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Assessment of hygroscopic conditioning performance of interior decorative materials IV: Sorption characteristics of wood under high relative humidity condition

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Abstract The equilibrium moisture content (EMC) of six wood species under desorption conditions of 20°C and 100% → 0% relative humidity (RH), and the rate of adsorption at various depths of three wood species blocks under 98% RH at 22.5°C were studied. There were no significant differences among the EMC values for these six wood species over the RH range 40% → 0%, but there were highly significant differences over the RH range 100% → 50% at constant 20°C. The amount of moisture absorbed in the wood decreased curvilinearly with the increase of depth in the specimens as sorption time increased, and their relation could be represented by a semilogarithmic equation. Time-dependent adsorption behavior at various depths of the wood specimens could be represented by an exponential equation as a function of the product of the difference between moisture contents at equilibrium and initial conditions and the term $(1 - e^{-t/\tau})$. The value of τ of various wood species was found to increase linearly with the increased depth of the specimen and showed the following trend: hard maple (*Acer* sp.) > China fir (*Cunninghamia lanceolata*) > Japanese cedar (*Cryptomeria japonica* D. Don).

Key words Depth of absorption · Absorbed moisture content · Time-dependent adsorption · Effectiveness of hygroscopic conditioning

Introduction

It is well known that the hygroscopic conditioning characteristics of wood used for interior paneling are affected by the change of its moisture content (MC). Therefore, the hygroscopic conditioning effect on the wood-based materials used for interior decorative panels in a residential house would be influenced not only by the quantities of such materials used but also by their geometry and dimension. This is understandable because the change of moisture content in wood is a time-delaying phenomenon, and hence the MC in the face portion may be always higher or lower than that of the core portion when the room temperature and relative humidity (RH) change. Such MC changes are referred as sorption hysteresis, and the MC of wood is generally defined as the equilibrium moisture content (EMC) – when it reaches equlibrium conditions. However, the adsorption and desorption of moisture in the core of wood is always in a delayed-changing mode because room temperature and RH generally fluctuate daily. Consequently, the variation of EMC in the surface portion would be somewhat greater than that in the core portion.

In general, the desorption and adsorption phenomenon of wood materials inside a house or building is influenced by the fluctuation of room temperature and RH in the surrounding environment. Thus, the EMC of wood is constantly changing, either periodically or sporadically, and the average values of certain wood species can be found in most generally used EMC diagrams in textbooks. The MC at certain positions in the depth direction may be equal to or less than its EMC value; hence the relation between the EMC (Ue) and actual MC (U) could be expressed by:

$$Ue - U = \Delta \quad (1)$$

when $\Delta \fallingdotseq 0$, the MC at a specific position has reached equilibrium condition; if $\Delta \neq 0$, the MC is changed toward the condition of $\Delta \fallingdotseq 0$ when temperature and RH continuously fluctuate. This suggests that the moisture movement inside the wood is proportional to the Δ value; such data could be considered the MC fluctuation in wood.

This study was designed to investigate the effective depth of hygroscopic conditioning of three wood species. First, the EMC under various RHs at constant temperature was measured, and the resorption EMC and the rate of resorption at various depths of wood under constant condi-

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tions of 22.5°C and 98% RH were examined. The collected data may provide useful information for establishing a database to be used for improved design of in-house used wood panels that provide better hygroscopic conditioning function in a living environment.

Materials and methods

Materials

Six wood species were selected for this study including two Taiwan-grown plantation trees: Japanese cedar [*Cryptomeria japonica* D. Don: r_u (specific gravity in an air-dried condition) 0.47] and China fir [*Cunninghamia lanceolata* (Lamb.) Hook: r_u 0.44); three American-grown trees: western hemlock (*Tsuga* sp.: r_u 0.51), red oak (*Quercus* sp.: r_u 0.63), and hard maple (*Acer* sp.: r_u 0.72); and one Southeast Asian tree: red meranti (*Shorea* sp.: r_u 0.45).

