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

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Running head: Sorption isotherm of wood composites.

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ABSTRACT

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

Key words: 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

$$RH = EXP\left\{\left(-\frac{W_W}{R\,T}\right) EXP\left[A\left(1.0 - \frac{EMC}{M_V}\right)\right]\right\} \qquad [1]$$

where:

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 of Gibbs free energy per gram of sorbed water as RH approaches zero (ΔG_o, cal/g), i.e. A = LN(ΔG_o); and

M_V = a material constant which approximates the fiber saturation point for desorption (%).

For a given temperature, the term ($-W_W/RT$) 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 sufficiently different from those of solid wood (Suchsland 1972, Wu and Suchsland 1996). This is mainly attributed to the heat treatment during manufacturing process. Several experimental studies have been made to determine the sorption isotherm for different wood composites (Burch et al 1992, Heebink and Haskell 1962, Suchsland 1972). 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 material 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 and two types of solid wood (Aspen and Southern pine) were selected for this study. Table 1 lists the thickness of different materials. 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 using 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 fourteen groups were 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 six weeks was used to condition the specimens.

EMC 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 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 six 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 hours. 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 Equation 1:

$$EMC = M_V \left\{ 1.0 - \frac{1}{A} LN \left[\left(-\frac{RT}{W_W} \right) LN\,(RH) \right] \right\} \qquad [2]$$

to determine the material parameters A and M_V. A regression analysis was performed using the measured EMC as the dependent variable and transformed RH as the independent variable:

$$EMC = M_V + B\ RH^T \qquad [3]$$

where, $B = -M_V/A$, and $RH^T = LN[(-RT/W_W)\ LN(RH)]$. The hysteresis ratio for each material was evaluated as $(M_V)_{ads.} / (M_V)_{des.}$

RESULTS

Sorption Isotherms

Typical sorption isotherms are shown in Figure 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 fitted experimental data well (lines in Figure 1) with the coefficient of determination varying from 0.94 to 0.99. Table 2 shows the parameters defining sorption isotherms for the various products tested.

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 shown 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 comparing with 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 manufacturing process. However, there appeared to be no particular trend in A values among the products tested (Figure 2a). This indicated that heat and pressure treatments had an insignificant effect on A or ΔG_O. Stamm and Loughborough (4) also showed that A or ΔG_O is independent of temperature.

Parameter M_V

The magnitude of $\mathbf{M_V}$ was higher in desorption than in adsorption for all materials tested for a given RH (Table 2). Effects of panel manufacturing processes on parameter $\mathbf{M_V}$ is clearly shown in Figure 2b. As shown, solid wood had the highest $\mathbf{M_V}$ 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 $\mathbf{M_V}$ values for both adsorption and desorption were lower than the values of other types of OSB. The mean $\mathbf{M_v}$ 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 oil-saturated papers), $\mathbf{M_v}$ values decreased considerably. Thermal treatments significantly lowered the $\mathbf{M_v}$ values for particle- and fiber-based products. Thus, it appears that heat and pressure have a larger effect on wood fibers than on large wood flakes in terms of their sorption behavior. Since $\mathbf{M_v}$ approximates the MC at saturation in desorption, different $\mathbf{M_v}$ 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, a 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 largely depends on the RH level and the nature of the sorbing materials. The hysteresis ratio calculated in this study varied 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 $\mathbf{M}_v$ 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 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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Table 1. List of materials used in the study.

Material		Thickness [a] (mm)
Aspen OSB	- Sheathing	11.2
	- Floor underlayment	19.1
Southern pine OSB	- Sheathing	10.9
	- I-beam web	10.4
	- Floor underlayment	15.2
Interior particleboard		19.1
Medium-density fiberboard		6.4
Hardboard		3.3
High pressure laminate		1.1
High pressure laminate backer		0.5
Solid wood	- Aspen	8.0
	- Southern pine	8.0

[a] Thickness was measured at 45% relative humidity at room temperature (25 °C).

Table 2. - Results of the regression analysis on sorption isotherm.

Material	Adsorption		Desorption		Hysteresis Ratio
	A (cal/g)	M_V (%)	A (cal/g)	M_V (%)	$r_{(Mv)}$
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 is from Nelson (1983) at 25 °C.

