Research Journal of Agriculture and Biological Sciences, 4(6): 660-665, 2008


# Effect of Heat Treatment on Equilibrium Moisture Content (EMC) of Some Wood Species in Turkey

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**Abstract:** Heat treatment is often used for improve the dimensional stability of wood. In this study, effect of heat treatment on equilibrium moisture content (EMC) of oak (*Quercus petraea* Lieb.), chestnut (*Castanea sativa* Mill.), calabrian pine (*Pinus brutia* Ten.) and black pine (*Pinus nigra* Arnold.) woods, obtained from Kastamonu Forest Enterprises of Turkey, was examined. Wood specimens were subjected to heat treatment under atmospheric pressure and presence of air at three different temperature (130, 180 and 230 °C) and two different time (2 and 8 h). The EMC of heat treated wood and control samples were tested. The results showed that values of EMC decreased with increasing temperature and time of heat treatment. According to this result, oak, chestnut, calabrian pine and black pine woods could be utilized by using proper heat treatment techniques in outdoors and indoors applications for several purposes such as musical instruments, kitchen furniture, garden furniture and windows frames.

**Key words:** Heat treatment, Equilibrium moisture content, Wood

## INTRODUCTION

Wood is a complex polymeric material constituted mainly of cellulose, hemicelluloses and lignin, with a minor proportion of extractives. The exposure of wood to elevated temperatures causes thermal degradation of its structure, i.e., changes in composition, often accompanied by loss of mass, and thus the properties of wood are somewhat modified. Thermal degradation is utilized commercially to produce wood products with improved dimensional stability and reduced hygroscopicity[3,5,23,25].

Renewable resources, their use and modification are involved in a multitude of important processes with a major influence on our everyday lives. Applications can be found in the energy sector, chemistry, pharmacy, the textile industry, paints and coatings, to name but a few. There is an increasing need to develop technologies in which renewable materials are used as direct replacements for nonrenewable[9].

Heat treatment of wood at high temperature is one of the wood modification methods to improve the dimensional stability and bio-durability of timber[21] and heat treatment equip the wood material with new properties[7]. However, the thermal modification of wood is defined as the application of heat to wood in order to bring about a desired improvement in the performance of the material. Thermal modification is invariably performed between the temperatures of 180 °C and 260 °C, with temperatures lower than 140 °C resulting in only slight changes in material properties and higher temperatures resulting in unacceptable degradation to the substrate[9].

Wood is a hygroscopic material, due to the fact that the cell wall polymers contain hydroxyl groups. In an environment containing moisture, dry wood will absorb moisture until it is in equilibrium with the surrounding atmosphere. Similarly, saturated wood, when placed in an atmosphere of lower relative humidity (RH), will lose moisture until equilibrium is attained. If the wood is placed in an environment where the RH is stable, it will attain constant moisture content (MC), known as the equilibrium moisture content (EMC). At this point, the flux of water molecules into the cell wall is exactly balanced by the outward flux into the atmosphere[9]. After treatment at 180 °C or higher, chemical changes in lignin and hemicelluloses occur and the treated wood becomes less hydroscopic[25,15,11,1].

Since heat-treated wood is less hygroscopic than untreated wood, its mechanical properties in service conditions may even be higher than at constant moisture content[4].

All obtained changes are achieved with heat-treatment process without any added chemicals. Thus, heat-treated wood has been considered as an ecological alternative to impregnated wood material[16].

The high temperature thermal treatment of wood is an environmentally friendly method for wood preservation. This technique has attracted considerable

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attention in recent years[13]. In contrast to common wood preservation methods involving impregnation of biocidal compounds, durability of heat treated wood is not due only to the presence of toxic chemicals but also to the change of basic wood properties like equilibrium moisture content, increase of dimensional stability or chemicals modification[8].

Research on the effects of heat treatment on the physical and mechanical properties and surface roughness of Turkish native trees is rather limited.