Method

Equilibrium moisture content of woods

Specimens of 2 cm^3 were cut from a clear, straight grain and air-dried wood block. For the first test, the temperature was maintained at a constant 20°C, but the RH was changed stepwise from 100% to 0% at intervals of 10%. At the beginning, all specimens were conditioned to equilibium under 100% RH, and the weight of each specimen was recorded (W_{100}). The weight of each specimen was scaled with a precision balance of 10^{-4}g accuracy. Then all the specimens were transferred to a 90% RH environment for desorption, and the constant weight of each specimen at equilibrium was recorded (W_{90}). In a similar fashion, the weights at other RHs (i.e., W_{80}, W_{70}, W_{60}, W_{50}, W_{40}, W_{30}, W_{20}, W_{10}, W_0) were measured. This process was repeated five times for all six wood species. After the weight of the last specimen was recorded, all specimens were placed in an oven with a temperature of 103° ± 2°C, and the oven-dried weight of each specimen. (W_0') was recorded. Finally, desorption data were substituted into the following equation for calculation of their EMC

$$\mathrm{EMC}(\%) = \left(\frac{W_{100}(\text{or } W_{90} \cdots W_0)}{W_0'} - 1 \right) \times 100 \tag{2}$$

The conditions of 90% → 0% RHs were obtained using solutions of sulfuric acid with concentrations of 18.23%–95.00%, respectively in a desiccator (weight basis); 100% RH was provided by pure water in a desiccator, as showed in Table 1. The sulfuric acid solution must be adjusted continuously to maintain a constant RH because the concentration of sulfuric acid solution was changed by the desorption/adsorption (resorption) of wood.

Table 1. Specific gravity and concentration of sulfate solution used for adjustment of relative humidity conditions

Relative humidity (%)	Specific gravity	Weight concentration (%)
0	Sulfuric acid (>95%)	–
10	1.55	64.4
20	1.48	58.0
30	1.42	52.7
40	1.37	47.9
50	1.33	43.2
60	1.29	38.4
70	1.25	33.3
80	1.19	26.3
90	1.13	18.2
100	Pure water	–

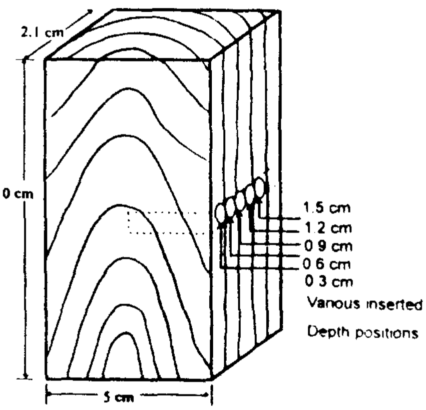

Fig. 1. Insertion positions of the moisture meter sensor at various specimen depths. Each specimen was measured at only one position

Hygroscopic properties at various depths of wood under high RH

Wood blocks 10 cm long (longitudinal direction) × 5 cm wide (tangential direction) × 2.1 cm thick (radial direction) cut from a clear, straight grain and air-dried were used. All specimens were conditioned to equilibrium under constant conditions of 20°C and 65% RH. The five faces of each specimen were then sealed with paraffin wax except one of the tangential faces (5 × 10 cm), which was left unsealed for MC measurement. The sensor of an electronic resistance-type moisture meter (TG-40R model; Sango KK) was inserted from the right radial face into the center position of the specimen at distances of 0.3, 0.6, 0.9, 1.2, and 1.5 cm from the unsealed face, as shown in Fig. 1. The sensor's diameter was 0.234 cm. Before inserting the sensor into specimens, a guiding hole, about 80% the size of the sensor diameter (0.234 cm), was drilled onto the radial surface of specimens for easy insertion. Then the area between the sensor and specimen surface was sealed with paraffin wax. Each specimen was measured at only one depth (i.e., 0.3 cm or 0.6 cm . . . 1.5 cm), and three measurements were made for each depth in each species. The specimens were then put in a programmable-environment chamber to conduct the adsorption experiment under constant conditions of 22.5°C and 98% RH. The changes in the MC of the specimens were recorded continuously by a computer that interfaced with the MC meter for a period of 20 days to examine the hygroscopic conditioning performance at various depths of the specimens.

