Drying properties of Sentang (*Azadirachta excelsa*) dried under different temperatures

Noor Zulai’ha Mohamad Ruddin¹, Shaharlina Rasid² and Andi Hermawan³

¹ Forest Resource Technology Program, Bachelor of Applied Science, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Kelantan, Malaysia
² Forest Resource Technology, Centre for Post Graduate Studies, Universiti Malaysia Kelantan, Pangkalan Chepa, Malaysia
³ Forest Resource Technology Program, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Kelantan, Malaysia

E-mail: andi@umk.edu.my

Abstract. In this study, we investigated the drying properties of Sentang (*Azadirachta excelsa*) dried at different temperatures. Sentang tree planted in Kelantan, Malaysia, was used in this study. Drying specimens with dimensions of 30 × 150 × 500 mm were dried under air-drying conditions, a constant temperature of 60, 80, 100, and 120 °C until the moisture content (MC) of the specimens reaches an equilibrium moisture content (EMC) at each drying condition. The drying properties of the specimens were then examined. The results confirmed that drying temperature had a significant effect on drying time. As expected, drying Sentang under air-drying conditions demanding considerable time than the other drying conditions.

1. Introduction

Akasia (*Acacia mangium*), Getah (*Hevea brasiliensis*), Sentang (*Azadirachta excelsa*), African Mahogany (*Khaya ivorensis*), Kelempayan (*Neolamarckia cadamba*), Batai (*Paraserianthes falcatoria*), and Teak (*Tectona grandis*) are major fast-growing species planted in Malaysia. The area planted with fast-growing species has been expanding due to the scarcity of commercial timber from natural forests. Sentang has paid attention to stakeholders in the forestry sector in Malaysia, such as researchers and planters. In 1997, Forest Research Institute Malaysia (FRIM) has established Sentang plantation and reported that Pahang, Negeri Sembilan, Perak, Terengganu, and Kelantan were the state that established massive Sentang plantation in Malaysia. In addition, the plantation agencies such as Sime Darby, RISDA, and FELDA start to establish Sentang plantation from 1992 until 1996.

Sentang belongs to medium hardwood, with the density ranged between 550 – 780 kg/m³. Sentang has a beautiful color with the reddish color heartwood and attractive pattern for furniture manufacturing purposes. Sentang is also suitable as raw materials for light construction purposes. It was reported that villager is using Sentang to build their house [1].

Generally, medium hardwood species are vulnerable to fungus and termite attack, and thus preservative treatment is suggested to improve the durability properties of the wood for a wider end-user application. It is recommended that wood has to be dried to moisture content (MC) less than 30% before preservative treatment. This is because dried-wood has better permeability and higher preservative penetration compare to green woods. It was reported that rubberwood with an average MC of 23% impregnated with 3% Chromate Copper Arsenate (CCA) by using the vacuum-pressure process.
for 2.5 hours has a double preservative intake than that with MC of 60-80% [2]. Much research has been conducted on the drying behavior of fast-growing species. However, limited information was available in Malaysia regarding the drying characteristics of Sentang dried under different temperatures. Thus, this study was conducted to investigate the drying characteristics of sentang dried under different drying conditions.

2. Materials and methods

2.1. Materials

Sentang tree grown in Kelantan was used in this study. A tree with a length of 20 m and diameter at breast height of 30 cm was selected and felled. The tree was cross-sectionally cut to a length of 50 cm produced five logs. The logs were then cut parallel to the grain and further processed into drying samples with a final dimension of 20 cm (width) × 50 cm (length) × 3 cm (thick), as shown in Figure 1.

![Figure 1. Cutting diagram of the specimens.](image)

2.2. Methods

A total of three drying samples obtained from the same log was dried under the same drying condition. Before drying, two cross-section surfaces of the samples were sealed using a silicone sealant to prevent excessive drying from the cross-section. The samples were dried by using a laboratory drying chamber to an equilibrium moisture content (EMC) under each drying conditions as presented in Table 1. Air-drying was conducted in an open-air under the shaded area. Laboratory oven was used to dry the specimens under the temperature of 120°C without relative humidity (RH) control.

| Temperature (°C) | RH (%) | EMC (%) |
|------------------|--------|---------|
| Air-drying       | -      | 15.4*   |
| 60               | 78     | 12.5    |
| 80               | 80     | 11.6    |
| 100              | 87     | 11.8    |
| 120              | -      | 3**     |

*Note: *: Obtained from annual average temperature and relative humidity in Jeli, Kelantan, Malaysia. **: Obtained from the measurement of wet-bulb depression.

During drying, the weight of the samples was periodically measured, and MC of the sample was calculated by using the following equations.
\[ MC(t) = \frac{w_t - w_0}{w_0} \times 100\% \]

where: \( MC(t) \) is the moisture content (%), \( w_t \) is the weight of the sample at \( t \) time (g), \( w_0 \) is estimated oven-dry weight of the sample (g). The graph of moisture content against time was then created, displaying the drying curve of the specimen dried under each drying condition.