In this study, we determined the effects of heat treatment on some wood species' equilibrium moisture content (EMC). Also, changing in EMC values with temperature and time were discussed.

## MATERIALS AND METHODS

**Material:** Oak (*Quercus petraea* Lieb.), chestnut (*Castanea sativa* Mill.), calabrian pine (*Pinus brutia* Ten.) and black pine (*Pinus nigra* Arnold.) woods obtained from Kastamonu in Turkey selected for this study. The wood samples were cut in parallel to grain directions and sawn into specimens measuring 20 x 20 x 30 (tangential x radial x longitudinal) mm dimensions[15].

**Heat Treatment:** During the rising period, the temperature of the oven is increased to the temperature at which the actual heat treatment occurs. If the moisture content of the material is too high (r > 10 %) before heat treatment a lot of splitting and color differences may result[16]. That's why; the wood samples were conditioned to 7% moisture contents at 25±2 °C and 35±5% relative humidity to prevent splitting of woods during heat treatment.

Heat treatment applications were conducted in a temperature controlled small heating unit. Three different temperatures (130, 180 and 230 °C) and two different durations (2 and 8 h) were applied for four different wood species under atmospheric pressure and in the presence of air. After treatments, the temperature is decreased to normal that taken about 24 hours. The same procedure was run for all experiments. After heat treatments, the moisture content of samples was measured.

**Equilibrium Moisture Content (EMC):** Equilibrium moisture content (EMC) is defined as that moisture content at which the wood is neither gaining nor losing moisture; an equilibrium conditions has been reached[22,29]. The treated wood samples were conditioned in a conditioning cabin at 20±2 °C temperatures and 70±5% relative humidity to reach EMC throughout 8 weeks[19]. At the end of the 8 weeks, the dimensions of wood samples and weights were measured sensitively and EMC was estimated according to the formula[20]:

$$EMC\ (\%) = \frac{m_r - m_o}{m_o} x100$$

where

- $m_r$ is the weight of heat treated wood with moisture content and
- $m_o$ is the oven dried weight of heat treated wood.

For independent variables, heat treatment time, temperature and wood species, all multiple comparisons were subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using multiple t-test.

## RESULTS AND DISCUSSION

Table 1 shows the results of equilibrium moisture content (EMC) of oak, chestnut, calabrian pine and black pine woods treated at three different temperature (130, 180 and 230 °C) for 2 hours and 8 hours. Treatment at 230 °C for both 2 h and 8 h was resulted the lowest values for the EMC. Heat treated wood samples at a temperature of 230 °C for 2 h gave the lowest EMC value as 7.0% for oak wood when compared with other species studied. On the other hand, the highest EMC value was found as 14.2% for calabrian pine wood at a temperature of 130 °C for 8 h. However, lower effect of heat treatment was observed when the samples were treated at 130 °C for both 2 h and 8h. All differences were statistically significant (Table 1).

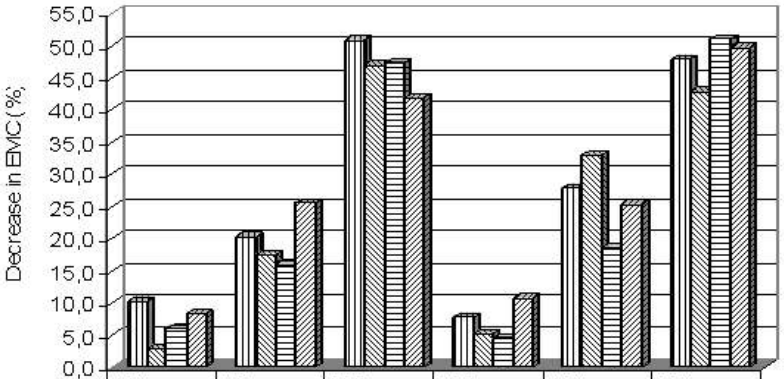
Changes on EMC values according to the control sample for each treatment presented in Fig.1. The maximum EMC decreases were recorded averagely at treatment of 230 °C for 8 h and 230 °C for 2 h as 47.9% and 46.7% respectively. So, the maximum EMC loss was obtained for species treated at 230 °C. Similar results can be seen from literature that, the heat treatment process leads to a reduction in EMC. When treated at the highest temperatures the EMC can be 40-50 percent lower compared to untreated wood[1,2]. According to Viitaniemi[29], the EMC decreases are 43-60%. However, the minimum EMC decreases for all parameters were recorded at the treatment of 130 °C for 2 h and of 130 °C for 8 h as 6.9% and 7.0% respectively. While the minimum EMC loss was obtained as 2.9% for chestnut at 130 °C for 2 h, the maximum EMC loss was obtained as 50.9% for