Results and discussion

Desorption EMC of six woods

Results of desorption EMCs for the six wood species studied under the constant temperature of 20°C and RHs of 100% → 0% are tabulated in Table 2. As expected, the EMC values decreased curvilinearly with the decrease in RH. These results are similar to those reported by Wang and Cho[1] in a previous study. From desorption isotherms of these six wood species as shown in Table 2, no significant differences in the EMC values for the RH range 40% → 0% among those species were observed. This may be due to the moisture content developed in this RH range mainly by the primary layer in which the molecules were absorbed directly on "primary" sorption sites in the cell wall, which possesses great binding energy accessible to hydroxyl groups. However, differences in the EMC values over the RH range 100% → 50% among those species were highly significant, as indicated by Duncan's new multiple range test. The relations of EMCs under various RH ranges among those six wood species could be summarized as follows: (1) With 50% RH, there was no significant difference between the EMCs of China fir (11.29%) and Japanese cedar (11.09%), but the differences were significantly greater than those of the other four wood species. (2) With 60% RH, differences were significant among the EMCs of the six wood species studied, and a decreasing order of those values was as follows: China fir (13.99%) > Japanese cedar (13.36%) > western hemlock (12.89%) > red meranti (11.95%) > hard maple (10.41%) > red oak (9.04%). (3) With 70% RH, significant differences appeared among the EMCs of the six species, in decreasing order, as follows: Japanese cedar (15.22%) > China fir (14.82%) > western hemlock (14.36%) > red meranti (13.59%) > hard maple (11.42%) > red oak (9.91%). (4) With 80% RH, there were no significant differences between the EMCs of Japanese cedar (17.90%) and western hemlock (17.49%) and between western hemlock and China fir (17.27%); but there were significant differences among the other wood species. (5) With 90% RH, there were no significant differences between EMCs of western hemlock (20.69%) and Japanese cedar (20.51%) and between red meranti (18.41%) and hard maple (18.20%); but there were significant differences among the other wood species. (6) With 100% RH, there were no significant differences of EMCs between hard maple (31.39%) and red oak (30.70%), between red oak and western hemlock (29.94%), and between western hemlock and Japanese cedar (29.58%); but there were significant differences among other wood species.

It was also found that with the RH lower than 90%, the EMCs of three softwoods were greater than those of hardwoods. In contrast, with 100% RH, the EMCs for hardwoods, including hard maple and red oak, were greater than for other wood species. However, under conditions of 90% → 0% RH, the EMC of Japanese cedar was 0.28%–5.31% greater than that of red oak; but with 100% RH, the values of red oak were slightly greater than those for Japanese cedar. This is probably due to the greater hemicellulose content in the hardwood; and the fiber saturation point (FSP) values for hardwoods are generally 1%–2% greater than those of softwoods. This result was similar to that reported by Wang and Cho,[1] who stated that the EMC under a 90% → 0% RH desorption condition for Japanese cedar was 1.8%–3.5% greater than that of red oak, but that a reversed situation was observed when the testing condition was set with 100% RH at 20°C.

