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CONSTRUCTION AND EVALUATION OF SOLAR KILN FOR WOOD SEASONING IN DUTSIN-MA, KATSINA STATE

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Abstract

A proto-type solar powered kiln was constructed and evaluated at Federal University Dutsin-Ma, Katsina State, Nigeria. The dimension of the wood used as the outer and inner walls were ½ and ¼ inch respectively. The inner part of the kiln was painted black for heat to serve as the solar absorber for the system. The kiln was constructed and the roof was glass of 5mm thickness. A total number of 18 wood samples were used for the evaluation of the solar kiln from three different wood species (Khaya ivorensis, Triplochiton scleroxylon and Milicia excelsa). The wood samples were sourced from Akure, Ondo State and wood were machined and trimmed to the size of 20 mm X 20 mm X 300 mm. The wood samples were replicated three times in the solar kiln and under shed, their consecutive weights were taken. Evaluation was done between the experimental results of solar kiln and natural air drying. The results showed that the wood dried using the solar powered kiln attained the lowest moisture content of 19.77 %, while those under shed have 27.40 % moisture content. With regards to species, the moisture content obtained were 22.87 %, 23.08% and 24.87% accordingly. The drying rate was also compared, in which the lowest moisture content was obtained in 144hrs, followed by 96 and 48hrs (21.97 % and 30.67 %) respectively. It can be concluded that solar powered kiln dryer dries wood faster than Air drying method. .However, other heat generating, absorption and retention materials should be incorporated to the solar kiln design in subsequent researches.

Keywords: Solar, Solar Kiln, Wood Seasoning, Drying Efficiency, Timber, Moisture Content

INTRODUCTION

Timber is usually dried to specific moisture content prior to further manufacturing or use because wood changes its dimensions with changes in moisture content (Bond, 2011). The amount of water in wood is usually expressed as moisture content and can be directly measured or calculated.

The moisture content of wood is defined as the ratio of the weight of water in wood to the dry weight of the wood material (Andersson *et al*., 2006 and Forsman, 2008). While timber can be air-dried, the ambient humidity in most localities prevents the timber from reaching the moisture content necessary for the dimensional stability, especially for interior use (Sowunmi, 2015).

The reasons for drying are almost as diverse as the materials that are dried. Fresh timber contains a great deal of moisture and if the moisture is not removed, the timber cannot be used to produce a high quality finished product (Bond, 2011). In addition, Khalil *et al.* (2007) states that In comparison to natural sun drying, solar dryers generate higher temperatures, lower relative humidity, and lower product moisture content and reduce spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and other artificial drying.

Solar kilns are an inexpensive alternative to conventional steam-heated kilns, especially for small operations, like wood crafts makers (Bond, 2011). Solar-heated kilns have great potential in developing countries, especially in far-off locations with little access to conventional energy sources.

A solar kiln is a cross between kiln drying and air drying. These kilns are generally a green house with a high-temperature fan and either vents or a condensing system (Owoyemi *et al.*, 2013). Solar kilns are slower and flexible due to the weather, but are low cost. Solar timber drying kilns merely apply the principles used in a greenhouse to the drying of timber where heat is trapped inside a structure glazed with a material which is transparent to short wave radiation (light) and non-transparent to longer wave radiation (heat) and which at the same time decreases heat loss by conduction and convection (Sowunmi, 2015).

Kiln drying is the process of drying timber in an insulated chamber and circulating air over it. Basically it involves the introduction of heat in the chamber (Owoyemi *et al.,* 2015). This may be directly using natural gas and/or electricity or indirectly through steam heat exchangers and solar energy (Joseph *et al.,* 2000).

The solar kiln is basically identical to the conventional kiln in its function except that the solar kiln relies on heat generated from sunlight which operates at a daily circle with its highest temperature and air speed in the kiln during the day while having a lower temperature level in the kiln during at night. Solar timber drying offers several advantages to those desiring an inexpensive means of drying small quantities of lumber (Rajendra, 2007).

The significant advantages of solar kiln drying include higher output and better control of the final moisture content ((Khalil *et al.,* 2007). Conventional kilns and solar drying both enable wood to be dried to any moisture content regardless of weather conditions and for most large-scale drying operations solar and conventional kiln drying are more efficient than air drying (Standard Australia, 2000).

Drying, if carried out promptly after felling of trees, also protects timber against primary decay, fungal stain and attack by certain kinds of insects (Rajendra, 2007). Organisms, which cause decay and stain, generally cannot thrive in timber with moisture content below 20 percent. Tageldin *et al*., (2013) reported that when compared with conventional steam or direct-fired drying kiln solar assisted air drying shows significant savings in capital and operating costs, he further posited that the performances of the solar dryers are satisfactory in respect to the final moisture content, drying time and quality of timber.

The utilization of wood is hindered by the absorption and desorption properties of wood and this, has made wood to be highly irregular dimensionally (Emmanuel, 2014). Furthermore, the dimension instability affect most properties of wood, ranging from physical, chemical, mechanical and resistance to biological degradation (Emmanuel, 2014).

