Moisture-content based on drying schedule of seven Indonesian woods species

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Abstract. A moisture-content based on drying schedule provides general guidance in determining the changes in temperature and humidity which is based on the average moisture content level of the wood being dried. The research aims to obtain a basic drying schedule for seven wood species based on their drying characteristics. The research is initiated by drying all these species at a temperature of 100 °C. The criterion used is the worst defect occurred in each wood such as end and surface, honeycomb defects, and deformation on the width of the wood. The result shows that each wood species has a different response to high temperature drying. The best drying properties is observed in Red Meranti wood (*Parashorea smythiesii*) and Jaha wood (*Terminalia arborea*). In contrary, Kiacret (*Spathodea campanulata*) and Kipasang (*Prunus javanica*) have the worst drying properties. Based on their drying properties, all of the species can be grouped into 4 drying schedules.

1. Introduction

Drying is a critical part of most wood products manufacturing process. The methods used and proper control are key to achieving the appropriate production level, quality, and costs. Wood products that will be exported to mainly four-season destination countries or used in room air-conditioned environment with very low relative humidity require moisture content about 10% or below. Therefore, the timber must be dried properly according to the required standard. Moisture-content based on drying schedule is general guidelines that include measuring of temperature and relative humidity changes based on the average moisture content of the wood. Based on the physical and drying properties of each wood, dry and wet-bulb temperatures are determined according to the level of certain moisture content [1]. Not every wood species is easy to be dried without developing any defect, because each wood species has its own sensitivity to drying temperature. Therefore the importance information about the drying properties of wood species, especially their relationship to the basic properties, such as the physical properties of the wood. Lack of understanding the drying schedule of each species leads to a high drying cost, drying time, and low quality of the finished products [2–5].

The research aims to obtain the basic drying schedules for seven wood species (i.e. Jaha, Kiacret, Kipasang, Red Meranti, White Meranti, Bira-Bira, and Bipa) based on their drying characteristics. The basic drying schedules of these species are still limited. A proper drying schedule of each species is an important factor in determining the success of the drying process. Commonly, the schedule used by industries is based on the change in the moisture content of the wood.
2. Materials and method

Seven wood species were used in this drying investigation, i.e. Jaha, Kiacret, Kipasang, Red Meranti, White Meranti, Bira-Bira, and Bipa. Information about each species is presented in Table 1.

Table 1. The seven wood species investigated

| Local name | Botanical name | Wood origin |
|------------|----------------|-------------|
| Jaha       | *Terminalia arborea* K. et. V. | West Java |
| Kiacret    | *Spathodea campanulata* P.B. | West Java |
| Kipasang   | *Prunus javanica* Miq. | West Java |
| Red Meranti| *Parashorea smithiesii* Wyatt.Sm ex P.S. Ashton F.Heim. | East Kalimantan |
| White Meranti| *Parashorea tomentella* (Sym.) Meijer | East Kalimantan |
| Bira-Bira  | *Barringtonia asiatica* (L.) Kurz. | Riau |
| Bipa       | *Pterygota horsfieldii* | Papua |

Physical properties, namely initial moisture content in green condition and wood shrinkages from green to air dry were measured according to ASTM D143-94 [6]. Total samples of each species for physical properties tests were 10 pieces (ten replications). The method for drying properties testing in this experiment was a quick-drying test (high drying temperature), which was a modification of the Terazawa Method [7]. Ten defect-free wood samples (2.5 cm x 10 cm x 20 cm) were taken from the green flat-sawn lumber for each species and weighed. The samples were then dried in an oven at 100 °C to constant weight is reached at an average moisture content of ± 2%.

A set of criteria were used to assess three types of defect. Size and number of defects taking place on the surface of the dried lumber were scored using a scaled set of values which ranged from 1 to 7 for initial checks as well as deformation, and from 1 to 6 for honeycomb defect. The lower of the values means the less of the defects while the higher of the values, the more severe the defects. The data for the drying properties from quick-drying test and condition of each sample was used to determine the optimum drying schedule for the wood.

By referring to the drying conditions (Table 2), dry-bulb temperature (DBT) and wet-bulb depression (WBD) (Table 3 and 4) as described in the Forest Products Laboratory manual [1], basic drying schedule of each species was determined.