When the specimens were placed under the constant conditions of 20°C and 100% RH and equilibrated, their EMC values were considered to be the FSP of these woods. In general, FSP values for woods range from 25% to 35%.[2] Wang and Cho[1] reported that the FSP values for six other softwood species obtained from adsorption and desorption experiments under the condition of 20°–40°C and 100%

Table 2. Percent equilibrium moisture content of six wood species under various relative humidities

RH (%)	China fir	Japanese cedar	Western hemlock	Red oak	Red meranti	Hard maple
0	2.35	0.76	0.16	0.56	0.41	0.17
10	3.47	2.35	2.23	2.07	2.11	1.95
20	4.64	3.83	3.66	3.26	3.33	3.16
30	6.59	5.65	4.98	4.29	4.62	4.48
40	7.03	6.50	6.30	5.43	5.88	6.08
50	11.29	11.09	10.47	8.00	9.65	9.07
60	13.99	13.36	12.89	9.04	11.95	10.41
70	14.82	15.22	14.36	9.91	13.59	11.42
80	17.27	17.90	17.49	12.18	16.12	14.78
90	20.06	20.51	20.69	15.19	18.41	18.20
100	26.62	29.58	29.94	30.70	25.03	31.39

The temperature was kept constant at 20°C.

RH were 21.62% for Taiwan red cypress (*Chamaecyparis formosensis* Matsum), −34.49% for taiwania (*Taiwania cryptomerioides* Hay.), 23.53% for Taiwan red cypress, and 31.47% for taiwania. Results from that study indicated that the EMCs of those six wood species decreased approximately 0.1% with each 1°C increase in temperature. Moreover, using the percent shrinkage calculation methods for wood, Wang et al. [3–7] indicated that the FSP values of 15 wood species ranged from 25.5% to 34.0%. In our study the EMC values ranged from 25.03% to 31.39% with 20°C and 100% RH. These results could be considered the FSP value of the wood species studied. Hence, the results obtained in this study were inconsistent with those of previous reports.

Changes of adsorption MC under high relative humidity

Prior to the adsorption experiment, the average MCs of specimens were adjusted to 11%–12% because the moisture gradients may vary in each specimen; hence the MCs in the surface layer were not equal to that in the core layer of individual specimens. It was found that the MC of specimens increased with increased absorbing times. The adsorption moisture content (AMC) increased rapidly during the initial stage, especially in areas about 0.3–0.6 cm away from the absorbing surface and then leveled off to a constant value at a certain adsorption time. The adsorption time was shortened for areas close to the absorbing surface.

When specimens were undergoing adsorption for 20 days, the AMC varied with the depth in specimens; values of 20.8%–19.9% for Japanese cedar, 19.37%–18.05% for China fir, and 18.17%–14.40% for hard maple were recorded. When the AMC and EMC values obtained at 20°C and 100% RH conditions were compared (Table 2), the differences may be designated $\varDelta MC = EMC - AMC$, which could be considered the effective hygroscopic-conditioning factor at various depths of the specimens. The $\varDelta MC$ values for Japanese cedar, China fir and hard maple at depths of 0.3–1.5 cm were, respectively, 9.50%–9.68%, 7.31%–8.57%, and 13.32%–16.99%, which suggested that the wood species with higher density and at a deeper position in the wood may be of more hygroscopic conditioning efficiency.

To compare the changes of adsorption content at various depths, the adsorption content was defined as $\delta_{(\%)} = MC_{(t)} - MC_{(i)}$, where $MC_{(t)}$ and $MC_{(i)}$ represent the moisture content of specimens at absorbing time (t h) and initial time (0 h), respectively.

The differences in adsorption content for various depths were discussed by the change of $\delta_{(\%)}$ values. From Figs. 2–4 it is evident that the $\delta_{(\%)}$ values of Japanese cedar, China fir, and hard maple were not affected by absorbing depth during the first hour of adsorption. However, the $\delta_{(\%)}$ of specimens increased with the increase in absorbing time and decreased curvilinearly with the increase in absorbing depth; a similar tendency existed among these three wood species. These tendencies may be fitted into the semilogarithmic regression equation of $\delta_{(\%)} = a \ln(D) + b$, where $\ln(D)$ represents the logarithmic value of absorbing depth,