In addition, the dimensionless moisture ratio (MR) was calculated and plotted against drying time. The MR curve of the samples dried under each drying condition was fitted to the Newton model, and the drying parameter \( k \) of each drying condition was identified by using the following equation.

\[ MR(t) = \frac{M_t - M_e}{M_i - M_e} = \exp(-kt) \]

where: \( MR(t) \) is dimensionless moisture ratio, \( M_t, M_e, \) and \( M_i \) is MC (%) at \( t \) time, EMC, and initial MC, respectively, \( t \) is time (h).

Lastly, the drying rate of the specimen dried at each drying condition was calculated by using the following equations.

\[ DR \left( t \right) = \frac{M_t + dt - M_t}{dt} \]

where: \( DR \left( t \right) \) is drying rate, \( M_t \) and \( M_{t+dt} \) are MC at \( t \), and \( t+dt \) time, respectively, \( t \) is drying time. After drying, the drying samples were conditioned at room temperature.

3. Results and discussion

The amount of moisture in wood is usually stated based on the percentage of oven-dried wood mass. In this study, the average initial MC of Sentang was 41.8%. This result was quite the same research conducted previously, which reported that the average initial MC of Sentang was 49.2% [3].

Wood is a hygroscopic material, which means its MC will fluctuate based on the humidity of the surrounding. In this study, the final MC of the specimen was set to around 12%, except for the specimen subjected to drying under air-drying condition and a constant temperature of 120°C. Figure 2 shows the typical drying curve of the specimen subjected to drying under air-drying conditions and a constant temperature of 80°C.

![Figure 2. Drying curve of the specimen dried under air-drying condition and a constant temperature of 80°C.](image)

As expected, the specimens dried under air-drying condition have longer drying time in comparison to those dried under the other drying conditions. This is because air-drying mainly depends on the...
surrounding climatic conditions and air movement. As can be seen from Figure 2, Sentang subjected to drying under air-drying conditions has the longest drying time, which required more than 850 hours to reach MC around 17%. These results confirmed that drying Sentang under air-drying conditions demanding considerable time. This is because temperature controls the external boundary conditions for drying, thus lower drying temperature affecting the rate of internal moisture movement. Moreover, Sentang has dried-extractive deposition in the vessel of its heartwood [4]. It is well known that dried-extractive deposition has a negative effect on the permeability of the timber due to partial or total occlusion and becomes a barrier to liquid or gas flow [5,6].

Figure 2 also shows that the drying time becomes shorter under a higher drying temperature. This is because drying under higher temperatures would increase the rate of moisture transfer to the wood surface, hence enhances the rate of diffusion of water molecules across the cell walls. In addition, it is believed that the dried-extractive deposition in the vessel of Sentang heartwood becomes thermally softened or melted under higher drying temperatures and thus improves the permeability of the wood due to removal or relocation of the extractive in response to MC gradients during drying.

Figure 3 presents the typical dimensionless moisture ratio of the specimen subjected to drying under air-drying conditions and a constant temperature of 80°C. The figure illustrated that the specimen dried under a constant temperature of 80°C has a steeper curve in comparison with that dried under air-drying conditions. From the calculation of the drying parameter \( k \), it was found that \( k \) value of the specimens dried under air-drying, a constant temperature of 60, 80, 100, and 120°C was 0.003, 0.015, 0.012, 0.023, and 0.059, respectively. The results confirmed that \( k \) value has a positive correlation with the drying temperatures.

\[
y = e^{-0.003x} \quad R^2 = 0.9372
\]
\[
y = e^{-0.012x} \quad R^2 = 0.8374
\]

\[\text{Figure 3. Non-dimensional moisture ratio (MR) curve of the specimen dried under air-drying condition and a constant temperature of 80°C.}\]

Figure 4 shows the typical drying rate of the specimen dried under air-drying and a constant temperature of 80°C. The figure shows that at the same MC, Sentang dried under air-drying conditions has a relatively lower drying rate in comparison to that dried under a constant temperature of 80°C. Higher drying temperature influences the drying rate by increasing the moisture-holding capacity of the air, as well as by accelerating the diffusion rate of moisture through the wood. At MC above the fiber saturation point (FSP), the drying rate of the specimen dried under a constant temperature of 80°C was almost four times higher than those dried under air-drying conditions.

The results above also indicated that \( k \) value corresponds with the drying kinetic, and thus \( k \) value has a tendency to increase as drying temperature increased.
4. Conclusion
In this study, we investigated the drying characteristics of Sentang dried under different temperatures. The results confirmed that drying temperature had a significant effect on drying time and drying under air-drying conditions demanding considerable time in comparison to the other drying conditions used in this study. The results also indicated that the drying parameter ($k$) corresponds with the drying kinetic, and thus $k$ value has a tendency to increase as drying temperature increased.

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Figure 4. The drying rate of the specimen dried under air-drying condition and a constant temperature of 80°C.