THEORETICAL EQUILIBRIUM MOISTURE CONTENT OF WOOD UNDER VACUUM

Zhangjing Chen†
Research Associate

Fred M. Lamb†
Professor
Department of Wood Science and Forest Products
Virginia Tech
Blacksburg, VA 24061

(Received January 2002)

ABSTRACT

Under vacuum drying, there is an equilibrium moisture content corresponding to the vacuum drying conditions, that is, temperature and pressure. Theoretical methods to calculate equilibrium moisture content were developed based on the Hailwood-Horobin sorption theory. The equilibrium moisture contents at pressures from 5 to 760 mm Hg and temperatures from 0 to 100°C were calculated and tabulated in this paper. These equilibrium moisture contents can serve as an aid in the vacuum drying control.

Keywords: Equilibrium moisture content, vacuum drying.

INTRODUCTION

In the atmospheric environment, wood loses or gains moisture until it reaches equilibrium with conditions of the air. During conventional drying, equilibrium moisture content (EMC) is related to the temperature and the relative humidity (or wet bulb depression) of the air (Forest Products Laboratory 1990). However, during vacuum drying, there is little air. In this case, EMC depends primarily on the total pressure and temperature conditions.

Wood contains the solid phase of wood substance, the liquid phase of free water, and the gaseous phase consisting of air and water vapor. During vacuum drying, the liquid water in the wood evaporates into water vapor. The water vapor and air are removed from the wood. The percentage of air volume becomes less and less as drying continues. Since the volume of water vapor from evaporation is much greater than the volume of air inside the wood (Chen 1997), the volume of air is neglected and the pressure of the air is not considered. Under atmospheric conditions, the total pressure is the sum of the air partial pressure and vapor partial pressure. Under vacuum conditions, total pressure is the same as vapor partial pressure.

Vacuum drying still requires control of EMC conditions, i.e., temperature and pressure. Thus, it is essential to know the relationship between temperature, pressure, and EMC. The objective of this paper is to develop a method to calculate EMCs under vacuum. These theoretical EMCs under various temperatures and pressures were tabulated.

THEORETICAL EMCS UNDER VACUUM DRYING

When wood is exposed to the air, EMC depends on the relative humidity and the temperature of the air. These relationships of EMC have been well established (Forest Products Laboratory 1990). The original data are based on Sitka spruce drying from the initial green condition at atmospheric temperature and humidity.

The Hailwood-Horrobin sorption theory has been applied to wood for many years (Hail-

† Member of SWST.

Wood and Fiber Science, 34(4), 2002, pp. 553–559

TABLE 1a. *Theoretical equilibrium moisture content at various temperatures and pressures.*

Temperature		Pressure mm Hg																			
C	F	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	32.0																				
1	33.8	28.8																			
2	35.6	23.0																			
3	37.4	19.4																			
4	39.2	17.0																			
5	41.0	15.1																			
6	42.8	13.8																			
7	44.6	12.6																			
8	46.4	11.7																			
9	48.2	10.9																			
10	50.0	10.2																			
11	51.8	9.6																			
12	53.6	9.1	25.0																		
13	55.4	8.6	20.8																		
14	57.2	8.2	18.0																		
15	59.0	7.8	16.0																		
16	60.8	7.4	14.5																		
17	62.6	7.0	13.2																		
18	64.4	6.7	12.2	27.5																	
19	66.2	6.4	11.4	22.4																	
20	68.0	6.1	10.7	19.1																	
21	69.8	5.8	10.1	16.8																	
22	71.6	5.5	9.5	15.1																	
23	73.4	5.2	9.0	13.8	25.9																
24	75.2	5.0	8.5	12.7	21.4																
25	77.0	4.7	8.1	11.8	18.5																
26	78.8	4.5	7.7	11.0	16.4																
27	80.6	4.3	7.3	10.4	14.7	24.7															
28	82.4	4.1	7.0	9.8	13.5	20.7															
29	84.2	3.8	6.7	9.2	12.4	17.9															
30	86.0	3.7	6.4	8.8	11.6	15.9	25.5														
31	87.8	3.5	6.1	8.3	10.8	14.4	21.2														
32	89.6	3.3	5.8	7.9	10.2	13.2	18.3														
33	91.4	3.1	5.5	7.5	9.6	12.2	16.2	24.0													
34	93.2	2.9	5.3	7.2	9.1	11.4	14.6	20.2													
35	95.0	2.8	5.0	6.9	8.7	10.7	13.4	17.6	26.1												
36	96.8	2.6	4.8	6.5	8.2	10.1	12.4	15.7	21.5												