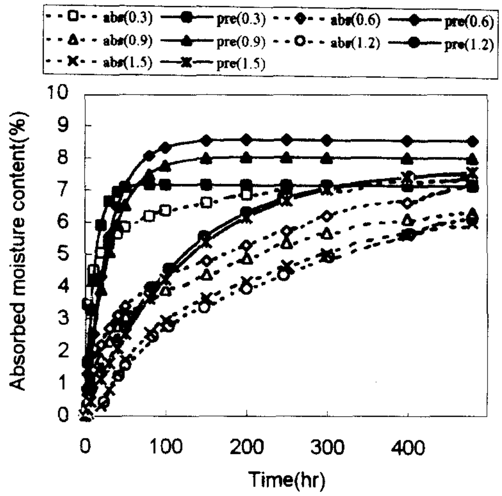

Fig. 2. Relations between absorbed moisture contents and absorbing times for various depths of Japanese cedar wood. Measurements were made 0.3–1.5 cm from the absorbing surface. *abs*, experimental data; *pre*, predicted data

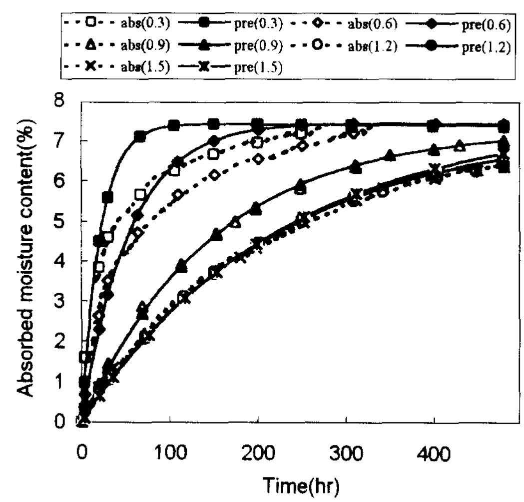

Fig. 3. Relations between absorbed moisture content and absorbing times at various depths of China fir wood. Measurements were made 0.3–1.5 cm from the absorbing surface. *abs*, experimental data; *pre*, predicted data

and a and b are material constants, respectively. When the absorbing time was considered a dependent parameter, it was obvious that it could be fitted into this equation at various absorbing times, as shown in Table 3. Large coefficients of determination (R^2) resulted, ranging from 0.896 to 0.974 for Japanese cedar (except with an absorbing time of 1h), 0.607 to 0.929 for China fir, and 0.752 to 0.983 for hard maple.

When $\delta_{(\%)}$ values at various depths for the abovementioned three wood species were compared, no significant differences among these three wood species were observed in the specimens examined with short absorbing times for an area about 0.3–0.6 cm from the absorbing surface. However, when the absorbing times were extended to 120–480h, there were significant $\delta_{(\%)}$ differences among these three wood species. Furthermore, with an absorbing time of 480h the $\delta_{(\%)}$ values were, in decreasing order, as follows: China fir (6.4%) > Japanese cedar (6.04%) > hard maple (3.37%) at an absorbing depth of 1.5cm, and an absorbing depth of 1.2cm for China fir (6.4%) > Japanese cedar (6.13%) > hard maple (4.2%).

Changes in absorbing rate

It is evident from the results that the absorbing rate (MC%/h) of specimens was high during the initial stage, decreased rapidly with the increase of adsorption time, and then leveled off to a constant value at a certain adsorption time, especially near the absorbing surface (including a depth of about 0.3–0.6cm from the surface). For example, the absorbing rate reached almost zero at 0.3cm and 0.6cm after 100h, and 220h, respectively. However, the absorbing rate at 0.3cm was 10 times higher than that at 1.5cm.

