ABSTRACT: The need to find alternative method for drying wood due to erratic electric power source necessitated the need to explore renewable energy source. Performance of solar kiln drying and air-drying on *Alstonia boonei* and *Brachystegia eurycoma* wood was examined. Daily temperature and relative humidity patterns in the two drying media were investigated to determine the influence of the drying methods on the attainable moisture content of the selected wood after 21 days. Average daily temperature and relative humidity in the solar kiln dryer for the drying periods were 39.83°C and 80% respectively while 28°C and 96% recorded for the air-drying shed. Higher temperature was recorded for the solar kiln dryer than the air-drying shed. The final moisture content for *Alstonia boonei* and *Brachystegia eurycoma* at the end of the 21 days of drying were 19.38% and 20.99% respectively. Statistical analysis showed that there was no significant difference in the final moisture attained by the two wood species because they were dried in the same compartment. However, there was significant difference in the interaction between the dryer and the wood species.

Keywords: Solar kiln, Temperature, relative humidity, *Alstonia boonei*, *Brachystegia eurycoma*

INTRODUCTION

Wood is a hygroscopic material with affinity for water and the major problem of wood in service is moisture related, hence the need for drying. The word drying is commonly used to describe the process of removing water from a substance or material. The reasons for drying are almost as diverse as the materials that are dried (Keey, 1978). Agricultural products are dried to prevent the growth of mould or fungi and to extend their shelf life (Hall, 1980). Glossop (1992) states that, basically a solar timber (kiln) dryer is a structure that makes used of trapped solar energy to increase the temperature of the circulating air for drying. Air humidity in the dryer is controlled by venting and in some cases water sprayers are used. Freshly cut lumber contains a great deal of moisture and if the moisture is not removed, the lumber cannot be used to produce a high quality finished product. This leads to drying of wood which could be done by natural air drying or solar kiln. Drying on its own improves the strength of the lumber, kills infestations, hardens pitch, reduces weight and controls shrinkage. A lumber that is not dried under controlled conditions is prone to warping, cupping, twisting; staining and other wood defect that diminishes its selling and workability.

Wood materials, especially green wood are generally moisture rich under natural conditions, therefore raw wood has to be severely controlled on a dried basis (Kanayama et al., 2012). According to Gan and Choo (2001), the drying rate can be expressed as percentage moisture content lost or mass of water lost per unit time (day) and can be calculated by either dividing a
chosen moisture content or mass of water lost from timber by the time taken to lose this amount, or by selecting a period and dividing the mass loss during that period by the time. It represents the moisture content drop per day. Quality of drying is determined, in large part, by rate of moisture loss. Drying rate is an important parameter because it is closely related to energy consumption and economic feasibility of the process. The final quality to be considered comprises parameters such as collapse, colour, timber deformation, cracks, case-hardening and the resultant mechanical strength properties, which directly affects marketing. Moisture gradient is expressed as the difference in moisture contents of inner and surface layer of wood (Uetimane, 2010).

Solar energy when applied to wood drying, becomes an attractive alternative in certain circumstances. Solar drying results in better wood quality than air drying. As a low-temperature operation, it can in certain instances result in better wood quality than conventional kiln drying. In solar applications, however, attention must be given to front-end and energy costs, plant location, production rates, size of stock and species (Rowell and Rowell, 1996). As part of efforts in reducing dependence on the use of electrically powered kiln dryer, a solar kiln dryer was developed which can be used by furniture manufacturers to reduce the effects of using wood with moisture content on their products.

MATERIALS AND METHODS

The Study Area
The experiment was carried in the Department of Forestry and Wood Technology Workshop, Federal University of Technology, Akure, Nigeria (Longitude 33.4738° E and Latitude of 130.5643° N).

Materials Used
Materials for this study were evostic gum, aluminum sheet (light weight), iron sheet, castor, glass, insulator (fiber glass), nail, measuring tape, top bond glue, hinges, paint and thinner for solar cabin construction. Others were Brachystegia eurycoma and Alstonia boonei wood, moisture-meter and hygrometer.

Construction Methods for Solar Kiln Dryer
The parts analysis of the solar kiln (SK) dryer in Figure 1, 2 and 3 showed the drawings used for construction. Wooden planks were used for the skeletal frame work while fibre glass was used to pad the interior structure of the kiln dryer and covered with aluminum sheet for proper insulation to avoid heat leakage. A metal sheet painted black was fixed at the top of the frame and then covered with glass which is the collector for sun radiation. For proper ventilation, vents holes were created which can be closed and opened. The interior part was also painted black to allow for proper heat transfer. Fully constructed SK dryer and air drying used for the study are shown in Plate 1 A and B.

Sample Collection and Preparation
Freshly cut samples of Alstonia boonei and Brachystegia eurycoma wood were obtained from a Sawmill in Akure, Ondo State, Nigeria. Each of the wood species was cut out into ten samples of 450 mm (length) × 75 mm (width) × 25 mm (thickness). Five samples of each wood species were placed inside the air dryer and the other five was placed in the SK.

