EXPERIMENTAL EQUILIBRIUM MOISTURE CONTENT OF WOOD UNDER VACUUM

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Abstract. Wood equilibrium moisture content (EMC) was measured under vacuum by an electronic method. A wafer was used to measure EMC using an in-house designed vacuum instrument. EMC at 4 to 100 kPa and temperature from 30 to 90°C were measured. The relationships among temperature, pressure, and EMC were determined, and a diagram of wood EMC was produced. The results showed there are obvious differences between experimental EMC values obtained and theoretical EMC values of other researchers. It is suggested that corrections should be introduced into theoretical models or a new model for the vacuum condition developed.

Keywords: Vacuum drying, equilibrium moisture content (EMC).

INTRODUCTION

Knowledge of the equilibrium moisture content (EMC) of wood is a basic necessity both for serious research and for industry, especially for the control of wood drying. EMC relationships with temperature and relative humidity under atmospheric pressure have been established, and serve well in wood drying control (Simpson and Rosen 1981). In the last decade, vacuum drying has been steadily increasing, especially for drying valuable species. Since vacuum drying offers low drying temperatures with a high drying rate, almost as rapidly as with high-temperature drying above 100°C (Simpson 1987), it is likely that it will be increasingly used. However, little technical EMC data on vacuum drying has appeared in the literature. Theoretical EMC under vacuum was studied by Chen (2002), but there was no experimental support. In this study, the relationships of wood EMC, temperature, and pressure under vacuum were experimentally determined.

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MATERIALS AND METHODS

Experimental Materials and Equipment

Since it takes time for moisture to reach equilibrium in solid wood, the thickness of the wood must be very small to get rapid results, and in producing such solid wood EMC pieces, it is difficult to maintain consistency. To avoid such problems, a commercial EMC wafer, which is a cellulose pad, was used in the experiments, with an electrical resistance method to measure EMC. The wafer and the monitor are manufactured by Lignomat.

Each EMC wafer is about 35 mm long × 20 mm wide × 1 mm thick. The quality of the wafers is consistent and the sensitivity is adequate for the experimental requirements. A schematic diagram of the vacuum drying system is shown in Fig 1. The main component was a vacuum dry kiln, consisting of a pressure control system, a steam generator, and an on-line monitoring system, including controller, EMC sensor, and dry bulb and wet bulb temperature sensors.

Experimental Methods

Since wood EMC is a function of temperature and relative humidity under atmospheric pressure, it can be obtained in many ways such as weather data, graphology, weighing, or an electromotive method (Zhu 2003). To ensure the accuracy of this study, pre-experiments were conducted to validate the EMC measuring system. The EMC data were compared between the data from electromotive and theoretical methods under atmospheric pressure, and a correlation coefficient was obtained.

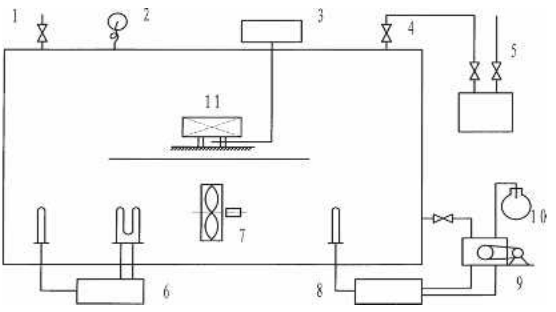

FIGURE 1. Schematic diagram of vacuum drying system. 1. Valve for recycled air, 2. Manometer, 3. Monitor, 4. Valve for inlet vapor, 5. Steam generator, 6. Temperature controller, 7. Circulating fan, 8. Pressure controller, 9. Vacuum pump, 10. Water collector, 11. EMC wafer.

Calibration of the EMC measuring system. Drying experiments were conducted under atmospheric pressure. The dry bulb temperature (DBT), wet bulb temperature (WBT), and EMC values were recorded. Each EMC wafer was used only once to avoid adsorption hysteresis, which may affect the EMC value. Temperature was set at 40, 60, and 80°C, and RH was adjusted by controlling vapor from the steam generator. EMC data were an average of three experimental values.

EMC measurement under vacuum. The EMC wafer was fixed in clips before the experiment, the DBT and WBT were set, and the circulating fan was turned on. After the setpoint temperature was reached, the vacuum pump was switched on until the vacuum was at 4 kPa, and then steam added to maintain pressure inside the chamber. The steam volume was increased step by step according to the planned schedule, and the experiments were ended when the pressure returned to atmospheric. It took about 5 min for the EMC wafer to reach equilibrium; to ensure the validity of EMC value, pressure was maintained for another 5 min at each control point. EMC data were recorded as the pressure increased from 4 to 100 kPa at intervals of 2 kPa. The temperature range was 30 to 90°C at intervals of 10°C.

RESULTS AND DISCUSSION

Validity of the EMC Measurement

The validity analysis was conducted by comparing experimental results and the calculated EMC values. The calculated EMC value was from the theoretical Eq (1) proposed by Zuritz et al (1979), which is the most precise among equations under atmospheric pressure (Avramidis 1989):

$$EMC = \left[\frac{-T \cdot \ln(1-h)}{C_2\,(1 - T/T_C)^{C_1}} \right]^{1/(C_3 T^{C_4})} \quad (1)$$

where T is temperature (K), h is relative humidity (%/100), $T_C = 647.1$ K (the critical temperature of water), and $C_1 = -6.64$, $C_2 = 0.13$, $C_3 = 1.10 \times 10^2$, $C_4 = -0.75$.

The EMC can be confirmed at a specific ambient temperature and RH, which can be calculated by measuring DBT and WBT (Simpson 1991).

