# Variation of Equilibrium Moisture Content of Heat-treated *Couratari oblongifolia*, *Fraxinus excelsior*, and *Quercus rubra* wood

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Heat treatment may result in variation of wood equilibrium moisture content (EMC). During this study, tauari (*Couratari oblongifolia*), ash (*Fraxinus excelsior*), and oak (*Quercus rubra*) woods were heat-treated at 190, 200, and 210ºC for 3 hours and then put into a conditioning chamber with a temperature from 30 to 75ºC and a relative humidity from 50 to 90%. The isothermal moisture adsorption curve was subsequently analyzed. Results indicated that the EMC of heat-treated wood was reduced by 23.4 to 37.4% compared to non-treated wood, but the EMC difference at different heat-treated temperatures for three hardwoods was quite small and the EMC of heat-treated wood was inversely proportional to their dry density.

*Keywords: Heat treatment; Equilibrium moisture content; Isothermal adsorption; Hygroscopicity*

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## INTRODUCTION

Solid wood flooring has been used extensively for interior decoration for decades due to its excellent properties, such as its tactile comfort (*i.e.*, "feet feeling"), aesthetic appearance, durability, *etc*. However, solid wood is a hygroscopic material and deforms easily when exposed to geothermal heat or moist-heat environments; thus, under these circumstances, composite flooring and brick are used instead. To overcome this limitation of solid wood, many modification methods have been tried for years, among which is heat treatment (Stamm 1956; Hillis 1984). This method is outstanding because it reduces the hygroscopicity of wood and limits environmental impact.

In some European countries, different heat treatment processes are under development or already marketed, such as Thermo-wood in Finland (Jamsa and Viitaniemi 2001), Retification in France (Vernois 2001), PLATO-wood in Holland (Militz and Tjeerdsma 2001), and Oil Heat Treatment in Germany (Rapp and Sailer 2001). Currently, the heat treatment process is increasingly applied and being refined in China, since this method was introduced here at the beginning of the 21$^{st}$ century (Gu and Ding 2008). For example, some solid wood flooring products under heat treatment are used in harsh environments (Ding *et al*. 2008; Tu *et al*. 2010).

In the last few years, research on heat treatment of wood has been active in two fields: (1) understanding of the chemical changes occurring with wood treatment (Tjeerdsma and Militz 2005; Repellin and Guyonnet 2005); and (2) evaluation of the mechanical behavior of heat-treated wood (Shi *et al*. 2007). However, the study of isothermal moisture adsorption behavior of heat-treated wood has been scarcely reported in the literature, according to the authors' knowledge. The objective of this paper is to study the isothermal moisture adsorption behavior of three hardwoods used for solid wood flooring, and analyze the effect of temperature and wood species on the equilibrium moisture content (EMC).

## EXPERIMENTAL

### Preparation of Heat-Treated Samples

Tauari (*Couratari oblongifolia*), ash (*Fraxinus excelsior*), and oak (*Quercus rubra*) were chosen for this study since they are often used to make solid wood flooring. These wood species have dry densities of 0.49, 0.63, and 0.68 g/cm$^3$, respectively. For each wood species, 12 clear and planed air-dried samples, with dimensions of 910 mm ($L$)×120 mm ($H$)×20 mm ($W$), were randomly selected. Three of the 12 samples were non-treated, while the remaining nine samples were divided into groups of three and were heat-treated as follows: each group of selected samples were dried to 5% moisture content in the drying chamber while the temperature was set to 90ºC and a relative humidity of 26%; and then the saturated steam filled in the chamber and the temperature was increased at a rate of 15ºC/h, and samples were treated at either 190ºC, 200ºC, or 210ºC for 3 h. At the completion of treatment, samples were cooled to 60ºC before taking them out.

### Isothermal Adsorption Experiment

After completion of heat treatment, four square specimens (20 mm on each edge) were cut from each experimental sample, as well as the non-treated sample. Then each of the square specimens was oven-dried and weighted. Afterwards, the oven-dried specimens were put into a conditioning chamber, and the temperature ($T$) was set to 30, 45, 60, or 75ºC. The relative humidity ($\varphi$) was set to 50, 60, 75, or 90% for each of the temperature settings. Once a temperature cycle was conducted, specimens were re-dried in the oven and then another isothermal adsorption was started. The square specimens were weighted when they equilibrated at each of the specific conditions. Equilibrium moisture content (EMC) for each condition was the average of 12 EMC values obtained from three specimens, which were either non-treated or treated at a target temperature.