Table 2. Drying condition based on degree of defects

| Types of defects          | Drying conditions (°C) | Defect classes |
|---------------------------|------------------------|----------------|
|                           | I     | II    | III   | IV    | V     | VI    | VII   |
| I. End and surface checks | Initial temperature    | 70    | 65    | 60    | 55    | 50    | 40    | 38    |
|                           | Wet bulb depression    | 6.5   | 5.5   | 4     | 4     | 3     | 2     | 2     |
|                           | Final temperature      | 95    | 90    | 85    | 80    | 70    | 65    | 50    |
| II. Deformation           | Initial temperature    | 70    | 66    | 58    | 54    | 50    | 40    | 38    |
|                           | Wet bulb depression    | 6.5   | 6     | 5     | 4     | 4     | 3     | 3     |
|                           | Final temperature      | 95    | 88    | 83    | 80    | 70    | 65    | 50    |
| III. Honeycombing         | Initial temperature    | 70    | 55    | 50    | 48    | 48    | 40    | -     |
|                           | Wet bulb depression    | 6.5   | 4.5   | 4     | 3     | 3     | 2.5   | -     |
|                           | Final temperature      | 95    | 83    | 77    | 73    | 71    | 70    | -     |

Remarks: *Modified from Terazawa Method [7]. 1 to 7 are its category. 1 = <5%, 2 = 5-10%, 3 = 10.1-20%, 4 = 20.1-40%, 5 = 40.1-60%, 6 = 60.1-80%, 7 >80%.
Table 3. Drying schedules as developed based on dry-bulb temperature (DBT).

| Moisture content at start of step (%) | Dry bulb temperature (DBT) (°C) |
|--------------------------------------|----------------------------------|
| Initial ~ 30                         | T1 38 T2 40 T3 45 T4 50 T5 50 T6 55 T7 55 T8 60 T9 60 T10 65 T11 70 T12 75 T13 80 T14 80 |
| 30 ~ 25                              | T1 42 T2 45 T3 50 T4 55 T5 55 T6 60 T7 60 T8 65 T9 65 T10 70 T11 75 T12 80 T13 90 T14 90 |
| 05 ~ 20                              | T1 42 T2 50 T3 55 T4 60 T5 60 T6 65 T7 65 T8 70 T9 70 T10 75 T11 80 T12 90 T13 90 T14 90 |
| 20 ~ 15                              | T1 45 T2 55 T3 60 T4 60 T5 65 T6 65 T7 70 T8 70 T9 70 T10 75 T11 80 T12 90 T13 90 T14 90 |
| < 15                                 | T1 50 T2 65 T3 70 T4 80 T5 80 T6 80 T7 80 T8 80 T9 80 T10 80 T11 90 T12 90 T13 90 T14 90 |

Source: (1)

Table 4. Patternized drying schedules based on wet-bulb depression (WBD).

| Initial MC and range (%) | Wet-bulb depression (WBD) (°C) |
|--------------------------|---------------------------------|
| A 40                     | B 50 C 60 D 75 E 90 F 110       |
| 40 ~ 30                  | T1 90 T2 110 T3 110 T4 110 T5 110 T6 110 T7 110 T8 110 T9 110 T10 110 T11 110 T12 110 T13 110 T14 110 |
| 30 ~ 25                  | T1 60 T2 70 T3 70 T4 70 T5 70 T6 70 T7 70 T8 70 T9 70 T10 70 T11 70 T12 70 T13 70 T14 70 |
| 25 ~ 20                  | T1 40 T2 50 T3 50 T4 50 T5 50 T6 50 T7 50 T8 50 T9 50 T10 50 T11 50 T12 50 T13 50 T14 50 |
| 20 ~ 15                  | T1 30 T2 40 T3 40 T4 40 T5 40 T6 40 T7 40 T8 40 T9 40 T10 40 T11 40 T12 40 T13 40 T14 40 |
| 15 ~ 10                  | T1 20 T2 30 T3 30 T4 30 T5 30 T6 30 T7 30 T8 30 T9 30 T10 30 T11 30 T12 30 T13 30 T14 30 |
| 10 ~ 15                  | T1 10 T2 20 T3 20 T4 20 T5 20 T6 20 T7 20 T8 20 T9 20 T10 20 T11 20 T12 20 T13 20 T14 20 |

Source: [1]

3. Results and discussion

Initial moisture content in all species woods investigated varied from the outside (near the cambium tissue) to the pith (center portion) of the stem (Table 5). The moisture gradient in wood is one of the most important physical parameters which can minimized internal stress and provide good dimensional stability (8).

