

Equilibrium Moisture Content Prediction for Wood

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Abstract

A formula for predicting equilibrium moisture content of wood without interpolation of tabular data or computer storage of large masses of data would be useful in controlling wood product quality. The formula presented, based on sorption theory and data, yields equilibrium moisture content values from temperature and relative humidity data that agree well with tabulated values. The average deviation of the calculated values from tabulated values is less than 0.13 percent moisture content, and deviation is never more than 0.9 percent.

ACCURATE PREDICTION of the equilibrium moisture content (EMC) of wood at given relative humidities and temperatures is important in controlling the quality of wood products. EMC values are useful in engineering wood products. For example, the moisture content of wood during kiln-drying and manufacture should be matched to the expected EMC condition where the product will be used. This prevents shrinking and swelling defects.

A large body of EMC-temperature-relative humidity data is contained in Table 38 of the Wood Handbook (7). The EMC data start at a temperature of 30°F. and increase in 5°F. increments up to 130°F., and then in 10°F. increments up to 210°F. The EMC values for a number of relative humidities are tabulated for each temperature. For easy interpolation, the table has also been graphed (5). If a formula existed for direct calculation of EMC from temperature and relative humidity, it would be convenient for computer use as it would be much easier and more efficient to store a formula than it would be to store Table 38 with an interpolation subroutine.

The Hailwood and Horrobin sorption theory (2) suggests such a formula. The sorption theory considers a polymer-water system to be a solution, and has been used in fundamental studies of the wood-water system (1, 6, 8).

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Water absorbed by a polymer is assumed to exist in two states: water in solution with the polymer (dissolved water) and water combined with a unit of the polymer to form a hydrate. The theory is based on the Equilibrium between three components: Polymer, hydrated polymer, and the dissolved water. If it is assumed that only one type of hydrate is involved, there are two chemical equilibria. One is the equilibrium between the hydrated water and the dissolved water (equilibrium constant = K_1) and the other is an equilibrium between the dissolved water and the water vapor of the surrounding atmosphere (equilibrium constant = K_2). Assuming that the polymer, hydrated polymer, and dissolved water form an ideal solid solution, it is possible to derive an equation for the sorption isotherm from these two equilibria. The final equation is

$$m = \left[\frac{K_1 K_2 h}{1 + K_1 K_2 h} + \frac{K_2 h}{1 - K_2 h} \right] \frac{1800}{W} \quad [1]$$

where m is percent moisture content, h is relative vapor pressure (relative humidity/ 100) and W is the molecular weight of the polymer unit that forms the hydrate. The first term in Equation [1] represents the hydrated water, while the second term is the dissolved water.

The Hailwood and Horrobin theory has been criticized on theoretical grounds (2, 3), but the fact

remains that it gives a representation of the sorption isotherm that is relatively simple analytically and gives excellent agreement with the experimental results over a broad range of relative vapor pressure.

The data for each temperature in Table 38 of the Wood Handbook were fitted to Equation [1] by a non-linear regression technique (4) to determine the values of K_1 , K_2 , and W for each temperature (Table 1). When these values are substituted back into Equation [1] and EMC values are calculated, the greatest deviation between the calculated and actual moisture contents is 0.76 percent moisture content, and the average of the absolute value of the deviations is 0.12 percent moisture content.

The values of K_1 , K_2 , and W in Table 1 were each related to temperature by the method of least squares, so that values for intermediate temperatures can be calculated. The equations are:

$$K_1 = 3.730 + 0.03642T - 0.0001547T^2 \quad [2]$$

$$K_2 = 0.6740 + 0.001053T - 0.0000017147T^2 \quad [3]$$

$$W = 216.9 + 0.01961T + 0.005720T^2 \quad [4]$$

where T is temperature in degrees Fahrenheit. When Equations [2], [3], and [4] are substituted into Equation [1], EMC can be calculated for temperatures and relative vapor pressures intermediate to those listed in Table 38. The maximum deviation between the calculated EMC's and those listed in Table 38 of the Wood Handbook is 0.90 percent moisture content, and the average of the absolute value of the deviations is 0.13 percent moisture content.

Two methods of calculating EMC are thus possible, and the choice of method depends somewhat on application and personal preference. Both eliminate the need to store or carry as large a body of information as Table 38 of the Wood Handbook. For computer use and for calculations at nontabulated temperature Equations [1], [2], [3], and [4] are probably more efficient. For noncomputer use at tabulated temperatures the values from Table 1 substituted into Equation [1] will avoid the arithmetic of Equations [2], [3], and [4].

Literature Cited

1. CHEN, C., and F. F. WANGAARD. 1968. Wettability and the hysteresis effect in the sorption of water vapor by wood. *Wood Sci. and Tech.* 2: 177-187.
2. HAILWOOD, A. J., and S. HORROBIN. 1946. Absorption of water by polymers: Analysis in terms of a simple model. *Trans. Faraday Soc.* 42B:84-102.
3. McLAREN, A. D., and J. W. ROWEN. 1951. Sorption of water vapor by proteins and polymers: A review. *J. of Polymer Sci.* 7:289-324.
4. SCARBOROUGH, J. B. 1962. *Numerical Mathematical Analysis*. Fifth Edition, The Johns Hopkins Press, Baltimore.
5. SMITH, H. H. 1963. Relative humidity and equilibrium moisture content graphs and tables for use in kiln drying lumber. *Forest Prod. Lab. Rep.* 1651. Madison, Wis.
6. SPALT, H. A. 1958. The fundamentals of water vapor sorption by wood. *Forest Prod. J.* 8(10):288-295.
7. U.S. FOREST PRODUCTS LABORATORY. 1955. *Wood Handbook*. Forest Prod. Lab., Forest Serv., U.S. Dep. Agric. Handb. 72. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
8. WANGAARD, F. F., and L. A. GRANADOS. 1967. The effect of extractives on water vapor sorption by wood. *Wood Sci. and Tech.* 1:253-277.

Table 1. - VALUES FOR EQUILIBRIUM CONSTANTS AND MOLECULAR WEIGHT WHICH MAY BE USED TO CALCULATE EQUILIBRIUM MOISTURE CONTENT WITH EQUATION [1].

Temperature (°F.)	Values		
	K_1	K_2	W
30	4.15	0.677	205
35	5.03	.706	224
45	4.81	.719	230
50	6.13	.753	252
55	5.74	.735	243
60	5.49	.733	241
65	5.13	.730	239
70	5.80	.746	252
75	5.28	.745	250
80	5.76	.757	261
85	5.24	.745	255
90	5.87	.754	266
95	5.22	.755	264
100	6.09	.762	278
105	5.22	.754	271
110	5.81	.772	289
115	5.68	.773	293
120	5.82	.771	297
125	6.11	.779	309
130	5.91	.782	315
140	5.74	.782	327
150	5.49	.790	345
160	5.89	.799	370
170	5.93	.806	393
180	5.61	.807	411
190	5.58	.814	438
200	4.72	.818	451
210	3.82	.821	462