APPLICATION OF NELSON'S SORPTION ISOTHERM TO WOOD COMPOSITES AND OVERLAYS[1]

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ABSTRACT

Equilibrium moisture content (EMC) as a function of relative humidity (RH) was measured in oriented strandboard, particleboard, medium-density fiberboard, hardboard, high pressure laminates, and solid wood. The measurements were made in both adsorption and desorption at 25°C. The EMC-RH data were fit to Nelson's sorption isotherm. It was found that Nelson's model can be used to describe the experimental data from different composite materials. The parameters that define the sorption isotherm varied with material type and sorption mode. Determination of the model parameters for various products allows the use of the model as a tool for predicting moisture change in wood-based products under varying environmental conditions.

Keywords: Adsorption, desorption, model, moisture, panel products

The relationships between equilibrium moisture content (EMC), relative humidity (RH), and temperature are of considerable practical interest for wood composite materials (Suchsland 1972). These relationships, known as sorption isotherms, greatly affect the strength and dimensional stability of different products during service. Their determination is required for analyzing moisture-related problems such as warping of a furniture panel and shrinkage and swelling of a structural composite (Burch et al. 1992; Wu and Suchsland 1996).

Nelson (1983) developed a model based on Gibbs free energy to describe the sorption behavior of cellulosic materials. The model is of the form

$$\frac{RH}{100} = \exp\left\{\left(-\frac{W_w}{R \cdot T}\right)\exp\left[A\left(1.0 - \frac{EMC}{M_V}\right)\right]\right\} \quad (1)$$

where:

RH = relative humidity in percent;
exp = exponential function;
W_w = molecular weight of water (18 $mole^{-1}$);
R = universal gas constant (1.9858 cal/mole/°K);
T = absolute temperature (°K);
A = natural logarithm (ln) of Gibbs free energy per gram of sorbed water as RH approaches zero (ΔG_o, cal/g), i.e., $A = \ln(\Delta G_o)$; and
M_v = a material constant which approximates the fiber saturation point for desorption (%).

For a given temperature, the term $[-W_w/(R \cdot T)]$ becomes a constant, and parameters A and M_v define the sorption isotherm. Nelson (1983) applied the sorption isotherm to wood and cotton. He found that it can reproduce the experimental data accurately. There is little specific information, however, available on how the parameters (A or ΔG_o and M_v) vary from one material to another.

Wood composite materials have sorption isotherms that are essentially different from those of solid wood (Suchsland 1972; Wu and

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Suchsland 1996). This is mainly attributed to the heat treatment during manufacturing process (Suchsland 1972). Several experimental studies have been done to determine the sorption isotherm for different wood composites (Burch et al. 1992; Heebink and Haskell 1962). However, few attempts have been made to analyze the data with a model. In this study, the EMCs of several types of wood composites, overlays, and solid wood were measured in both adsorption and desorption at room temperature. The data were fit to Nelson's model through nonlinear regression analysis. The objectives of the study were a) to determine the applicability of the model, and b) to evaluate and compare the model parameters among different materials.

PROCEDURE

Specimens from five types of oriented strandboard (OSB), one type of particleboard (PB), one type of medium-density fiberboard (MDF), one type of hardboard (HB), one high pressure laminate (HPL), one HPL backer, aspen (*Populus* sp.), and southern pine (*Pinus* sp.) lumber were selected for this study. Thickness and density of test materials are summarized in Table 1. All the composites and overlays were commercially made. They were either purchased from a local supplier or obtained directly from the manufacturers. One strip (25.4 mm wide by 610 mm long by thickness) was first cut from the larger panel of each material with a table saw. All the strips were then cross-cut into specimens of 25.4 mm in length. Two specimens (25.4 mm wide by 25.4 mm long by thickness) were randomly selected from each material type. They were numbered and combined to form a group. A total of 14 groups was prepared.

Seven groups of samples were randomly selected before testing. They were conditioned at 0% relative humidity in two desiccators over dry phosphorous pentoxide (P_2O_5) for the adsorption tests. The remaining seven groups were conditioned over distilled water to reach a saturated state for the desorption tests. A period of 6 weeks was used to condition the specimens.