Table 5. Types of defects and drying condition of each wood investigated.

| Species     | Initial moisture content (%) | T/R ratio | Type of defects | Initial Temp. (°C) | WBD (°C) | Final Temp. (°C) |
|-------------|-----------------------------|-----------|-----------------|-------------------|---------|-----------------|
| Jaha        | 52 - 83                     | 1.9       | 2 2 2 3 2       | 55                | 4       | 85              |
| Kiacret     | 109 - 145                   | 1.7-2.2   | 2 6 7 4 5       | 40                | 3       | 50              |
| Kipasang    | 41 - 60                     | 2.3-3.1   | 6 7 6 7 5 6     | 40                | 3       | 50              |
| Red Meranti | 53 - 58                     | 1.8-2.1   | 2 2 2 3 2       | 55                | 4       | 85              |
| White Meranti | 52 - 80                  | 2.5-3.0   | 4 5 5 6 3 5     | 40                | 3       | 65              |

Source: [1]
The initial moisture content in all wood species investigated varied from the outside to the pith of the stem, but it was still above fiber saturation point (Table 5). The high variability in initial moisture content at wood may be caused by its anatomical structure, reflected mainly in the variabilities in heartwood content and wood density [9]. The research result of drying five lesser-known woods species from Riau [10] showed that the variation in the initial moisture content of each wood species produces drying defect such as surface check, deformation on cross-section and honeycombing in various levels. At the same species, the wetter the wood is, the higher the difference between tangential and radial (T/R) shrinkage. T/R shrinkage values high, indicating its poor dimensional stability.

Early in the quick-drying test (at 100 °C temperature), when the moisture content is high, the fibers in the outer board dry first and begin to shrink. However, the inner has not yet begun to dry and shrink; consequently, the inner prevents the outer board from shrinking fully. Thus, the outer goes into tense and the inner into compressed causing a defect of the board, i.e. surface check, internal check/honeycombing, and spool-like deformation on the cross-section of the board. Surface check usually early in drying step and it occurs because drying stresses exceed the tensile strength of the wood perpendicular to the grain of the board, while honeycombing is internal crack caused by a tensile failure across the grain of the wood and usually occurs in the wood rays [1]. The failures can be the extended result from the surface and/or end checks. The research results of (11), showed the presence of honeycombing or internal check in wood could weaken its strength. So that it affects the quality and the value of wood. Deformation on the cross-section of the board can be caused by differences between radial and tangential shrinkage in the board when it dries, also aggravated by irregular grain and the presence of abnormal tree growth, such as juvenile and reaction wood [1]. Any deformation accompanied by the presence of internal checks (honeycomb defects) and wavy surface indicates the formation collapse where the wood cells are flattened due to excessive stress generated in the cells [3]. Severe deformation on the cross-section of the board or collapse must be avoided because it is a serious defect. The presence of these defects in dry wood is difficult to be processed further, except to be used as a specific product with artistic elements.

Based on the quick drying test results, it can be seen that surface check, deformation, and honeycomb defect was found in all species but with different degrees (Table 5). Jaha and Red Meranti wood have the best drying properties of the seven wood investigated. The tendency for Jaha and Red Meranti wood to develop a surface check, deformation, and honeycomb defects during quick-drying test process were lower compared with the rest of the woods species. The woods species had the lowest shrinkage level, with a T/R ratio of ≤2. In general the smaller the difference between T/R-ratio in shrinkage, the smaller the degree of wood defects, like deformation and honeycomb [4,12,13]. Based on their drying properties in the quick-drying test, the drying condition for these wood species is at a dry-bulb temperatures range of 55 to 85 °C and initial wet-bulb depression of 4 °C.