## RESULTS AND DISCUSSION

The isothermal adsorption behavior of heat-treated tauari (*Couratari oblongifolia*) at 200ºC is shown in Fig. 1. Although tauari was treated under high temperature, its hygroscopic performance was still obvious, in that it could adsorb more moisture when exposed to an environment with higher relative humidity. This trend was accelerated when the relative humidity surpassed 80%. This may result from the accumulation of the liquid condensation in the cavity between microfibres. The radius of the capillary spaces within the cell wall (the space between adjacent wood microfibrils) is about 5 nm, and the vapor would be about to condense in such a pore when the relative humidity in the capillary reaches 80%, based on Kelvin’s equation. Condensation of water occurred in the cell wall when the relative humidity continued to increase, which caused the EMC to increase dramatically. From the isothermal adsorption curve (Fig. 1), it is obvious that EMC increased when the temperature was decreased at constant relative humidity ($\varphi$). At

$\varphi$ 60% the EMC increased from 5.56% at 75ºC to 7.02% at 30ºC. As the temperature was decreased at constant relative humidity, the capacity of the air to hold moisture decreased as well; thus more moisture remained in the wood and this resulted in higher EMC. Similar phenomena took place for ash and oak specimens treated at 200ºC (Figs. 2 and 3). At 190 and 210ºC heat treatment, the treated wood specimens showed similar phenomena (specifics are not shown).