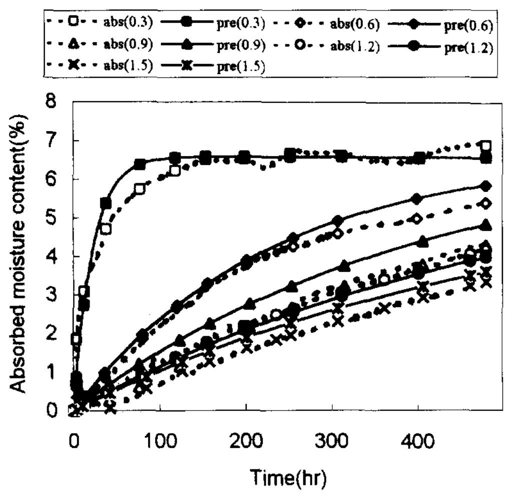

Fig. 4. Relations between absorbed moisture contents and absorbing times for various depths of hard maple wood. Measurements were made 0.3–1.5cm from the absorbing surface. *abs*, experimental data; *pre*, predicted data

When the effect of the absorbing depth on the absorbing rate was considered, it seems that the absorbing rate decreased curvilinearly with the increase in absorbing depth during the first 24h of adsorption, and their relations could be expressed by the following semilogarithmic equation:

$$Y_1 = -a \ln D + b \tag{3}$$

where Y_1 and D represent the absorbing rate (MC%/h) and absorbing depth of specimens (cm), respectively; and a and b were material constants. When the adsorption time was longer than 24h, the absorbing rate increased curvilinearly with the increase in absorbing depth, and their relation could be expresented by a semilogarthmic equation:

$$Y_2 = c \ln D + d \tag{4}$$

where Y_2 and D represent absorbing rate and absorbing depth, respectively; and c and d are material constants.

Based on these results, it seems that the correlation between absorbing rate and absorbing depth changed from negative to positive when the adsorption time was more than 24h. This finding suggests that the MC may reach an equilibrium condition at a position close to the absorbing surface. Differences still existed between the actual moisture content and the EMC at deeper positions. This point also could be recognized as evidence that a thick wood panel may perform better during hygroscopic conditioning under extended fluctuating climate conditions.

Time-dependent behavior of adsorption content

The time-dependent behavior of adsorption content at various absorbing depths in wood may be seen in plots of absorbed MC% versus absorbing times for Japanese cedar, China fir, and hard maple (Figs. 2, 3, 4, respectively). It was found that the adsorption content increased rapidly during the initial stage for an absorbing depth of 0.3cm; it then leveled off to a constant value after 100h of adsorption. However, at an absorbing depth of 0.9–1.5cm, the adsorption content increased slowly after the initial stage. The time-dependent adsorption content at various depths of these three wood species could be represented by an exponential equation:

Table 3. Semilogarthmic regression formulas as a function of adsorption contents and absorbed depth for various wood species

Adsorption times (h)	Japanese cedar		China fir		Hard maple	
	Formula	R^2	Formula	R^2	Formula	R^2
1	$\delta(\%) = -0.145 \ln(D) + 0.495$	0.607	$\delta(\%) = -0.162 \ln(D) + 0.501$	0.607	$\delta(\%) = -0.391 \ln(D) + 0.780$	0.882
2	$\delta(\%) = -1.527 \ln(D) + 2.866$	0.965	$\delta(\%) = -0.440 \ln(D) + 1.078$	0.635	$\delta(\%) = -0.685 \ln(D) + 1.344$	0.841
3	$\delta(\%) = -2.073 \ln(D) + 3.181$	0.957	$\delta(\%) = -0.715 \ln(D) + 1.365$	0.735	$\delta(\%) = -0.805 \ln(D) + 1.639$	0.866
4	$\delta(\%) = -2.325 \ln(D) + 3.360$	0.936	$\delta(\%) = -0.882 \ln(D) + 1.551$	0.788	$\delta(\%) = -0.919 \ln(D) + 1.758$	0.851
5	$\delta(\%) = -2.515 \ln(D) + 3.567$	0.927	$\delta(\%) = -1.019 \ln(D) + 1.751$	0.817	$\delta(\%) = -1.028 \ln(D) + 1.852$	0.766
10	$\delta(\%) = -2.828 \ln(D) + 4.042$	0.941	$\delta(\%) = -1.557 \ln(D) + 2.713$	0.895	$\delta(\%) = -1.570 \ln(D) + 2.329$	0.752
120	$\delta(\%) = -2.081 \ln(D) + 6.219$	0.943	$\delta(\%) = -2.316 \ln(D) + 6.731$	0.929	$\delta(\%) = -3.307 \ln(D) + 5.630$	0.864
360	$\delta(\%) = -1.183 \ln(D) + 7.219$	0.974	$\delta(\%) = -1.055 \ln(D) + 7.670$	0.781	$\delta(\%) = -2.773 \ln(D) + 6.654$	0.951
480	$\delta(\%) = -0.906 \ln(D) + 7.470$	0.896	$\delta(\%) = -0.713 \ln(D) + 7.623$	0.757	$\delta(\%) = -2.124 \ln(D) + 6.876$	0.983

