature for specimens that have 14 growth rings intercepted by the glue line.

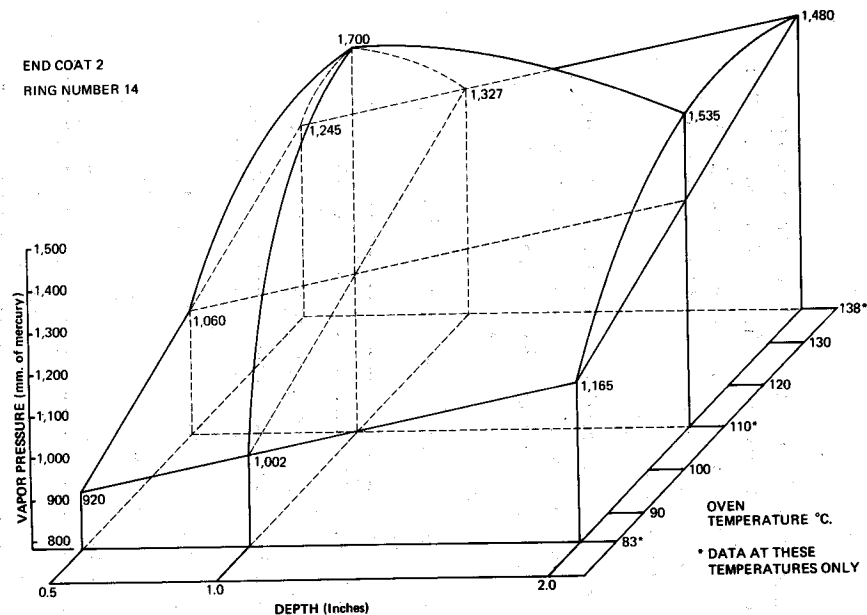


Figure 6.--Model for coating treatment 2 (tangential faces and ends) showing the interrelationship between absolute vapor pressure, chamber depth, and oven temperature for specimens that have 14 growth rings intercepted by the glue line.

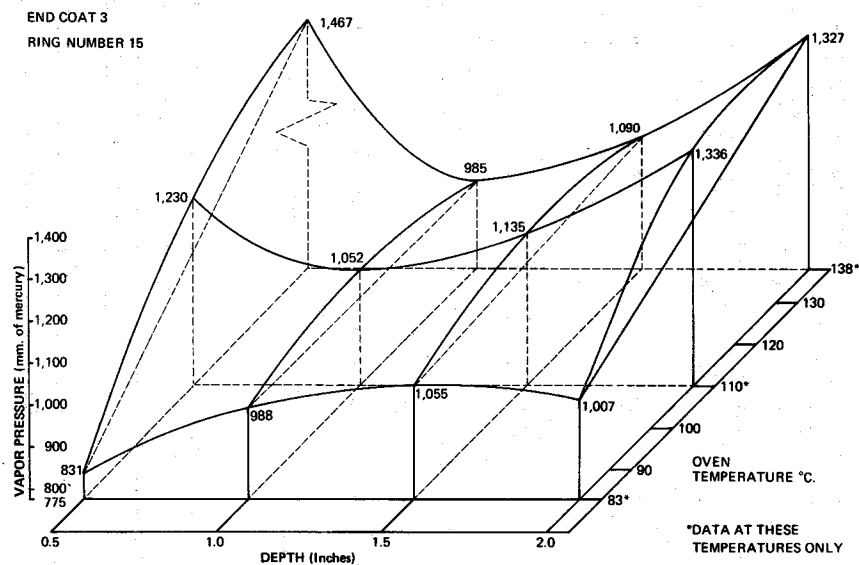


Figure 7.--Model for coating treatment 3 (ends only) showing the interrelationship between absolute vapor pressure, chamber depth, and oven temperature for specimens that have 15 growth rings intercepted by the glue line.

developed that permitted the vapor to escape.

The number of growth rings intercepted by the glue line also affected the time required to attain maximum pressure. As the number of annual rings increased, the time necessary to attain maximum pressure decreased. This relationship may be explained on the basis that an increase in the number of growth rings may be associated with an increase in the specific gravity and that specific gravity is closely related to heat conduction. Also, pit pairs of the latewood are less likely to aspirate, or seal, than are pit pairs of the earlywood.