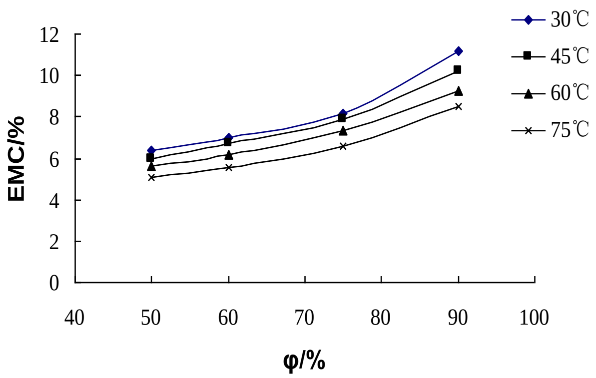



**Fig. 1.** The isothermal adsorption curve of heat-treated tauari at 200ºC

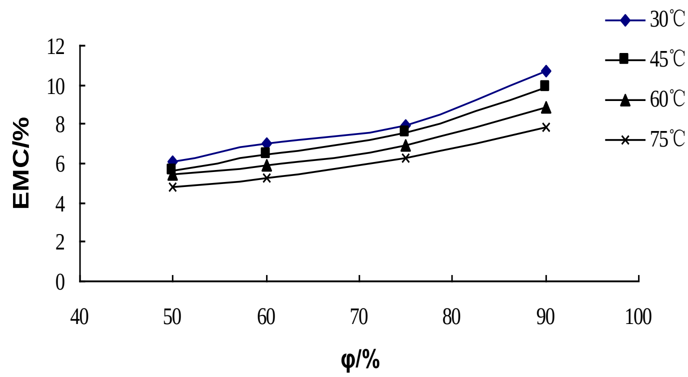



**Fig. 2.** The isothermal adsorption curve of heat-treated ash at 200ºC

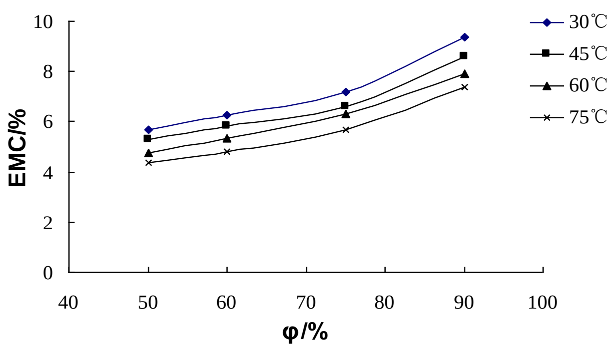
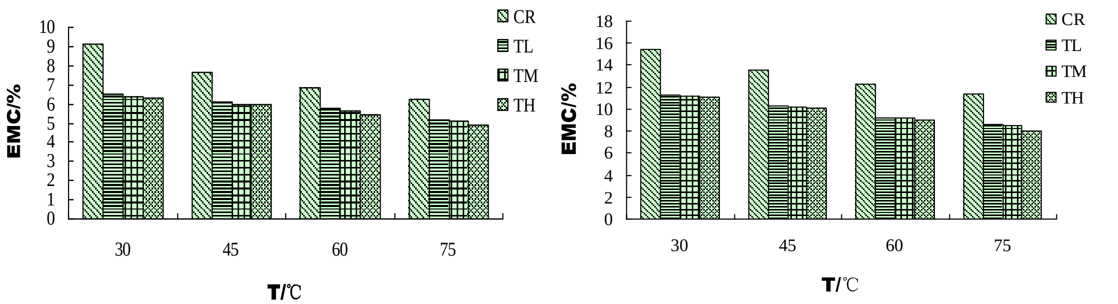



**Fig. 3.** The isothermal adsorption curve of heat-treated oak at 200ºC

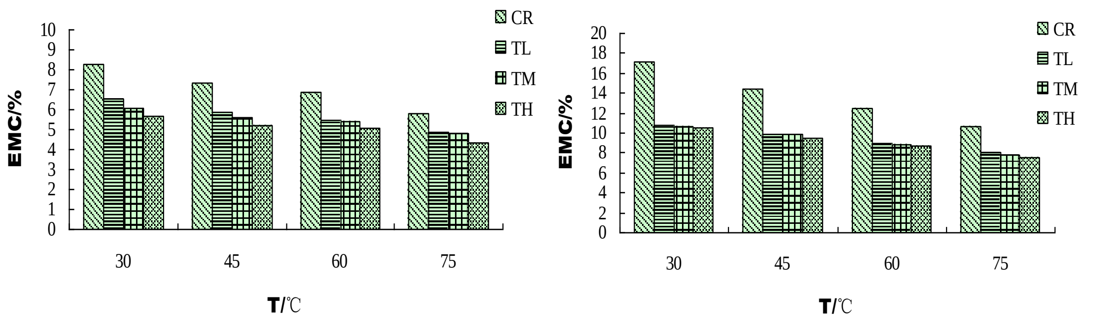
Different wood species were non-treated (CR) or heat-treated (TL=190ºC, TM=200ºC, TH=210ºC), and then subjected to isothermal adsorption in the conditioning chamber. Comparison of EMC of the non-treated and the treated tauari specimens at 50% and 90% relative humidity are shown in Figs. 4a and 4b. After heat treatment, the EMC of tauari specimens decreased by 23% when $\varphi$ was 50%, and by 27% when $\varphi$ was 90%. The EMC of ash and oak specimens decreased by 23.4% (Fig. 5a) and 25.1% (Fig. 6a) when $\varphi$ was 50%, and by 31.7% (Fig. 5b) and 37.4% (Fig. 6b) when $\varphi$ was 90% at all TL, TM, and TH. Esteves *et al.* (2007) also reported that equilibrium moisture content decreased by 46% for pine and 61% for eucalypt heat-treated at 210ºC for longer treatment time (*i.e.*, 12 hours).

EMC of treated tauari specimens decreased as the treatment temperature increased; however, the difference of EMC among the TL, TM, and TH treated tauari specimens were not obvious and were less than 0.5%, as shown in Figs. 4a and 4b. Ash and oak treated specimens showed similar phenomena (Figs. 5 and 6).