Adsorption experiment under conditions of 22.5°C and 98% relative humidity (RH). δ(%), adsorption contents; D, absorbed depth.

$$\delta_{(\%)} = (MC_{(\infty)\%} - MC_{(0)\%})(1 - e^{t/\tau}) \quad (5)$$

where $\delta_{(\%)}$ is the adsorption content; $MC_{(\infty)\%}$ is the EMC; $MC_{(0)\%}$ is the initial MC during adsorption; τ is the time required to reach the EMC condition; and t is the time to be used for the determination. The exponential equations (Eq. 5) for the adsorption content of these three wood species and their corresponding τ values for various absorbing depths are given in Table 4. It is obvious that the τ values increased linearly with the increasing absorbing depth. The relations can be expressed by the following linear formulas:

$$\text{Japanese cedar: } \tau = 371.08D - 114.66 \quad R^2 = 0.86^{*} \quad (6)$$

$$\text{China fir: } \tau = 687.24D - 140.60 \quad R^2 = 0.95^{**} \quad (7)$$

$$\text{Hard maple: } \tau = 1723.20D - 262.58 \quad R^2 = 0.94^{**} \quad (8)$$

where D represents absorbing depth of specimens. Large coefficients of determination, ranging from 0.86 to 0.95, were found; and significant differences (* 0.05 level) and highly significant differences (** 0.01 level) among various absorbing depths existed as indicated by F-tests. That the τ values increased with the increase in absorbing depth suggested that thick wood specimens may require longer absorbing times to reach the equilibrium condition under the same temperature and RH than do thin specimens. It also implies that thick wood specimens may perform better in terms of hygroscopic conditioning than thin specimens. Therefore, thick wood panels are more suitable for in-house hygroscopic conditioning in a longer fluctuating climate.

When the slopes of linear regression equations of three wood species were compared, a tendency, in decreased order, became apparent: hard maple (1723.2) > China fir (687.2) > Japanese cedar (371.08). This finding is consistent with the tendency of τ values obtained at various absorbing depths, but it was in contrast to the trend seen with the absorbing rate. Results indicated that hard maple had a larger slope than those of the other two wood species, which may be due to its higher density; hence it needs more time to reach the equilibrium condition.

Wang and Cho.[8] studied the diffusion coefficients below the FSPs in four wood species and reported that τ values in the radial and tangential direction were much lower than those in the longitudinal direction. In other wood species it showed a decreasing order, as follows: Southern red oak (density $0.64\,g/cm^3$) > Griffiths' ash ($0.70\,g/cm^3$) > Taiwan red cypress ($0.37\,g/cm^3$) > Taiwania ($0.34\,g/cm^3$). They reported also that the diffusion coefficients of these wood species had negative correlations with the wood density.