Determination of Temperature and Relative Humidity Pattern in the Solar Kiln and Air-Dry Shed
The daily temperature and relative humidity (RH) pattern of the SK and air dry shed (ADS) were assessed by using hygrometer. Readings were taken daily at intervals of two hours from 8 am to 6 pm. Values obtained were used to determine mean daily Temperature and RH. The experiment
Determination of the Influence of Drying Methods on the Attainable Moisture Content of *Alstonia boonei* and *Brachystegia eurycoma* after Twenty one Days

The initial moisture content of the wood species was determined using weighing balance and loaded into the two media for assessment until constant moisture content was attained after twenty one days of drying according to Siau (1984); using:

\[
\frac{T_0 - T_2}{T_2} \times 100\%
\]  

(1)

Where;

\[T_1 = \text{daily reading for day one}\]
\[T_2 = \text{daily reading for day two}\]

\[
\text{MC}\% = \frac{x}{y} \times (100 + \%MC) - 100\%
\]  

(2)

Where;

\[\text{M.C}\% = \text{percentage of moisture content}\]
\[x = \text{final weight after drying}\]
\[y = \text{initial weight before drying}\]

Statistical Analysis

The experimental design was 2 × 2 factorial experiment in randomized complete block design (RCBD). The mean and standard error of the treatments were calculated and analysis of variance (ANOVA) was also carried out to test for significance difference.
RESULTS AND DISCUSSION

Mean Temperature and Relative Humidity Pattern (RH) in the Solar Kiln and Air Drying Shed

The result of the mean temperature and RH in the SK and ADS taken during the drying period covering 21 days in the SK ranged from 27.13°C to 40.92°C and 54.17 to 94.4 % respectively. The mean temperature and RH recorded in the air-drying shed ranged from 33.21°C to 24.88°C and 71.83 % to 96 % respectively (Figure 4).

It was observed that the daily mean temperature taken was higher in the SK than the air-drying shed because of the effectiveness of the metal heat collector installed in the kiln which raised the temperature above the ambient by 14°C and lowering the RH. Higher temperature in the kiln was an evidence of its efficiency, making the SK effective in spite of high rainfall experienced during the period of study. These results comply with earlier studies by Buk et al., (2001) which...
compared solar drying with air drying revealing that SK dries wood faster than air drying method.

**Temperature Pattern in the Solar Kiln and Air-Dry Shed at Different Hours of the Day**

The daily mean temperature for both SK and ADS at different hours of the day showed that SK increased from 27.42°C to 38.42°C between the hours of 8 am and 12 pm, and to 42.06°C between 2 pm and 3 pm while it dropped to 35.1°C at 6 pm. The highest temperature regime was observed between 2 and 4 pm. The dry bulb temperature in the air-dry shed increased from 25.88°C to 28.94°C between the hours of 8 am and 12 pm.
and 12 pm. The air-dry shed temperature reached its peak of 29.86°C and drops back to 27.44°C at 6 pm (Figure 5).

The mean temperature for both media increased gradually from morning till afternoon and decreased in the evening because of high sun intensity during the afternoon and the low radiation in the morning and evening. Higher temperature recorded for SK was caused by the ability to trap and retained the heat received from the sun. The result obtained in this study is in agreement with previous report by Keey et al., (2000) which affirmed the ability of the SK to harness the free energy of the sun.

**Mean Relative Humidity Pattern in the Solar Kiln and Air-Dry Shed at different hours of the day**

The mean RH for SK was 86.19% and drops to 73.22% between 8 am and 4 pm and rose back to 75.74% at 6 pm during the evening period, while for the air-dry shed, mean RH increased at 12 pm to 87.93% and decreased to 72.56% at 4 pm but rose again to 78.94% at 6 pm (Figure 6). The period was characterized by frequent rainfall which resulted in high RH for both drying media. This study was carried out from August to September, 2012 which recorded heavy rainfall. This resulted into low sun radiation which raised the humidity of the surrounding air. 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. The RH in the SK was significantly lower than the RH in the air dry shed. The heat trapped in the SK may be responsible for stable RH. The absence of trapping device in the air drying shed accounted for the differences in the RH of both SK and air drying shed. The results obtained in this study correspond with previous report by Hague and Langrish (2005), which compared the RH of both solar system and air drying system and discovered that the heating air in the SK lower its RH.

**Moisture loss of *Brachystegia eurycoma* in both Solar Kiln and Air-drying shed for 21 days**

The pattern of moisture loss in *Brachystegia eurycoma* both in SK and ADS is shown in Figure 7. *Brachystegia eurycoma* wood in the SK dried rapidly from initial moisture content of 45% to 37.7% on day one, at day twelve the moisture content dropped to 24.9% and recorded 15.9% at day 21 when the experiment was terminated. In the air-dry shed, the moisture content was reduced from 45% to 32.7% on the first day, but at day twelve, the wood gains moisture from the environment due to high RH. It dried to 27.9% on day fifteen and absorbs moisture again to reach 30.5% on day eighteen and dried to 26.1% on the last day (Figure 7).