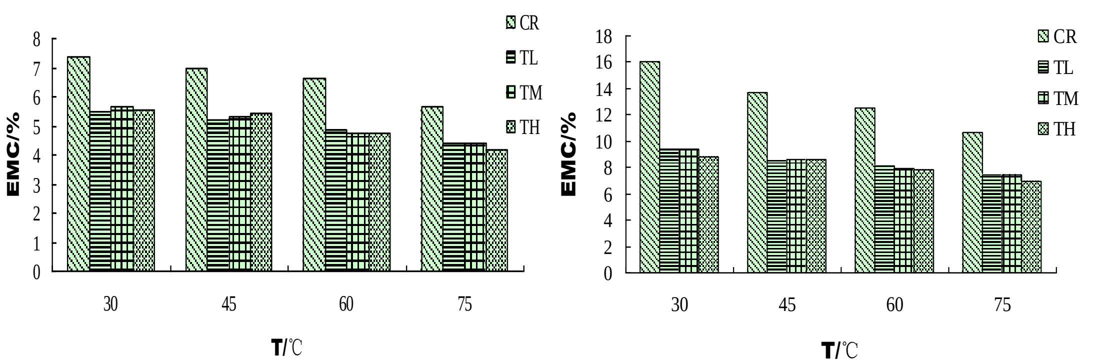

(a) $\varphi$=50% (b) $\varphi$=90%

**Fig. 4.** Comparison of EMC of tauari specimens at constant relative humidity




(a) $\varphi$=50% (b) $\varphi$=90%

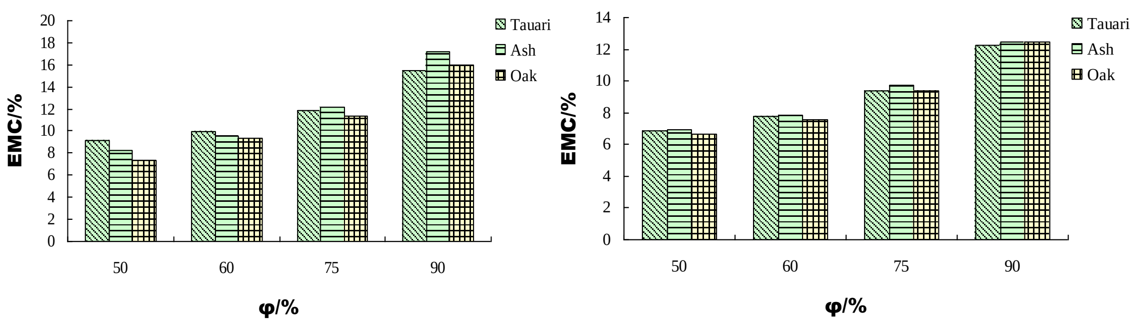
**Fig. 5.** Comparison of EMC of ash specimens at constant relative humidity




(a) $\varphi$=50% (b) $\varphi$=90%

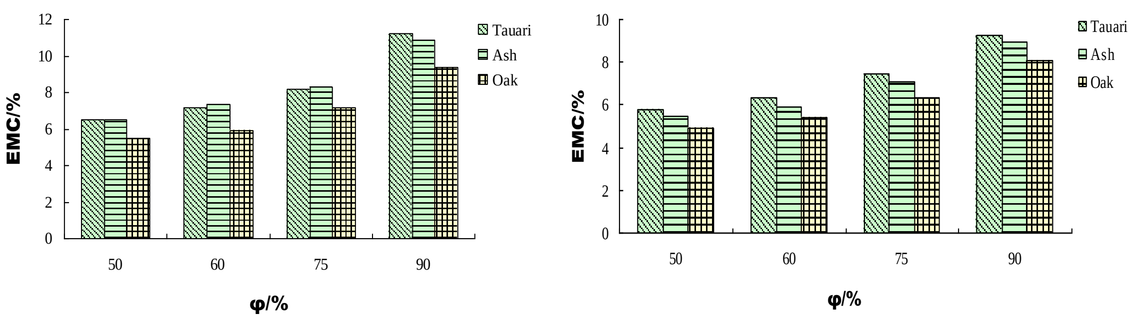
**Fig. 6.** Comparison of EMC of oak specimens at constant relative humidity

The effect of wood species on the EMC of non-treated wood specimens was not consistent, as shown in Fig. 7a. The EMC of tauari specimens was the highest, 9.1% at 50% relative humidity and *T* at 30ºC; however, as relative humidity increased, it became the lowest, 15.5% at 90% relative humidity. The differences of EMC of tauari, ash, and oak specimens were not larger than 0.5% at different humidity (Fig. 7b). However, the wood species played an important role in the EMC of wood specimens treated at different temperature. In general, the order from highest to lowest EMC of wood specimens was tauari>ash>oak, regardless of heat treatment temperature (Figs. 8 through 10). For example, heat treatment at 200ºC afforded EMC levels of tauari, ash, and oak specimens of 5.7%, 5.4%, and 4.8% at 50% relative humidity at 60ºC; as relative humidity went up to 90%, the EMC of tauari, ash, and oak specimens reached 9.2%, 8.9%, and 7.9%, respectively, conforming to the EMC order: tauari>ash>oak (Fig. 9b). It should be noted that the dry densities of tauari, ash, and oak were 0.49, 0.63, and 0.68 g/cm$^3$, respectively, and the EMC of specimens was inversely proportional to their dry density. Although this phenomenon has not been reported and the reason remains unknown, it reminds us that the effect of wood species on the EMC should be considered in the application of wood treatment.