During the early 1960s, Stamm and Nelson[9] reported that the diffusion coefficient decreases with an increase in wood density. China fir has lower density than Japanese cedar, so as a general rule the absorbing rate of China fir should be greater than that of Japanese cedar; it was obvious from the above-mentioned experimental results, however, that its absorbing rate was lower than that of Japanese cedar. This may be attributed to the volatile oil and crystal substance present in the cell lumens of China fir, which obstructed the diffusion of moisture. In general, the white needle-like crystals often appear on the wood surface of China fir, referred to as cedrol by Chang and Yin.[10]

Table 4. Regression of adsorption content curves at various depths for three wood species and their τ values

Absorbing depth (cm)	$\delta(\%) = (MC_{(\infty)\%} - MC_{(0)\%})(1 - e^{-t/\tau})$	τ (h)
Japanese cedar		
0.3	$\delta(\%) = 7.17 \times (1 - e^{-t/11.56})$	40.46
0.6	$\delta(\%) = 8.56 \times (1 - e^{-t/28.76})$	100.66
0.9	$\delta(\%) = 8.05 \times (1 - e^{-t/30.12})$	105.42
1.2	$\delta(\%) = 7.67 \times (1 - e^{-t/115.79})$	405.27
1.5	$\delta(\%) = 7.79 \times (1 - e^{-t/128.08})$	444.78
China fir		
0.3	$\delta(\%) = 7.43 \times (1 - e^{-t/21.56})$	75.46
0.6	$\delta(\%) = 7.48 \times (1 - e^{-t/54.76})$	191.66
0.9	$\delta(\%) = 7.37 \times (1 - e^{-t/152.56})$	533.96
1.2	$\delta(\%) = 7.44 \times (1 - e^{-t/220.79})$	772.75
1.5	$\delta(\%) = 7.72 \times (1 - e^{-t/233.08})$	815.78
Hard maple		
0.3	$\delta(\%) = 6.59 \times (1 - e^{-t/22.57})$	79.0
0.6	$\delta(\%) = 6.73 \times (1 - e^{-t/232.76})$	814.66
0.9	$\delta(\%) = 7.12 \times (1 - e^{-t/418.25})$	1463.88
1.2	$\delta(\%) = 7.11 \times (1 - e^{-t/578.79})$	2025.77
1.5	$\delta(\%) = 6.50 \times (1 - e^{-t/588.08})$	2058.28

Adsorption experiment under conditions of 22.5°C and 98% RH.
The values of MC(∞)% ranged from 19.18% to 21.96% for Japanese cedar, 18.58% to 19.16% for China fir, and 17.33% to 18.24% for hard maple.

Conclusions

The EMC values of the six wood species studied decreased in a curvilinear fashion with a decrease in the RH. There were no significant differences among these six wood species over the RH range 40% → 0%. Significant differences were seen over the RH range of 100% → 50%. With an RH lower than 90%, the EMCs of the softwoods studied were greater than those of hardwoods. In contrast, under 100% RH the EMC values of hardwoods were greater than those of other wood species.

Under the constant conditions of 22.5°C and 98% RH, the adsorption content was not affected by the absorbing depth within the first hour of adsorption. However, it increased with an increase in adsorption times and decreased curvilinearly with increased absorbing depth. These relations could be expressed by a semi logarthmic regression formula.

There were no significant differences among adsorption contents of these three wood species at depths of 0.3–0.6 cm from the absorbing surface, but the adsorption content decreased when the absorbing time was increased to 120–480 h. There was a decreasing order: Japanese cedar > China fir > hard maple.

The time-dependent behavior of adsorption content at various depths of each wood species could be expressed by an exponential equation: $\delta_{(\%)} = (MC_{(\infty)\%} - MC_{(0)\%})(1 - e^{t/\tau})$, where $\delta_{(\%)}$ is defined as the adsorption content; $MC_{(\infty)\%}$ is the EMC; $MC_{(0)\%}$ = initial moisture content prior to adsorption; and τ is the time required to reach the EMC condition. The τ values increased linearly with the increase in absorbing depth, and a decreasing order was revealed: hard maple > China fir > Japanese cedar.

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