TABLE 1. *List of materials used in the study.*

Material	Thickness[a] (mm)	Density[b] (g/cm^3)
Aspen OSB		
Sheathing	11.2	0.59
Floor underlayment	19.1	0.54
Southern pine OSB		
Sheathing	10.9	0.62
I-beam web	10.4	0.70
Floor underlayment	15.2	0.63
Interior particleboard	19.1	0.64
Medium-density fiberboard	6.4	0.65
Hardboard	3.3	1.10
High pressure laminate	1.1	1.32
High pressure laminate backer	0.5	1.20
Solid wood		
Aspen	8.0	0.41
Southern pine	8.0	0.51

[a] Thickness was measured after specimens reached equilibrium at 45% relative humidity and room temperature (25°C).
[b] Density is based oven-dry weight and volume at EMCs corresponding to 45% relative humidity and 25°C temperature.

Equilibrium moisture content tests were made at relative humidity of 20, 35, 45, 66, 75, 81, and 93%. Seven desiccators charged with saturated salt solutions of different vapor pressures were used to achieve these specified conditions. For adsorption, the seven groups of specimens preconditioned over phosphorous pentoxide (P_2O_5) were randomly allocated for the seven atmospheric conditions. For desorption, the seven groups of specimens preconditioned over distilled water were used. The initial weight of all specimens was measured. All specimens were then allowed to reach equilibrium at the specified RH in a period of 6 weeks. At the end of the exposure for both adsorption and desorption, the specimens were weighed and then oven-dried at 103°C for 24 h. Their moisture content (MC) was calculated based on the oven-dry weight.

Experimental data of EMCs at various RHs were fit to the inverse form of Eq. (1):

$$EMC = M_V\left\{1.0 - \frac{1}{A}\ln\left[\left(-\frac{R \cdot T}{W_w}\right)\ln\left(\frac{RH}{100}\right)\right]\right\} \quad (2)$$

to determine the material parameters A and M_v. A regression analysis was performed with the measured equilibrium moisture content, EMC, as the dependent variable and transformed relative humidity, RH^T, as the independent variable:

$$EMC = M_v + B\ RH^T \quad (3)$$

where, $B = -M_v/A$, and $RH^T = \ln [(-R \cdot T/W_w) \ln (RH/100)]$. The hysteresis ratio for each material was evaluated as $(M_v)_{ads.}/(M_v)_{des.}$

RESULTS

Sorption isotherms

Typical sorption isotherms are shown in Fig. 1 (a: OSB and b: MDF). All materials tested showed a sorption hysteresis, i.e., the adsorption curve being lower than the desorption curve indicating a lower MC value at a fixed RH level as approached from adsorption. Nelson's model fits the experimental data well (lines in Fig. 1) with the estimated coefficient of determination varying from 0.94 to 0.99. Listed in Table 2 are the parameters defining sorption isotherms for the various products tested.