**Table 1:** The effect of heat treatment for different durations on EMC

| Times (h) | Heat Treatment (°C) | Unit | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Oak | | Chestnut | | Calabrian pine | | Black pine | |
| Control | | Avg. | 14.3 | B | 13.4 | CDE | 14.8 | A | 15.1 | A |
| | | ±s | 0.3756 | | 0.2168 | | 0.1396 | | 0.4688 | |
| | | $s^2$ | 0.1411 | | 0.0470 | | 0.0195 | | 0.2198 | |
| | | V | 2.6336 | | 1.6224 | | 0.9412 | | 3.0974 | |
| 2 | 130 | Avg. | 12.8 | FG | 13.0 | EFG | 13.9 | BC | 13.9 | BC |
| | | ±s | 0.3157 | | 0.1417 | | 0.7791 | | 0.2076 | |
| | | $s^2$ | 0.0996 | | 0.0201 | | 0.6070 | | 0.0431 | |
| | | V | 2.4632 | | 1.0917 | | 5.5901 | | 1.4964 | |
| | 180 | Avg. | 11.4 | I | 11.0 | I | 12.5 | GH | 11.3 | I |
| | | ±s | 0.3416 | | 0.3007 | | 0.1966 | | 0.8039 | |
| | | $s^2$ | 0.1167 | | 0.0904 | | 0.0387 | | 0.6463 | |
| | | V | 3.0027 | | 2.7250 | | 1.5756 | | 7.1316 | |
| | 230 | Avg. | 7.0 | O | 7.1 | O | 7.8 | L | 8.8 | K |
| | | ±s | 0.1425 | | 0.1308 | | 0.1412 | | 0.7384 | |
| | | $s^2$ | 0.0203 | | 0.0171 | | 0.0199 | | 0.5453 | |
| | | V | 2.0312 | | 1.8413 | | 1.8075 | | 8.3826 | |
| 8 | 130 | Avg. | 13.2 | DEF | 12.7 | FG | 14.2 | B | 13.5 | CD |
| | | ±s | 0.3584 | | 0.1979 | | 0.1855 | | 0.5032 | |
| | | $s^2$ | 0.1285 | | 0.0392 | | 0.0344 | | 0.2532 | |
| | | V | 2.7247 | | 1.5606 | | 1.3079 | | 3.7216 | |
| | 180 | Avg. | 10.3 | J | 9.0 | K | 12.1 | H | 11.3 | I |
| | | ±s | 0.2348 | | 0.2781 | | 0.2491 | | 0.1111 | |
| | | $s^2$ | 0.0551 | | 0.0773 | | 0.0620 | | 0.0123 | |
| | | V | 2.2817 | | 3.1062 | | 2.0639 | | 0.9833 | |
| | 230 | Avg. | 7.4 | LMN | 7.6 | LM | 7.3 | MNO | 7.6 | LM |
| | | ±s | 0.0719 | | 0.2048 | | 0.1270 | | 0.0482 | |
| | | $s^2$ | 0.0052 | | 0.0419 | | 0.0161 | | 0.0023 | |
| | | V | 0.9668 | | 2.6837 | | 1.7442 | | 0.6334 | |