TABLE 1a. *Continued.*

Temperature		Pressure mm Hg																			
C	F	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
37	98.6	2.5	4.5	6.3	7.8	9.5	11.5	14.2	18.5	26.9											
38	100.4	2.4	4.3	6.0	7.5	9.0	10.8	13.0	16.4	22.0											
39	102.2	2.2	4.1	5.7	7.1	8.5	10.1	12.1	14.7	18.8	26.5										
40	104.0	2.1	3.9	5.4	6.8	8.1	9.6	11.3	13.4	16.6	21.8										
41	105.8	2.0	3.7	5.2	6.5	7.7	9.1	10.6	12.4	14.9	18.7	25.2									
42	107.6	1.9	3.5	4.9	6.2	7.4	8.6	9.9	11.5	13.6	16.5	20.9	29.2								
43	109.4	1.8	3.4	4.7	5.9	7.0	8.2	9.4	10.8	12.5	14.8	18.1	23.4								
44	111.2	1.7	3.2	4.5	5.7	6.7	7.8	8.9	10.1	11.6	13.5	16.0	19.8	26.1							
45	113.0	1.6	3.0	4.3	5.4	6.4	7.4	8.5	9.6	10.9	12.4	14.4	17.2	21.5	28.8						
46	114.8	1.5	2.9	4.1	5.2	6.1	7.1	8.0	9.1	10.2	11.5	13.2	15.4	18.4	23.1						
47	116.6	1.4	2.7	3.9	4.9	5.9	6.8	7.7	8.6	9.6	10.8	12.2	13.9	16.2	19.5	24.7					
48	118.4	1.3	2.6	3.7	4.7	5.6	6.5	7.3	8.2	9.1	10.1	11.3	12.8	14.6	17.1	20.6	26.1				
49	120.2	1.2	2.4	3.5	4.5	5.3	6.2	7.0	7.8	8.6	9.6	10.6	11.8	13.3	15.2	17.8	21.4	27.2			
50	122.0	1.2	2.3	3.3	4.3	5.1	5.9	6.7	7.4	8.2	9.1	10.0	11.0	12.3	13.8	15.8	18.4	22.2	28.1		

wood and Horrobin 1946). This sorption theory considers wood as a polymer. Simpson (1971, 1973) derived the coefficients of the Hailwood-Horrobin model to calculate the EMC for Sitka spruce. He found that the maximum deviation from traditional tabulated data is only 0.9% with the average deviation of 0.13%. Although based on Sitka spruce, results are applicable to other species (Simpson 1973).

The Hailwood-Horrobin formula to calculate EMC is (Simpson 1973, Forest Products Laboratory 1990):

$$EMC = \left(\frac{KK_1h + 2K^2K_1K_2h^2}{1 + K^2K_1K_2h^2 + K_1Kh} + \frac{Kh}{1 - Kh}\right) \times \frac{1{,}800}{W} \quad (1)$$

where

$$W = 349 + 1.29 \times T + 0.0135 \times T^2 \quad (2)$$

$$K = 0.805 + 0.000736 \times T - 0.00000273 \times T^2 \quad (3)$$

$$K_1 = 6.27 - 0.00938 \times T - 0.000303 \times T^2 \quad (4)$$

$$K_2 = 1.91 + 0.0407 \times T - 0.000293 \times T^2 \quad (5)$$

where, EMC is equilibrium moisture content, (%); T is temperature (°C); and h is the relative humidity, (%/100).

This model representing sorption isotherm is relatively simple and is in excellent agreement with the experimental results in a broad range of relative humidity (Simpson 1973). Simpson used these equations to calculate the EMC of wood in outdoor locations with the United States and also worldwide (Simpson 1998). Sorption isotherms are experimentally determined in the humid air at normal pressure. Voigt et al. (1940) demonstrated the validity of sorption isotherms for vacuum condition. Thus, the Hailwood-Horrobin model that is used for normal atmospheric pressure can also be applied to vacuum condition.