The SK performed better than ADS in the drying of *Brachystegia eurycoma*. Although, the differences were close but SK proved more effective in the drying of the wood (Figure 7). The fluctuation in moisture content of *Brachystegia eurycoma* in SK may be caused by the vent hole which allows the wood to reabsorb moisture from the environment due to high humidity. In spite of the fluctuations in the weather condition and high humidity of the surrounding air, samples placed in the SK were dried to lower moisture content. The intermittent raining situations during the period may be the responsible for fluctuation in the moisture content of *Brachystegia eurycoma* during the air drying shed. Aladejana et al. (2014) also observed similar result with *Brachystegia eurycoma* dried under open air and shed method. They discovered that the prevalent weather condition is a key factor in wood drying.

**Moisture loss in *Alstonia boonei* in the Solar Kiln and Air-drying Shed for 21 days**

The moisture of *Alstonia boonei* in both SK and ADS (Figure 8) dried from initial moisture content of 115.5% to 74.3% on day one. On day eighteen the moisture content dropped to 21.5% and further reduced to 20.9% on the last day. In the ADS, the wood dried from 115.5% to 80.4% on
Figure 6: Periodic mean Relative Humidity pattern in the Solar Kiln and Air-dry Shed

Figure 7: Pattern of Moisture loss in *Brachystegia eurycoma* in both Solar Kiln and Air-dry Shed for 21 days
day one and dropped to 17.8% on the last day. The study showed that both media have the capacity to reduce the moisture content of *Alstonia boonei*. Comparison of the two media showed a slight difference at the time the experiment was terminated because the efficiency of the SK is a function of sun radiation outside the kiln. Fluctuation in the *Alstonia boonei* moisture content was caused by re-absorption of moisture from the environment through the vent hole which made the moisture of the wood to rise again. This correspond with the work by Owoyemi *et al.* (2015), which found out that solar radiation with stable environmental condition is an important factor for attaining low moisture content in wood.

**Influence of Dry media on the Final Moisture Content attained by the Wood Species**

Analysis of variance carried out at 5% probability level to test for significant differences among the wood species and the dryer presented in Table 2 showed that there were no significant differences in dryer and wood species at 5% probability level. The interaction between the dryer and the wood species showed a significant difference at 5% probability levels. Also, there were no significant differences in the mean values of moisture contents for both dryer and the wood species (Table 3).

There was no significant difference in the final moisture content attained by the wood species. The fluctuation in the weather condition could account for the insignificant difference observed in the final moisture content in the SK and ADS as low temperature and high humidity were recorded during the period. Bosquet (1981) explained that when wood is exposed in a building with temperatures usually between 26.7°C and 43.3°C, humidity may be partially controlled. Vents are usually closed to achieve a lower RH during rainy season.
Table 2: ANOVA result for the Variables tested

<table>
<thead>
<tr>
<th>Source</th>
<th>Df</th>
<th>Sum of Square</th>
<th>Mean Square</th>
<th>F-cal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryer</td>
<td>1</td>
<td>64.01</td>
<td>64.01</td>
<td>1.572</td>
</tr>
<tr>
<td>Species</td>
<td>1</td>
<td>12.8</td>
<td>12.8</td>
<td>0.314</td>
</tr>
<tr>
<td>Dryer * Species</td>
<td>1</td>
<td>223.78</td>
<td>223.78</td>
<td>5.495</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>651.562</td>
<td>40.723</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>952.153</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = Significant  ns = not significant (p<0.05) probability level

Table 3: Mean values of Moisture Content for the Variables

<table>
<thead>
<tr>
<th>Source</th>
<th>Variation</th>
<th>Mean Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Dryer</td>
<td>Solar Kiln</td>
<td>18.40 ± 2.24a</td>
</tr>
<tr>
<td></td>
<td>Air-drying Shed</td>
<td>21.97 ± 2.19a</td>
</tr>
<tr>
<td>Wood Species</td>
<td>Brachystegia eurycoma</td>
<td>20.99 ± 2.83a</td>
</tr>
<tr>
<td></td>
<td>Alstonia boonei</td>
<td>19.38 ± 1.56a</td>
</tr>
</tbody>
</table>

Means with the same alphabets (*) are not significantly different (p<0.05)

CONCLUSION

Solar kiln dryer is not as expensive as the conventional kiln and does not require electricity for heat generation. It can be built with local materials to reduce cost. Wood dried in the kiln is free from stress thereby improving its quality. Solar kiln will dry wood faster than the air drying shed when used during the dry season of the year when there is low RH. Lower moisture content could have been reached in the solar kiln provided the vents were closed at appropriate periods. The solar kiln used in the study was constructed without fan for air circulation, natural air circulation through the vent was not enough to dehumidify the kiln and this accounted for the low performance of the solar kiln dryer.

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