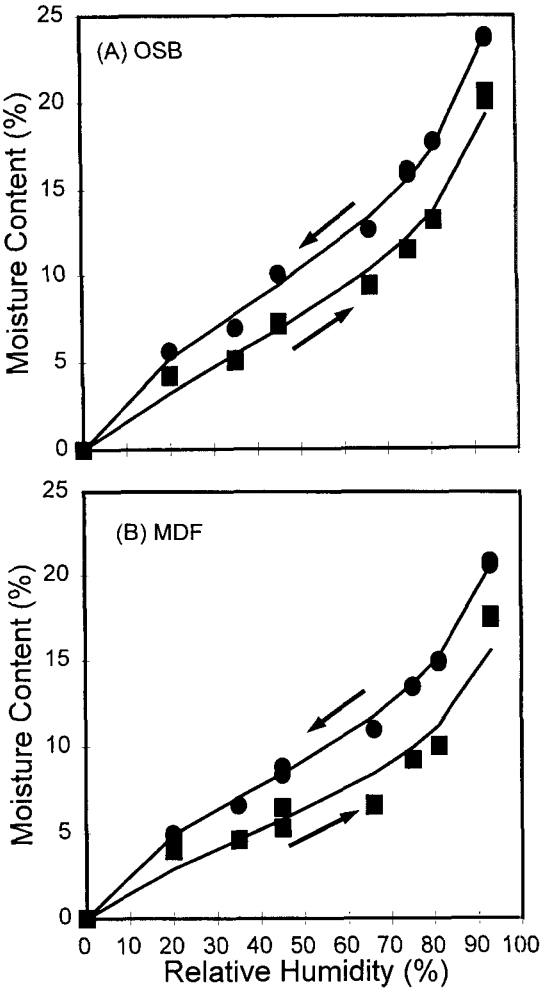

FIG. 1. Typical sorption isotherms for OSB (A) and MDF (B) at 25°C. Lines show values predicted by the model.

Parameter A

Parameter A averaged 4.81 for adsorption and 5.02 for desorption among the materials. Thus, parameter A is nearly identical for adsorption and desorption as reported by Nelson (1983). Nelson quoted A values of 4.92 for adsorption and 5.11 for desorption in solid wood, which are comparable to the fitted values for aspen and southern pine in this study.

The Gibb free energy per gram of sorbed water at 0% RH, ΔG_o ($=e^A$), varied from 86 to 194 cal/g in adsorption and from 120 to 191 cal/g in desorption among the materials tested. The mean value of ΔG_o for desorption was 151 cal/g compared to Nelson's value of 165 cal/g for wood. All materials used in this study are wood-based products. The panel products were subjected to different heat and pressure treatments during the manufacturing process. However, there appeared to be no particular trend in A values among the products tested (Fig. 2a). This indicated that heat and pressure treatments had an insignificant effect on A or ΔG_o. Stamm and Loughborough (1935) also showed that A or ΔG_o is independent of temperature.

Parameter M_v

The magnitude of M_v was higher in desorption than in adsorption for all materials tested for a given RH (Table 2). Effects of panel manufacturing processes on parameter M_v are

TABLE 2. *Results of the regression analysis on sorption isotherm.*

Material	Adsorption		Desorption		Hysteresis ratio $r_{(MV)}$
	A (cal/g)	M_V (%)	A (cal/g)	M_V (%)	
Aspen OSB					
Sheathing	4.45	22.20	4.79	27.49	0.808
Floor underlayment	4.49	22.94	4.89	28.28	0.811
Southern pine OSB					
Sheathing	4.60	23.77	4.85	29.00	0.822
I-beam web	4.71	21.77	5.06	26.70	0.815
Floor underlayment	4.64	23.22	5.10	27.58	0.842
Interior particleboard (PB)	5.18	20.02	5.11	25.93	0.770
Medium-density fiberboard (MDF)	4.68	19.13	4.94	24.94	0.767
Hardboard (HB)	4.54	15.95	4.97	20.73	0.769
High pressure laminate (HPL)	5.15	10.05	5.19	12.68	0.793
HPL backer (BCK)	5.27	11.52	5.25	13.61	0.845
Solid wood					
Aspen	4.97	22.90	4.91	28.28	0.809
Southern pine	5.11	22.66	5.17	27.60	0.821
Wood[a]	4.92	24.80	5.11	29.60	0.831

[a] Data for wood are from Nelson (1983) at 25°C.