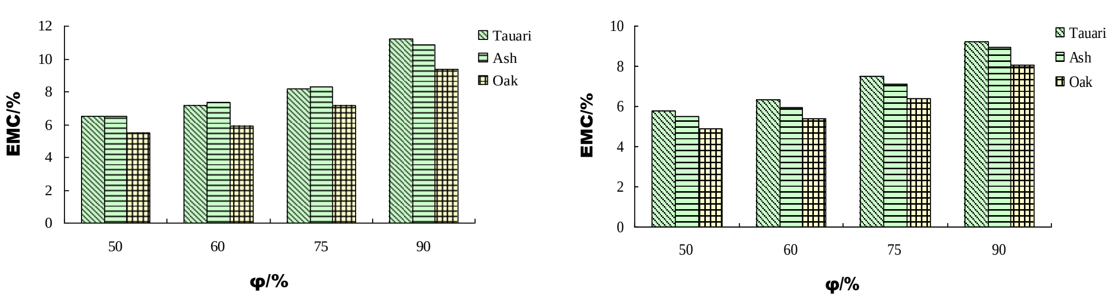

(a) $T$=30ºC (b) $T$=60ºC

**Fig. 7.** Wood species effect on the EMC of non-treated specimens



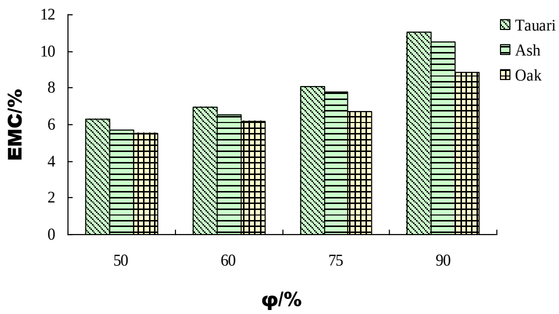

(a) $T$=30ºC (b) $T$=60ºC

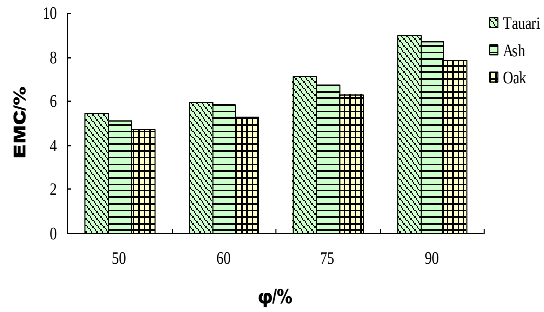
**Fig. 8.** Wood species effect on the EMC of specimens treated under 190ºC




(a) $T$=30ºC (b) $T$=60ºC

**Fig. 9.** Wood species effect on the EMC of specimens treated under 200ºC




(a) *T*=30ºC (b) *T*=60ºC

**Fig. 10.** Wood species effect on the EMC of specimens treated under 210ºC

## CONCLUSIONS

Tauari (*Couratari oblongifolia*), ash (*Fraxinus excelsior*), and oak (*Quercus rubra*) wood were heat-treated at 190, 200, and 210ºC for 3h and then subjected to isothermal moisture adsorption in a conditioning chamber. The isothermal adsorption behavior of different wood species was studied. The conclusions drawn from this study were as follows:

1. Treated under high temperature, different wood species still showed a good hygroscopicity; however the dimension stability of the wood was enhanced by heat treatment. The EMC of heat-treated specimens increased with increasing relative humidity, but decreased with temperature.
2. The EMC of treated specimens decreased by 23.4% to 37.4% comparing to non-treated specimens, but the difference of the EMC of heat-treated wood under different treatment temperature was negligible.
3. The EMC of heat-treated specimens was inversely proportional to their dry density.

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