FIGURE CAPTIONS:

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

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

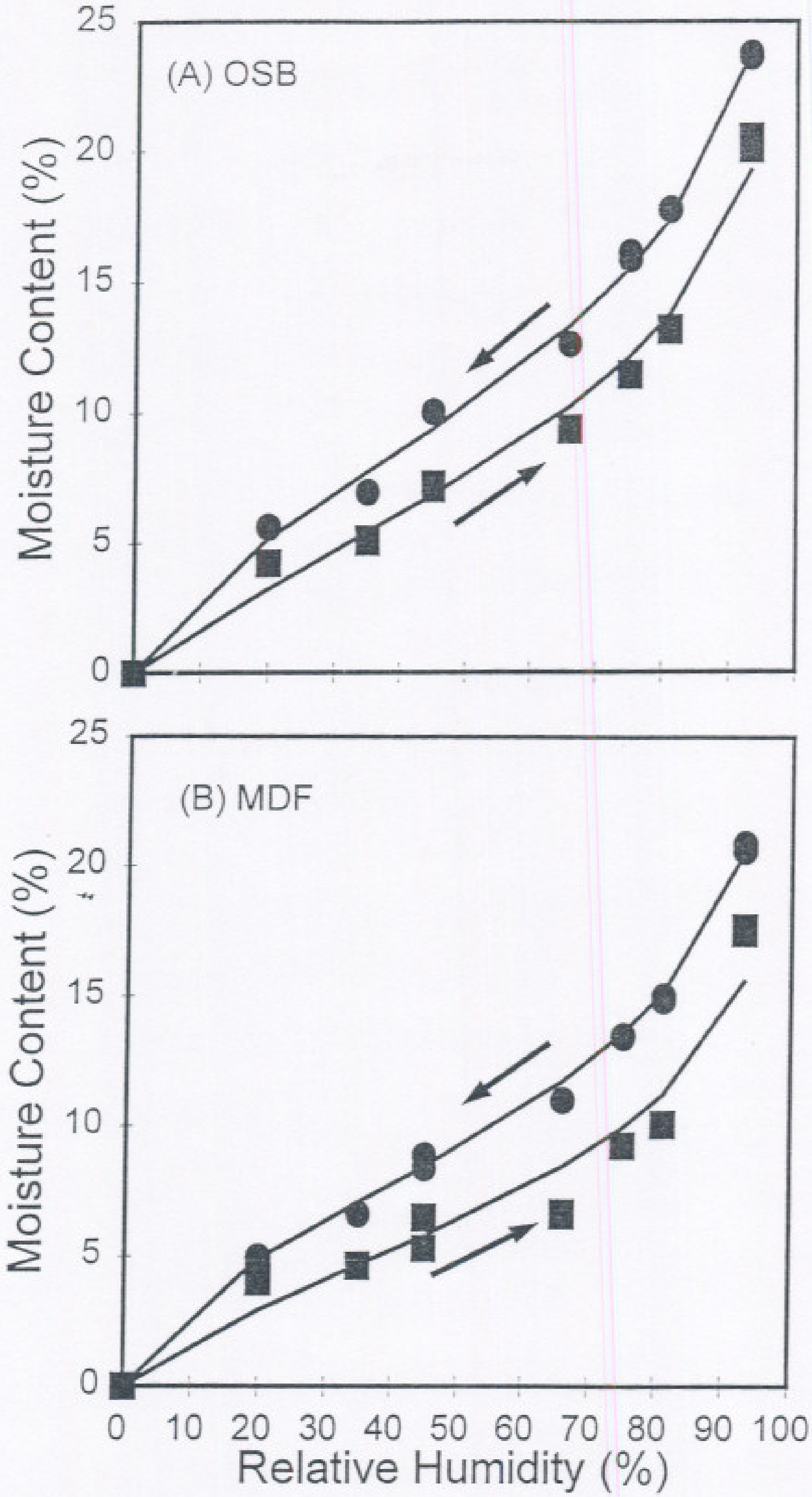
(A) OSB
(B) MDF
Moisture Content (%)
Moisture Content (%)
Relative Humidity (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100