clearly seen in Fig. 2b. As shown, solid wood had the highest M_v value, averaging 22.8 for adsorption and 27.9 for desorption. Among the five types of OSB, southern pine OSB for I-beam web had the highest density. As a result, its M_v values for both adsorption and desorption were lower than the values of other types of OSB (Table 2). The mean M_v values for OSB in both adsorption and desorption were similar to the values for solid wood. This indicates that large flakes such as those used in OSB can recover most of the lost sorption ability due to thermal treatments over a long-term exposure to high humidity conditions. However, as the size of wood particles decreased and treatment conditions (pressure, temperature, etc.) used to manufacture the products changed from OSB to particleboard, to MDF, to hardboard and to high pressure laminates (made of resin-saturated papers), M_v values decreased considerably. Thermal treatments significantly lowered the M_v values for particle- and fiber-based products. Thus, it appears that heat and pressure have a greater effect on wood fibers than on large wood flakes in terms of their sorption behavior. For high pressure laminate overlays and backers, their resin contents are probably higher than 50%. Therefore, their hygroscopic property may be dominated by the adhesives rather than by the manufacturing process. Since M_v approximates the MC at saturation in desorption, different M_v values in HPL, hardboard, MDF, and particleboard mean different saturation MCs at a fixed temperature. When these products are laminated together and then exposed to a given RH, an unbalanced moisture gradient across the panel thickness can develop, which may lead to warping of the panel (Wu and Suchsland 1996).

Hysteresis ratio

The amount of water held by cellulosic materials at a given temperature and relative humidity depends on the direction from which equilibrium is approached (i.e., sorption hysteresis). Stamm and Loughbrough (1935) showed that the hysteresis ratio, the quotient of the adsorption and desorption moisture contents, varied from about 0.75 to 0.90. The variability depends largely on the RH level and the nature of the sorbing materials. The hysteresis ratio calculated in this study varied

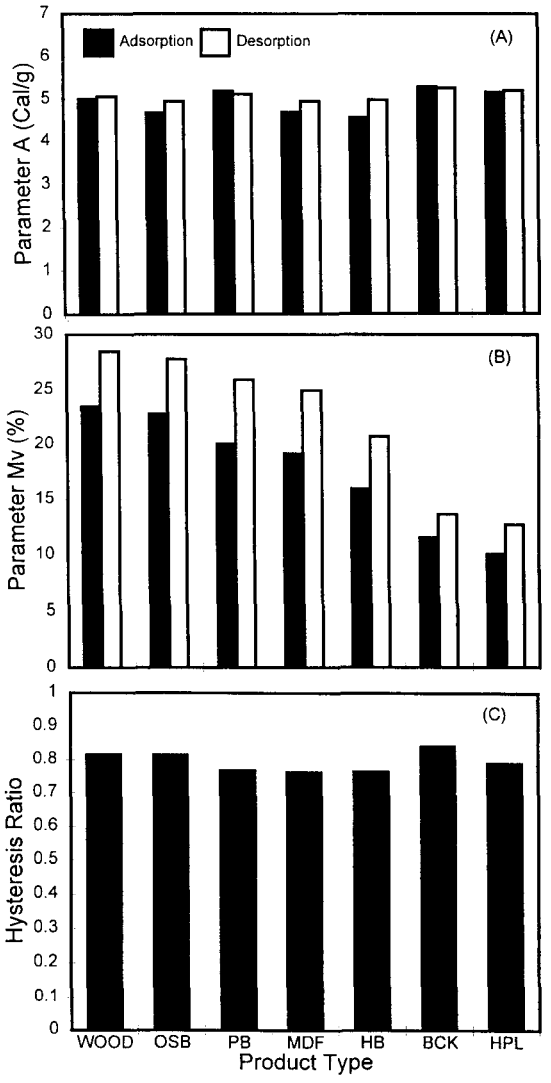

FIG. 2. A comparison of sorption parameters for various materials tested. (A) Parameter A, (B) Parameter my and (C) Hysteresis Ratio.

from 0.77 to 0.85. Thus, the hysteresis ratios derived from this study are in the expected range. There appears to be no particular trend in hysteresis ratio among the various products. Therefore, even though M_v values were considerably lower for the fiber-based products (HPL, hardboard, and MDF), their hysteresis ratios were not greatly different from wood, OSB, and particleboard.

SUMMARY

Nelson's sorption isotherm can be used to describe the sorption data for a number of different wood composite materials. The parameters that define the sorption isotherm varied with sorption mode and product type. Determination of these parameters makes it possible to use Nelson's model as an analytical tool in predicting, for example, moisture flow through building walls (Burch et al. 1992) and moisture gradient in overlaid furniture panels (Wu and Suchsland 1996).

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