In atmospheric pressure, the relative humid-

TABLE 1b. *Theoretical equilibrium moisture content at various temperatures and pressures.*

Temperature		Pressure mm Hg																			
C	F	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
51	123.8	1.1	2.2	3.2	4.1	4.9	5.6	6.4	7.1	7.8	8.6	9.4	10.3	11.4	12.7	14.2	16.2	18.9	22.7	28.6	
52	125.6	1.0	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.7	11.7	13.0	14.6	16.5	19.2	23.0	28.8
53	127.4	1.0	1.9	2.8	3.7	4.4	5.1	5.8	6.5	7.1	7.8	8.5	9.2	10.0	10.9	12.0	13.3	14.8	16.8	19.4	23.1
54	129.2	0.9	1.8	2.7	3.5	4.2	4.9	5.6	6.2	6.8	7.4	8.0	8.7	9.5	10.3	11.2	12.2	13.5	15.0	16.9	19.5
55	131.0	0.9	1.7	2.6	3.3	4.0	4.7	5.3	5.9	6.5	7.1	7.7	8.3	8.9	9.7	10.4	11.3	12.4	13.6	15.1	17.0
56	132.8	0.8	1.6	2.4	3.2	3.8	4.5	5.1	5.6	6.2	6.8	7.3	7.9	8.5	9.1	9.8	10.6	11.5	12.5	13.7	15.1
57	134.6	0.8	1.5	2.3	3.0	3.7	4.3	4.8	5.4	5.9	6.5	7.0	7.5	8.1	8.6	9.3	10.0	10.7	11.6	12.5	13.7
58	136.4	0.7	1.5	2.2	2.8	3.5	4.1	4.6	5.2	5.7	6.2	6.7	7.2	7.7	8.2	8.8	9.4	10.0	10.8	11.6	12.5
59	138.2	0.7	1.4	2.1	2.7	3.3	3.9	4.4	4.9	5.4	5.9	6.4	6.8	7.3	7.8	8.3	8.9	9.5	10.1	10.8	11.6
60	140.0	0.6	1.3	1.9	2.6	3.1	3.7	4.2	4.7	5.2	5.6	6.1	6.5	7.0	7.4	7.9	8.4	8.9	9.5	10.1	10.8
61	141.8	0.6	1.2	1.8	2.4	3.0	3.5	4.0	4.5	4.9	5.4	5.8	6.2	6.7	7.1	7.5	8.0	8.5	9.0	9.5	10.1
62	143.6	0.6	1.2	1.7	2.3	2.8	3.3	3.8	4.3	4.7	5.1	5.6	6.0	6.4	6.8	7.2	7.6	8.1	8.5	9.0	9.5
63	145.4	0.5	1.1	1.6	2.2	2.7	3.2	3.6	4.1	4.5	4.9	5.3	5.7	6.1	6.5	6.9	7.3	7.7	8.1	8.5	9.0
64	147.2	0.5	1.0	1.5	2.1	2.5	3.0	3.5	3.9	4.3	4.7	5.1	5.5	5.8	6.2	6.6	6.9	7.3	7.7	8.1	8.5
65	149.0	0.5	1.0	1.5	1.9	2.4	2.9	3.3	3.7	4.1	4.5	4.8	5.2	5.6	5.9	6.3	6.6	7.0	7.3	7.7	8.1
66	150.8	0.4	0.9	1.4	1.8	2.3	2.7	3.1	3.5	3.9	4.3	4.6	5.0	5.3	5.7	6.0	6.3	6.6	7.0	7.3	7.7
67	152.6	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.7	4.1	4.4	4.8	5.1	5.4	5.7	6.0	6.4	6.7	7.0	7.3
68	154.4	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.5	3.9	4.2	4.5	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0
69	156.2	0.4	0.8	1.2	1.5	1.9	2.3	2.7	3.0	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7
70	158.0	0.3	0.7	1.1	1.5	1.8	2.2	2.5	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.5	5.8	6.1	6.4
71	159.8	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.7	3.0	3.4	3.6	3.9	4.2	4.5	4.8	5.0	5.3	5.6	5.8	6.1
72	161.6	0.3	0.6	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.0	4.3	4.5	4.8	5.1	5.3	5.6	5.8
73	163.4	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	2.7	3.0	3.3	3.6	3.8	4.1	4.3	4.6	4.8	5.1	5.3	5.5
74	165.2	0.3	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.1	3.4	3.7	3.9	4.1	4.4	4.6	4.8	5.1	5.3
75	167.0	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.5	2.7	3.0	3.2	3.5	3.7	3.9	4.2	4.4	4.6	4.8	5.1
76	168.8	0.2	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6	2.8	3.1	3.3	3.5	3.8	4.0	4.2	4.4	4.6	4.8
77	170.6	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.4	2.7	2.9	3.1	3.4	3.6	3.8	4.0	4.2	4.4	4.6
78	172.4	0.2	0.4	0.7	0.9	1.1	1.4	1.6	1.9	2.1	2.3	2.5	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
79	174.2	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2
80	176.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8	4.0
81	177.8	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8
82	179.6	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.8	2.9	3.1	3.3	3.5	3.6
83	181.4	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.6	2.8	3.0	3.1	3.3	3.4
84	183.2	0.1	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.6	2.8	3.0	3.1	3.3
85	185.0	0.1	0.3	0.4	0.6	0.7	0.9	1.1	1.2	1.4	1.6	1.7	1.9	2.0	2.2	2.4	2.5	2.7	2.8	3.0	3.1
86	186.8	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.5	2.7	2.8	3.0
87	188.6	0.1	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.2	2.4	2.5	2.7	2.8