Results showed that the measured EMC value was higher than the calculated value, and the relationship of measured and calculated values is near linearity, with a regression coefficient of 0.90. Analyzing with Origin software, the results showed that degree of confidence of two groups (measured and calculated) was greater than 0.95. This indicated that the measuring system is suitable for wood EMC measurement.

EMC Measured under Vacuum

EMC values were determined from 4 to 100 kPa at intervals of 2 kPa, and from 30 to 90°C at intervals of 10°C. The diagram for EMC under vacuum is illustrated in Fig 2. It is possible to obtain EMC at a given temperature and absolute pressure under vacuum from the diagram.

The comparison of experimental and theoretical EMC by Chen (2002) was conducted, and the results are shown in Fig 3 at different temperatures. It is evident that there are obvious differences between the experimental and theoretical EMC. There is a crossing point between the experimental and theoretical EMC lines, and the related pressure at the crossing point is different at different temperatures. This showed that the theoretical method by Chen (2002) is only partially correct, ie at the crossing point. The reason may be that the equation used by Chen is valid only for an ideal gas; inevitably, there would be a serious deviation with the use of a real gas such as water vapor, with much different molecular properties. When the temperature is constant and pressure is P_c (pressure at crossing point, Fig 3), the drying medium can be treated as ideal gas, and the experimental EMC value is the same as theoretical value. When the pressure

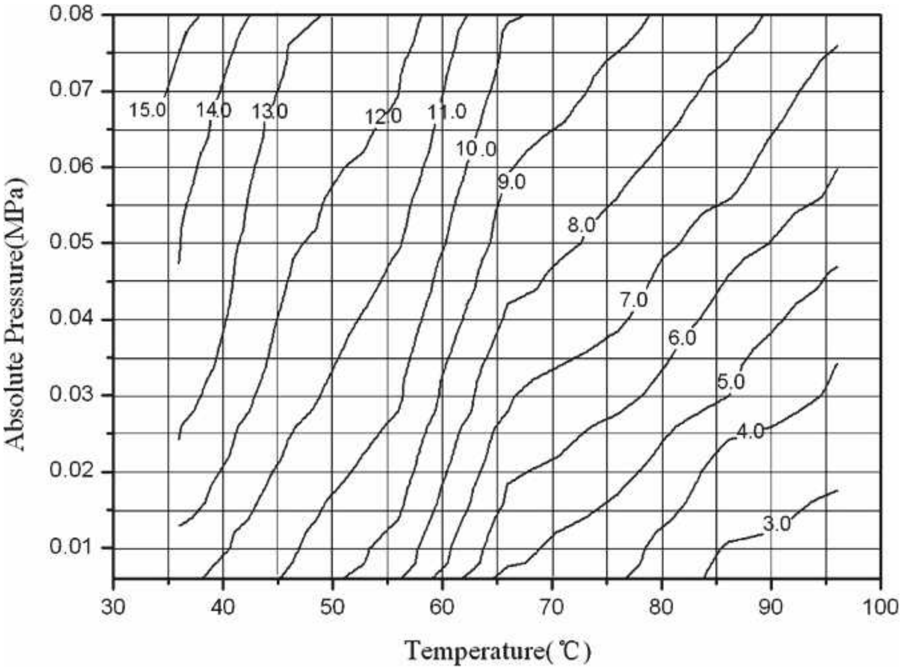

FIGURE 2. Diagram of experimental EMC of wood under vacuum.

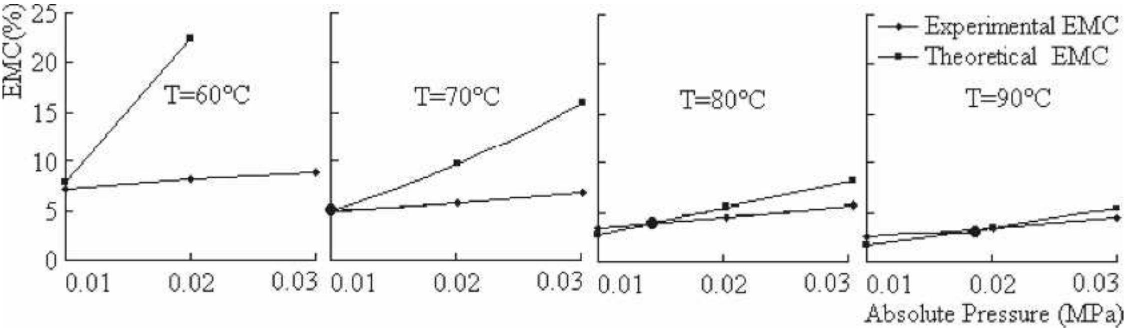

FIGURE 3. EMC differences between experimental and theoretical values.

is lower or higher than P_c, the theoretical EMC is lower or higher, respectively than the experimental EMC.

The results also showed: (1) when temperature is constant, the EMC value decreases as pressure decreases. The difference of vapor pressure between the wafer and air is greater under low pressure and the water is more easily vaporized, making the EMC value lower, and (2) when the pressure is constant, the EMC decreases with increasing temperature. The vapor pressure is greater with higher temperature, and the high vapor pressure difference between wood and environmental drying medium makes water removal easier.

CONCLUSIONS

The measuring system used in this study is suitable for wood EMC monitoring, with a linear correlation existing between the measured value and the calculated value, having a regression coefficient of 0.90.

In a wood EMC diagram under vacuum, EMC increases with increasing pressure and with decreasing temperature. It can be utilized as a reference for controlling wood drying under vacuum.

The experimental EMC value in this research is different from the theoretical values of Chen (2002). A correction should be introduced into the theoretical model or new model for the vacuum condition should be developed.

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