Maximum pressure. --The maximum pressure was affected by the same independent variables. The greatest vapor pressures were obtained at 110° C. and the lowest pressures were obtained at 83° C. There was no great difference in maximum vapor pressure between the 110° C. and 138° C. drying temperatures (Table 3).

Table 2. Effect of drying temperature, coating treatments, and number of growth rings on the sums of times required to attain maximum vapor pressure at three different chamber depths.

Chamber depth	Sums of time to attain maximum vapor pressure <sup>1</sup>								
	Drying temperature °C.			Coating treatment <sup>2</sup>			No. of annual rings		
	83	110	138	1	2	3	15	20	25
Inches	Minutes								
0.5	750	668	577	540	745	710	790	665	540
1.0	1,410	1,080	695	795	1,250	1,140	1,465	1,055	665
2.0	1,465	1,115	715	925	1,020	1,350	1,560	1,105	630
Total	3,625	2,863	1,987	2,260	3,015	3,200	3,815	2,825	1,835

<sup>1</sup> Each value is the sum of 12 specimen times.

<sup>2</sup> Treatment 1 = coated on the radial faces with asphalt paint;  
Treatment 2 = coated on the tangential faces with asphalt paint;  
Treatment 3 = coated on the ends only with epoxy resin adhesive.

Table 3. Effect of drying temperature, coating treatment, and number of growth rings on the sums of maximum vapor pressures at three different chamber depths.

Chamber depth	Sums of maximum vapor pressure (mm. of mercury) <sup>1</sup>								
	Drying temperature °C.			Coating treatment <sup>2</sup>			No. of annual rings		
	83	110	138	1	2	3	15	20	25
Inches									
0.5	7,792	9,081	9,742	8,472	8,912	9,211	9,955	8,775	7,865
1.0	8,250	10,462	9,247	9,001	10,325	8,633	10,439	9,291	8,229
2.0	8,559	10,665	10,068	9,090	10,484	9,718	11,133	9,715	8,444
Total	24,581	30,208	29,057	26,563	29,721	27,562	31,527	27,781	24,538

<sup>1</sup> Each value is the sum of 12 specimen vapor pressures.

<sup>2</sup> Treatment 1 = coated on the radial faces with asphalt paint;  
Treatment 2 = coated on the tangential faces with asphalt paint;  
Treatment 3 = coated on the ends only with epoxy resin adhesive.

Coating the tangential faces of the specimens usually resulted in large vapor pressure sums; small vapor pressure sums were usually associated with the radial coating. For chamber depths of 1.0 and 2.0 inches, maximum vapor pressures were obtained at a drying temperature of 110° C. Apparently the rate of moisture movement at 138° C. is increased and the vapor pressures do not attain the high levels generated at 110° C.

As the number of annual rings intercepted by the glue line increases, the vapor pressure sum decreases. Generally, latewood develops fewer aspirated pits during drying than does earlywood and, as a result, more open pit passageways are available for the movement of moisture to the surface as the ring number increases.

### Conclusions

Equations developed from the vapor pressure data indicate the four study variables that interacted were number of annual rings intercepted by the glue line, depth of the specimen chamber, drying temperature, and the coating treatment.

In general, the time to attain maximum vapor pressure was influenced by all the study variables. As the depth of the chamber was increased, the time to maximum vapor pressure increased. There was practically no difference in the times required for chamber depths of 1 and 2 inches. An increase in the number of annual rings intercepted by the glue line decreased the time required to attain maximum vapor pressure. An increase in drying temperature resulted in a decrease in the time required to achieve maximum vapor pressure. The radial face and end-coated specimens required the least amount of time to attain maximum pressure.

The maximum vapor pressures increased as the drying temperatures increased; the greatest pressures were generally obtained at 110° C. The highest vapor pressure values were obtained when the specimens were coated on the tangential faces and ends. The maximum vapor pressures decreased as the number of annual growth rings intercepted by the glue line increased. Also, the maximum vapor pressure increased as the depth of the chamber was increased; no significant pressure differences were attained at chamber depths of 1 and 2 inches.