Avg. : average, ±s : standard deviation, $s^2$ : variance, V : coefficient of variation, Homogeneity groups: same letters indicate that there is no statistical difference between the samples according to multiple t-test at $P<0.01$.

calabrian pine at 230 °C for 2 h among species treated (Fig. 1). The decreases in the EMC can be explained reduction of OH-groups and/or cleavage of the chains and losses of substance after heat treatments. The reduction of accessible OH-groups leads to a limited interaction with water compared to untreated wood[10]. On the other hand, it may be effective that material loses in cell lumen and hemicelluloses degradation due to the applied height temperature[6,20].




| | 2 | | | 8 | | |
|---|---|---|---|---|---|---|
| | 130 | 180 | 230 | 130 | 180 | 230 |
| Oak | 10,1 | 20,2 | 50,8 | 7,8 | 27,8 | 47,8 |
| Chestnut | 2,9 | 17,4 | 46,8 | 5,1 | 33,0 | 42,9 |
| Calabrian pine | 6,1 | 15,9 | 47,4 | 4,4 | 18,7 | 50,9 |
| Black pine | 8,4 | 25,5 | 41,8 | 10,7 | 25,4 | 49,7 |

**Fig. 1:** Percentage decrease in EMC as a function of temperature and time

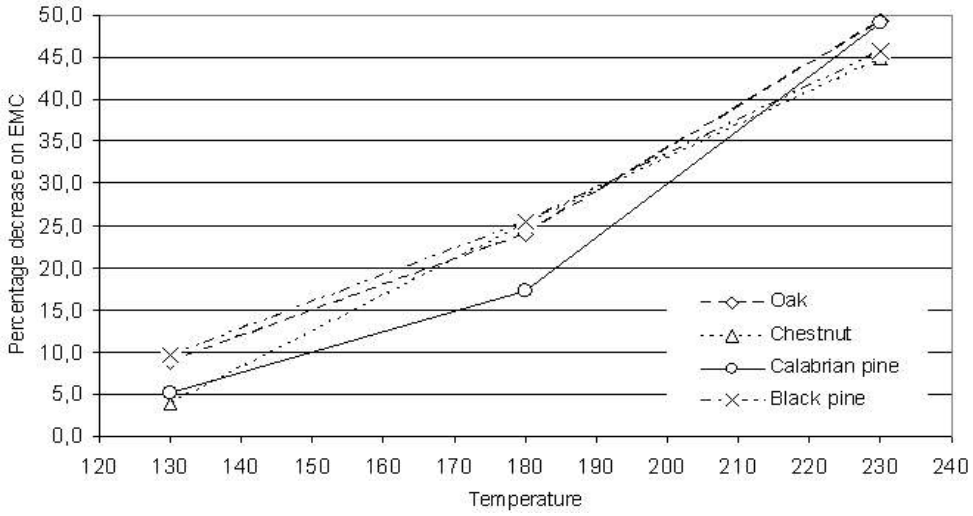



**Fig. 2:** Percentage decrease in EMC as a function of temperature.

Percentage decreases in EMC values according to temperature are presented in Fig. 2. It can be clearly seen that, the values of all measured EMC decreased with increasing temperature (Fig. 2). While calabrian pine wood effecting from heat treatment at 180 °C as 17.3%, the other species are around 25.0%. This may be caused by high resin content of calabrian pine.

Percentage decrease of EMC values according to treatment time was showed in Fig. 3. Differences between 2 h and 8 h heat treatment time are changing with wood species. Maximum EMC decrease from 2 h to 8 h can be seen in chestnut as 4.6%. So, a minimum decrease from 2 h to 8 h is 0.7% for oak wood. This can be explained with high density of oak wood. All EMC values of heat treated samples were lower than in control samples.