Table 5 shows, kipasang woods had T/R shrinkage value 2.6 was categorized as difficult to dry. The wood tends to develop severe deformation and honeycomb during the drying process. Kipasang wood is difficult to dry because the density of the wood is high, which is an average of 0.89 g/cm³ and there is a possibility of crystal in the parenchyma. If water is forced out of the wood using high temperature and low humidity at the beginning of the drying process, the wood will be damaged. Kiacret wood in the investigated had T/R shrinkage value 1.8, but the wood was difficult to dry. Although the T/R shrinkage ratio on Kiacret wood is low, it is difficult to dry. This is because of the...
possibility of tylosis in the wood vessels, thus inhibiting the process of removing water from the wood. For this reason, tylosis must be removed before the wood drying process. The process of removing tylosis from the wood vessels can be done using steam or boiling. Based on their drying properties in the quick-drying test, the drying condition for Kiacret and Kipasang are at a dry-bulb temperatures range of 40 to 50 °C and initial wet-bulb depression of 3 °C. Bipa wood, although the T/R shrinkage ratio slightly exceeds 2, but is tangential shrinkage is very small, only about 3%. This is causes the structure of the wood cell walls to be strong even when subjected to high temperature. Therefore, an investigation on basic properties in wood drying of Bipa wood is worth continuing in more detail, with respect to especially its relationship with the structure and or chemical composition of the wood. Based on their drying properties in the quick-drying test, the drying condition for Bipa wood is at a dry-bulb temperatures range of 50 to 77 °C and initial wet-bulb depression of 4 °C.

Referring to the drying schedule as presented in Tables 3 and 4, as well as to the difference between wet and dry bulb temperature Table (1), the basic drying schedule for each wood species, which has 1-inch thick timber is presented in Table 6-9. However, modifying such drying schedules are still possible, depending on the drying-kiln type and thickness of the timber.

| Table 6. Basic drying schedule for Jaha and Red Meranti wood. |
|---------------------------------|----------------|----------------|
| Moisture content, %             | Temperature, °C | Humidity, %    |
| Green–30                        | 55             | 81             |
| 30–25                           | 60             | 73             |
| 25–20                           | 65             | 64             |
| 20–15                           | 70             | 47             |
| 15–10                           | 80             | 30             |
| ≤10                             | 85             | 24             |

| Table 7. Basic drying schedule for Bipa wood. |
|---------------------------------|----------------|----------------|
| Moisture content, %             | Temperature, °C | Humidity, %    |
| Green–30                        | 50             | 80             |
| 0–25                            | 55             | 72             |
| 25–20                           | 60             | 62             |
| 20–15                           | 65             | 45             |
| 15–10                           | 80             | 30             |
| ≤10                             | 80             | 22             |

| Table 8. Basic drying schedule for White Meranti and Bira-Bira wood. |
|---------------------------------|----------------|----------------|
| Moisture content, %             | Temperature, °C | Humidity, %    |
| Green–30                        | 40             | 83             |
| 30–25                           | 45             | 78             |
| 25–20                           | 50             | 71             |
| 20–15                           | 55             | 57             |
| 15–10                           | 65             | 38             |
| ≤10                             | 65             | 14             |
Table 9. Basic drying schedule for Kiacret and Kipasang wood.

| Moisture content, % | Temperature, °C | Humidity, % |
|---------------------|----------------|-------------|
| Green–30            | 40             | 83          |
| 30–25               | 42             | 77          |
| 25–20               | 42             | 77          |
| 20–15               | 45             | 69          |
| 15–10               | 50             | 54          |
| ≤ 10                | 50             | 29          |

4. Conclusion
Among the seven species investigated for their drying properties, Jaha and Red Meranti woods have the best drying properties and low tendency to develop defects, while Kiacret and Kipasang have the poor drying properties, and tend to develop severe deformation and honeycomb during their drying process.

Based on the drying condition of each wood, which obtained in the quick-drying test process showed that basic drying schedule of Jaha and Red Meranti wood required to achieve below 10% were at 55–85 °C in temperature and 81–24% in relative humidity, Bipa wood were 50–65 °C and 83–17%, and for both White Meranti and Bira-Bira wood were 40–65 °C and 83–29%. Meanwhile, the corresponding temperature and relative humidity regarding the drying schedule for both Kiacret and Kipasang were 40–50 °C and 83–29% in relative humidity. However, it is still possible by modifying the drying schedule which considers the condition of drying kiln and dimensional sizes of board/lumber.

Acknowledgments
The authors gratefully acknowledge the support from the Forest Products Research and Development Center, Research Development and Innovation Agency, for financial support. We also thank to Abdurachman, ST. for his advice and suggestions.

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