Measurement of Diffusion Coefficient of Poplar Wood
(p. nigra)

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Abstract

In this research, the fundamentals of diffusion coefficient measurement of wood by cup and sorption methods were discussed. Thus, the diffusion coefficient of poplar wood was measured using the two methods. In the cup method, cylindrical samples with 12 % EMC and 18 mm in diameter and 7 mm in length were prepared from the sapwood. The water vapor diffusion along the wood samples occurred as a result of a relative humidity gradient between the inside of cup (RH: 70%) and the outside (RH: 12%). The diffusion coefficient was determined from the slop of cup weight reduction vs. time curve under steady-state condition based on first Fick’s law. In the absorption method, the oven dried cylindrical samples of 18 mm in diameter and 3 mm in length in the longitudinal direction were prepared. Then, in four relative humidity ranges, including 0-20, 20-40, 40-60 and 60-80 % in the temperature of 30 °C, the diffusion coefficient of wood were measured according to the second Fick’s law. The diffusion coefficient obtained by the cup and
absorption methods was different. The coefficient determined by the cup method was about 31 times greater than that obtained by the sorption method. This is because of different principals of two methods. The average values of diffusion coefficient determined by the cup and absorption methods was, $93.71 \times 10^{-9}$ (m$^2$s$^{-1}$) and $2.94 \times 10^{-9}$ (m$^2$s$^{-1}$), respectively. The results also showed that, the diffusion coefficient measured in the lower range of relative humidity was higher.

**Keywords** Diffusion coefficient, Poplar, Cup, Absorption

**Introduction**

Mechanism of moisture transmission in wood, in the two moisture range namely above and below fiber saturation point (FSP) is completely different. In moisture more than FSP transmission of moisture is take place mainly as bulk flow by wall pores and lumens while in moisture less than FSP, moisture transmission is done by diffusion process and water vapor deplete thorough cell walls. Study of Houngan et al (2006) on measurement of diffusion coefficient by absorption and desorption method in constant temperature of 50°C and different relative humidity of 0 to 90% showed that method is different diffusion coefficient by the two in absorption method is higher than desorption one. Many research efforts have been conducted to measure the diffusivity properties of wood by two main methods: the steady-state cup method and unsteady-state sorption method (Fick 1855, Martley 1966, Lianbai and Ping 2003, Burch et al 1992, Absetz et al 1993, Pang 1997, Mouchot et al 2002). Among all modification methods, surface coating is widely used to reduce the mass diffusivity through wood (Gholamiyan and Tarmian 2009).

**Material and Methods**

Measurement of diffusion coefficient in cup method is done under stable condition (equations 1 & 2):

$$ F = -D_a \frac{\partial \alpha}{\partial X} $$

$$ f_{exp} = \frac{Q}{D_v A} \times \frac{E}{(R \times H - R \times H_1) \times P_{v3}(T)} \times \frac{RT}{M_v} $$

An equation of diffusion coefficient measurement by this method is required to air flow in wood and under wood samples to be understood.
Diffusion coefficient measured by cup method

Sampling
In this study, poplar (*p. negra*) lumbers with moisture content of up to 12 percent was used. Of these lumbers, cylindrical samples with diameter of 18 and length of 7 mm were cut and their longitudinal diffusion coefficient was measured. For measurement of water vapor diffusion coefficient of samples, their side surfaces were coated by epoxy resin. Before testing, samples were placed in conditioning room in relative humidity of 64% and temperature of 20 °C till achieving to equilibrium moisture content of 12 percent. The number of replication was 30.

Preparations of cups
A picture of cup preparation is shown in picture 2. After mounting of samples on cups they were placed in the conditioning room. Due to higher amount of relative moisture content of inside of cup (70 percent) in comparison to conditioning room ones (20 percent), diffusion of water vapor to outside of cup was done through samples. Weight loss of cups was measured every 24 hours till constant weight was achieved. After 20 days, constant weight was reached.
In cup method phenomena of water vapor diffusion in wood samples is measured with lower or higher relative humidity of outside of cup in comparison with inside of cup. That is if relative humidity of cup inside be more that relative humidity of conditioning room then water vapor from inside of cup with higher RH, goes to lower RH of out of cup through wood samples and eventually weight of cup will be decreased (figure 2). However when relative humidity of inside of cup is low, weight of cup will increase. When cups weight reached a constant point, their weight was measured periodically till there was no their weight changing. Then curve of weight changing and time period was drawn. From the slope of the curve, amount of diffusion can be calculated (Malmquist 1991) (figure 3).

![Figure 3: measurement of diffusion coefficient by cup method.](image)

**Diffusion coefficient measured by sorption method**

**Testing method**

In this method, first equilibrium moisture content of samples was adjusted in an initial relative humidity (RH₁) in conditioning room. Then relative humidity of conditioning room were increased to new one (RH₂). So the samples uptake water vapor and will gain weight till reaching equilibrium moisture content. The weight changing will be record periodically. Finally the results can be plotted by the root square of time that called sorption curve from the slope of this curve in the initial portion diffusion coefficient can be measured.

**Case study**

Following determination of diffusion coefficient by cup method, poplar samples with length of 3 mm were cut and placed in oven for 24 hours till reaching zero equilibrium moisture content. Then samples were placed in conditions with temperature of 30°C and relative humidity ranging from 20, 40, and 60 to 80 percent respectively corresponding equilibrium moisture content of 4, 7.5, 11.2 and 14.2. Finally weight gain of samples due to uptake of water vapor was determined by a 0.001 gram precision balance.
Results and discussion

In cup method, for all the samples at first variation of cups weight was high. In all cups, after 18 days the weight reaches a constant point (figure 4, 5).

![Graph showing weight changes of cups due to diffusion of water vapor.](image1)

*Figure 4: weight changes of cups due to diffusion of water vapor.*

![Graph showing weight loss of cups due to emission of water.](image2)

*Figure 5: weight loss of cups due to emission of water.*

Due to low density of poplar, its diffusion coefficient is high. Results showed that amount of weight increasing for poplar samples are about 0.037 to 0.048 grams and mean weight gain of them is equal to 0.011 grams per day.
Table 1: longitudinal diffusion coefficient of the poplar samples measured by cup method.

<table>
<thead>
<tr>
<th>Wood sample</th>
<th>Specific gravity</th>
<th>Diffusion coefficient ($f$)</th>
<th>Diffusion coefficient ($D$) $10^{-9}$ m² s⁻¹</th>
</tr>
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<tbody>
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<td>1</td>
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Figure 6: amount of weight change according to the time.

Figure 7: Relationship of time, relative humidity, equilibrium moisture content and weight changes of the samples amount of diffusion is a function of wood properties especially its density according to this fact that diffusion coefficient of water vapor from wood pores is greater than diffusion coefficient of bond water from cell wall, hence the greater the wood density and material of wall cell the lower the diffusion process because of this measured diffusion coefficient of poplar is high that it affirms the findings of Absetz et al 1993 and Pang 1997.
Figure 7: Relationship of time, relative humidity, equilibrium moisture content and weight changes of the samples

References

Absetz, I., Koponen, S., and Lehtinen, M., 1993. Effects of cell and cell wall structure on mechanical and moisture physical properties of wood, Annual report, Helsinki University of Technology, Laboratory of Structural Engineering and Building Physics.