TABLE 1b. *Continued.*

Temperature		Pressure mm Hg																			
C	F	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
88	190.4	0.1	0.2	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.1	2.3	2.4	2.5	2.7
89	192.2	0.1	0.2	0.3	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.3	2.4	2.5
90	194.0	0.1	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.3	2.4
91	195.8	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.0	2.1	2.2
92	197.6	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0	2.1
93	199.4	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
94	201.2	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
95	203.0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
96	204.8	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
97	206.6	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6
98	208.4	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5
99	210.2	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.2	1.3	1.4
100	212.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.2	1.3

ity is defined as the ratio of the partial vapor pressure in the air to the saturated vapor pressure for a given temperature. In vacuum, since there is little or no air, the partial air pressure is practically negligible. Thus, the absolute pressure in the vacuum can be assumed to be the same as water vapor pressure. In such a vacuum drying system, there are, therefore, two parameters: the absolute pressure and the medium temperature. Complete vacuum is 0 mm Hg of the absolute pressure. The relative humidity (h) in a vacuum system is defined as the ratio of absolute pressure (p) in the system to the saturated vapor pressure (p_o) at a given temperature (T). Thus, the relative humidity in a vacuum can be expressed as:

$$h = \frac{p}{p_o} \times 100\% \qquad (6)$$

where h is relative humidity (%), p is absolute pressure (mm HG), p_0 is the saturated vapor pressure at the given temperature (mm Hg).

The relation between the saturation pressure and temperature from 0 to 100°C is expressed as (Siau 1984):

$$P_o = 8.75 \times 10^8 \times \mathrm{Exp}\left(-\frac{10{,}400}{RT}\right) \qquad (7)$$

where P_0 is saturation pressure, mm Hg. R is gas constant, 1.987 cal/mol K, and T is the temperature in Kelvin.

Thus, by combining equations Eqs. (1), (6,) and (7,) it is possible to estimate EMC for wood under vacuum conditions.

Tables 1a, 1b, 1c illustrate the calculated EMC values under vacuum conditions. The values calculated using Eq. (1.) Figure 1 is the graphical representation of the same EMC values at the various pressures. During vacuum drying, EMC increases with increasing the pressure (less vacuum) and with decreasing temperature.