FIG 1

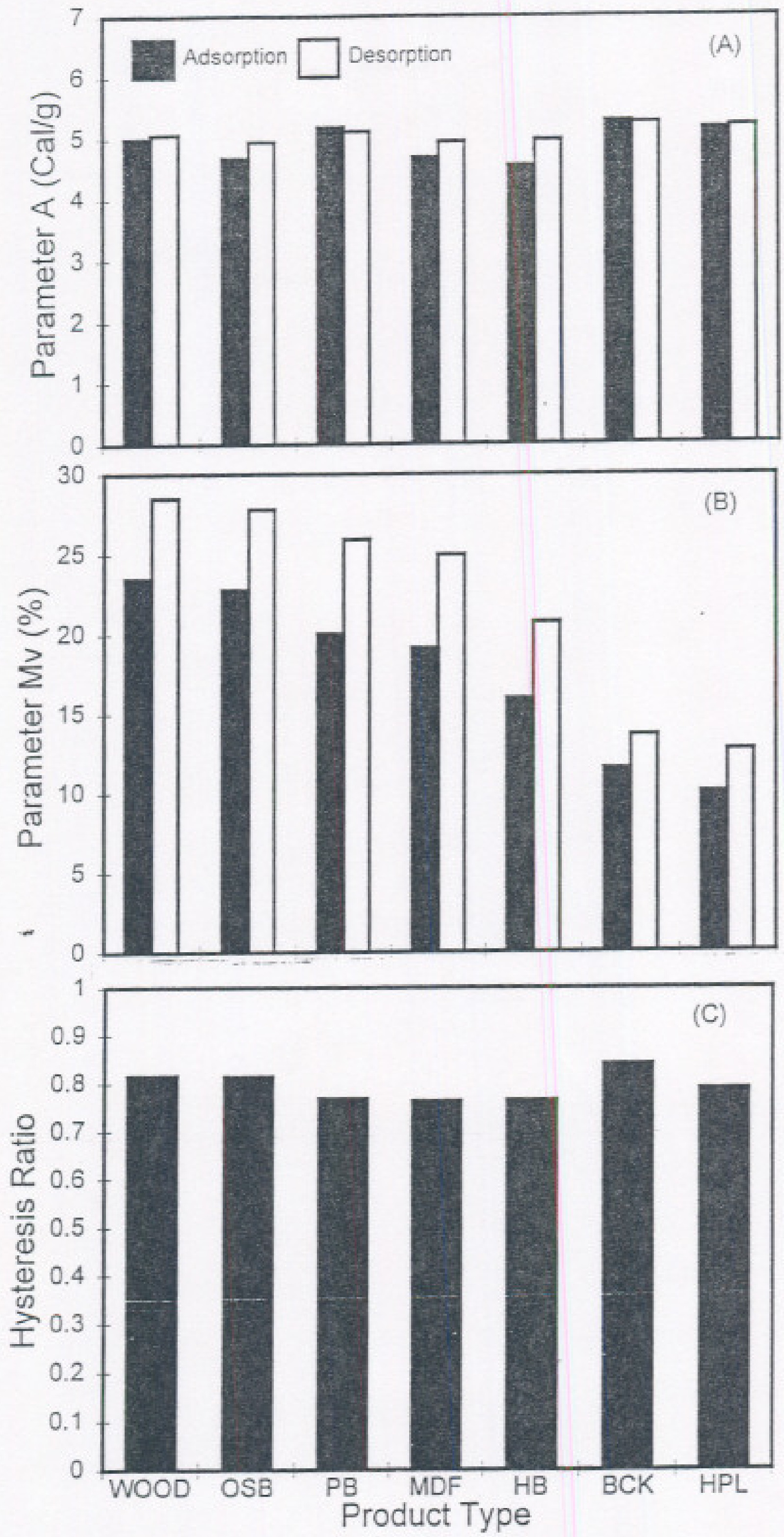
Adsorption
Desorption
(A)
Parameter A (Cal/g)
(B)
Parameter Mv (%)
(C)
Hysteresis Ratio
WOOD
OSB
PB
MDF
HB
BCK
HPL
Product Type

FIG2