The temperature and duration for heat treatment generally vary from 180 to 280 °C and 15 min to 24 h depending on the heat treatment process, wood species, sample size, moisture content of the sample, and the desired mechanical properties, resistance to biological attack, and dimensional stability of the final product[12,17]. Temperature has a greater influence than time on many properties. Treatment at lower temperatures for longer periods, however, does not give similar results compared to treatments at higher

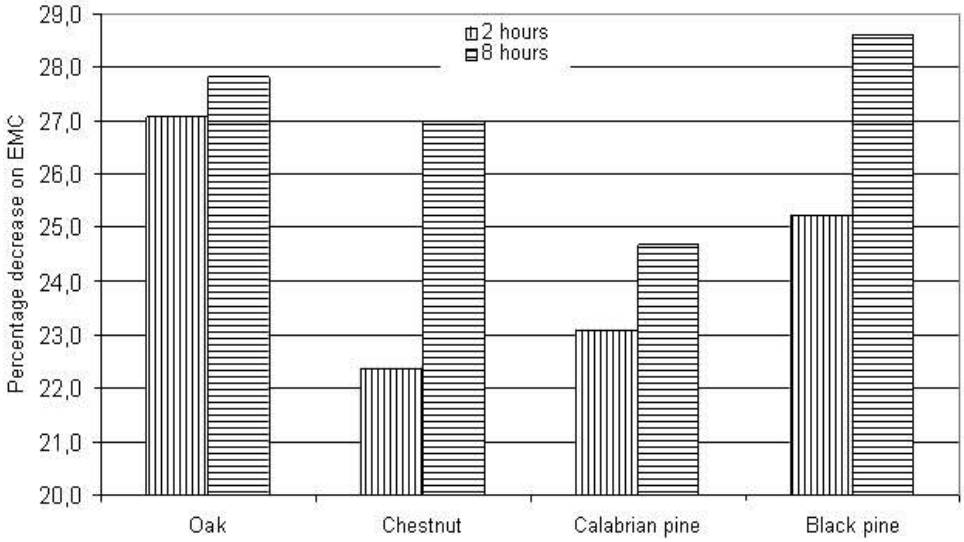



**Fig. 3:** Percentage decrease in EMC as a function of time.

temperatures. Temperatures over 150 °C alter the physical and chemical properties of wood permanently[18,14].

Heat treatment reduces certain mechanical properties, but the dimensional stability and the biological durability of wood increases through heat treatment. Also, heat treatment results in favorable changes in the physical properties of the wood, such as reduced shrinkage and swelling, low equilibrium moisture content, enhanced weather resistance, a decorative dark color, and better decay resistance[30,1].

**Conclusions:** According to the averages, EMC values decreased with increasing temperature and time. It is evident from the results that these values were all lower in heat-treated samples than in control samples. The effect of the heat treatments was significant for all the variables analyzed.

The smallest decrease of EMC values was determined at the heat treatment of 130 °C for 2 h. In this study, EMC values decreased with increasing temperature and time treatments for all species. The largest decrease of EMC values for all species was found at the heat treatment of 230 °C for 8 h under the conditions stated.

The most important property, when compared to untreated wood, is that the equilibrium moisture content of the heat-treated wood is reduced and as a consequence of this shrinkage and swelling of the wood is also reduced.

Improved wood properties such as shrinkage and swelling depending on equivalent moisture content thought to be a new approach for lumber utilization places. Therefore, heat treatment may improve these properties of wood, having no industrial usage. Strength losses can be limited through alternative modified heat treatment techniques. Wood species having no commercial value can also be utilized effectively, following heat treatment.

Due to its good weather resistance, heat-treated wood materials can be used for several purposes, e.g. for garden furniture, external cladding, musical instruments, kitchen furniture, paneling, parquets, sauna, doors and windows frames. As a result of the dimensional stability the heat-treated wood gives better durability for coating.

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