Some considerations should be noted about the EMC data from this model. The data in Table 1 are derived from isotherm sorption theory and are based on experimental data determined at atmospheric pressure. They are not

TABLE 1c. *Theoretical equilibrium moisture content at various temperatures and pressures.*

Temperature		Pressure mm Hg																				
C	F	110	120	130	140	150	160	170	180	190	200	250	300	350	400	450	500	550	600	650	700	760
51	123.8																					
52	125.6																					
53	127.4																					
54	129.2	28.3																				
55	131.0	22.7																				
56	132.8	19.2	26.8																			
57	134.6	16.8	21.8																			
58	136.4	15.0	18.6	24.7																		
59	138.2	13.5	16.3	20.5	28.0																	
60	140.0	12.4	14.6	17.6	22.5																	
61	141.8	11.5	13.2	15.6	19.0	24.6																
62	143.6	10.7	12.2	14.0	16.6	20.4	26.8															
63	145.4	10.0	11.3	12.8	14.8	17.6	21.7	28.8														
64	147.2	9.4	10.5	11.8	13.4	15.5	18.5	22.9														
65	149.0	8.9	9.9	10.9	12.3	13.9	16.2	19.3	24.0													
66	150.8	8.4	9.3	10.2	11.3	12.7	14.4	16.7	20.0	24.9												
67	152.6	8.0	8.8	9.6	10.6	11.7	13.1	14.9	17.2	20.5	25.6											
68	154.4	7.6	8.3	9.1	9.9	10.9	12.0	13.4	15.2	17.6	20.9											
69	156.2	7.3	7.9	8.6	9.3	10.1	11.1	12.3	13.7	15.5	17.9											
70	158.0	6.9	7.5	8.1	8.8	9.5	10.4	11.3	12.5	13.9	15.7											
71	159.8	6.6	7.1	7.7	8.3	9.0	9.7	10.5	11.5	12.6	14.0											
72	161.6	6.3	6.8	7.3	7.9	8.5	9.1	9.9	10.7	11.6	12.7	25.2										
73	163.4	6.0	6.5	7.0	7.5	8.0	8.6	9.3	10.0	10.8	11.7	20.6										
74	165.2	5.7	6.2	6.7	7.1	7.6	8.2	8.7	9.4	10.1	10.8	17.6										
75	167.0	5.5	5.9	6.4	6.8	7.3	7.7	8.3	8.8	9.4	10.1	15.4										
76	168.8	5.2	5.7	6.1	6.5	6.9	7.4	7.8	8.3	8.9	9.5	13.8	26.0									
77	170.6	5.0	5.4	5.8	6.2	6.6	7.0	7.4	7.9	8.4	8.9	12.5	21.1									
78	172.4	4.8	5.2	5.5	5.9	6.3	6.7	7.1	7.5	7.9	8.4	11.5	17.9									
79	174.2	4.6	4.9	5.3	5.6	6.0	6.4	6.7	7.1	7.5	7.9	10.7	15.6									
80	176.0	4.4	4.7	5.0	5.4	5.7	6.1	6.4	6.8	7.1	7.5	9.9	13.9	23.6								
81	177.8	4.1	4.5	4.8	5.1	5.5	5.8	6.1	6.5	6.8	7.2	9.3	12.6	19.5								
82	179.6	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.5	6.8	8.7	11.5	16.8								
83	181.4	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.5	8.2	10.6	14.7	24.5							
84	183.2	3.6	3.9	4.2	4.5	4.7	5.0	5.3	5.6	5.9	6.2	7.8	9.9	13.2	20.0							
85	185.0	3.4	3.7	4.0	4.2	4.5	4.8	5.1	5.3	5.6	5.9	7.4	9.2	12.0	17.1							
86	186.8	3.2	3.5	3.8	4.0	4.3	4.6	4.8	5.1	5.3	5.6	7.0	8.7	11.0	14.9	23.5						
87	188.6	3.1	3.3	3.6	3.8	4.1	4.4	4.6	4.8	5.1	5.3	6.6	8.2	10.2	13.3	19.4						

Table 1c. *Continued.*

Temperature C	Temperature F	110	120	130	140	150	160	170	180	190	200	250	300	350	400	450	500	550	600	650	700	760
		Pressure mm Hg																				
88	190.4	2.9	3.2	3.4	3.7	3.9	4.1	4.4	4.6	4.9	5.1	6.3	7.7	9.5	12.1	16.6	27.0					
89	192.2	2.8	3.0	3.2	3.5	3.7	3.9	4.2	4.4	4.6	4.9	6.0	7.3	8.9	11.1	14.6	21.5					
90	194.0	2.6	2.8	3.1	3.3	3.5	3.7	4.0	4.2	4.4	4.6	5.7	6.9	8.3	10.2	13.0	18.0	29.9				
91	195.8	2.5	2.7	2.9	3.1	3.3	3.6	3.8	4.0	4.2	4.4	5.4	6.6	7.8	9.5	11.8	15.6	23.1				
92	197.6	2.3	2.5	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	5.2	6.2	7.4	8.8	10.8	13.8	19.0				
93	199.4	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.9	5.9	7.0	8.3	10.0	12.4	16.3	24.1			
94	201.2	2.1	2.3	2.5	2.7	2.9	3.0	3.2	3.4	3.6	3.8	4.7	5.6	6.6	7.8	9.3	11.3	14.3	19.6			
95	203.0	2.0	2.1	2.3	2.5	2.7	2.9	3.1	3.2	3.4	3.6	4.5	5.3	6.3	7.4	8.6	10.3	12.7	16.6	24.2		
96	204.8	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.1	3.2	3.4	4.2	5.1	6.0	6.9	8.1	9.6	11.5	14.5	19.6		
97	206.6	1.7	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3.1	3.2	4.0	4.8	5.7	6.6	7.6	8.9	10.6	12.9	16.6	23.6	
98	208.4	1.6	1.8	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.1	3.8	4.6	5.4	6.2	7.2	8.3	9.7	11.7	14.5	19.2	
99	210.2	1.5	1.7	1.8	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.6	4.3	5.1	5.9	6.8	7.8	9.0	10.6	12.9	16.3	24.3
100	212.0	1.4	1.6	1.7	1.9	2.0	2.2	2.3	2.4	2.6	2.7	3.4	4.1	4.8	5.6	6.4	7.3	8.4	9.8	11.6	14.2	19.6

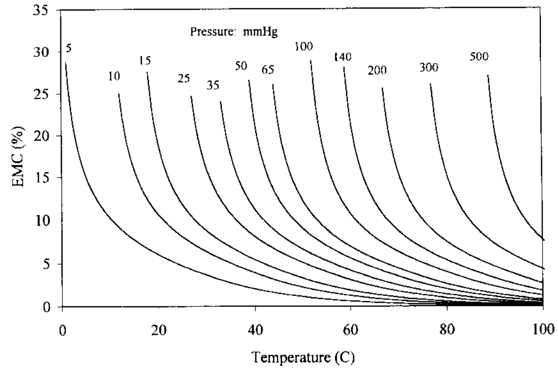

Fig. 1. Theoretical EMC under vacuum at the various temperatures and pressures.

experimental data developed under vacuum conditions. EMCs may differ for various species in a practical situation. There is no information available on the presence or absence of a hysteresis effect under vacuum. A potential hysteresis may generate different EMC values under vacuum. Furthermore the pressure used in the calculation of EMC was taken as vapor pressure where the air was assumed to be absent. Because many factors can affect EMC under vacuum, these data are only approximations. However, they can serve as useful practical estimates.

REFERENCES

Chen, Z. 1997. Primary driving force in wood vacuum drying. Ph.D. dissertation, Virginia Tech.., Blacksburg, VA. http://scholar.lib.vt.edu/theses/available/ed-02198-185538/

Forest Products Laboratory. 1990. Wood engineering handbook. Prentice Hall, Englewood Cliffs, NJ. 438 pp.

Hailwood, A. J., and S. Horrobin. 1946. Absorption of water by polymers: Analysis in terms of a simple model. Trans. Faraday Soc. 42B:84–92, 94–102.

Siau, J. F. 1984. Transport process in wood. Springer-Verlag, New York, NY. 218 pp.

Simpson, W. T. 1971. Equilibrium moisture content prediction for wood. Forest Prod. J. 21(5):48–49.

———. 1973. Predicting equilibrium moisture content of wood by mathematical models. Wood Fiber Sci. 5(1): 41–49.

———. 1998. Equilibrium moisture content of wood in outdoor locations in the United States and worldwide. Research Note FPL-RN-0628, USDA Forest Products Laboratory, Madison, WI. 11 pp.

Voigt, H., O. U. Krischer, and H. Schauss. 1940. Special technique for wood drying. Holz Roh-Werkst. 11(9):364–375.