On the other hand, tradition method of seasoning timber which is air drying is associated with a lot of difficulties such as, rate of drying, efficiency of drying, evenness in drying. All these associated problems have made timber drying cumbersome and not efficient in the tropics (Owoyemi, *et al.,* 2015).

Acceptable kiln drying can generally be obtained by regulating the temperature and humidity of the circulating air to control the moisture content of the lumber at any given time. This condition is achieved by applying kiln-drying schedules (Poncsak, *et al.,* 2009). Although, Conventional kiln drier which would have been a more convenient and very efficient means of drying is very expensive in terms of installation and operations due to high cost of electricity and management (Diego, *et al.,* 2009).

Hence, there is need to research into a kiln dryer that is cheaper and affordable with respect to high efficiency and cost of establishment. The general objective to the study was to design, construct and study the efficiency of the solar kiln in investigating the drying characteristics of selected indigenous wood species. To design, construct, evaluate the solar kiln for wood seasoning and to test the drying characteristics of some indigenous wood species. This research describes the construction and operation of low-cost solar kiln for timber drying in tropical regions, like Katsina state

MATERIALS AND METHODOLOGY

Study Area

The study was conducted in the Department of Forestry and Wildlife Management, Federal University Dutsin-Ma Katsina (FUDMA), Katsina State located on $12^0$27, 10''N and $12^0$27, 16''N and longitude $07^0$29, 56''E and $07^0$30, 04''E, (Tukur *et al.,* 2013)

The climatic of Katsina State is the tropical wet and dry type (tropical continental climate) classified by Koppan as Aw climate. Rainfall is between May and September with a peak in August. The average annual rainfall is about 700 mm. the pattern of rainfall in the area is highly variable. The mean annual temperature ranges from 290C – 310C. The highest air temperature normally occurs in April/May and lowest in December through February. Evapo-transpiration is generally high throughout the year. The highest amount of evaporation occurs during the dry season. The vegetation of the area is Sudan savanna type which combines the characteristics and species of both the Guinea and Sahel savanna (Abaje, 2007, Tukur *et al.,* 2013)

Materials used

The following materials were used for the construction of the prototype solar Kiln: Wood (plywood and sawn wood) as the casing (housing of the entire system, wood was selected being a good insulator and relatively cheaper than metals, Fan (5 watts), Solar panel (80 watts) 5mm Glass and Wooden frame for constructing the trays.

Other materials used were nails and glue as fasteners and adhesives, Hinges and handles for the dryer's door and Black Paint to improve rate of absorption.

Construction of wood dryer

The solar Kiln was constructed with locally available and relatively low-cost materials. Since the entire casing is made of wood and the cover is glass, the major construction was carpentry work.

The following tools were used in measuring and marking out the wooden planks.

These includes; Carpenter's pencils, Steel tapes (push-pull rule type), Steel meter rule, Vanier caliper, glass cutter, Steel square, Scriber, Hand saw (crosscut saw and tip saw),Wood chisel Hammer and Pinch bar

Sawn wood and plywood, nails and adhesives were the major materials used for this construction. The first stage was the construction of floor, 2× 3 sawn wood was used for the floor and the kiln skeletal (Figure I and II). The wood used for the construction was treated with preservative (solignum) to prevent insect attack especially termite that is well known to the experimental site. The walls of the kiln were made up of two types of plywood; the outer phase was covered with half inch plywood while inner phase was covered with quarter inch plywood. A mixture of top bond (Gum) with calcium carbonate was used in filling the possible gaps between plywood, joints and nail fringe. The inner of the kiln was painted black (sinklear) for its known property of heat absorption.

The exterior of the kiln is painted with exterior-grade paint (milk colour) for good looking and to prevent weathering. Two doors of 1500 mm was made at the front of the structure for loading, unloading, and monitoring kiln samples with vent of 250 mm^2 for exit of heated the air.

Two fans with plastic blades were mounted on the rear wall of the Kiln inwardly, circulating the heated air throughout the kiln. Four trolley were used which made the Kiln movable and to ease translocation. The roof was constructed sloppy for optimum collection of heat, covered with 5mm glass. A hole was made for the taking of temperature readings to avoid frequent opening of the kiln during operation.

Design considerations

1. Temperature: The minimum temperature for drying wood is 30℃ and the maximum temperature is 60^0C, therefore 45^0C and above considered average and normal for drying vegetables, fruits, roots and tuber crop chips, crop seeds and some other crops.

2. Air gap: It is suggested that the hot climate test solar dryers, a gap of 250 mm was created as air vent.

3. Glass and flat plate collector: the glass covering of 5mm thickness was used. And the solar panel of 80 watts was installed for fans (DC fans) air circulation within the heating chamber.

4. Dimension: the dimension was 1598mm × 1100mm × 840mm.

Figure I: Complete Set Kiln

Descriptive Statistics and Analysis of Variance

Descriptive statistics will be used for species moisture loss. Also, two-way analysis of variance will also be used to compare significant differences in species mean among the samples and daily moisture loss. Where there will be significant differences in mean among species and a Least significant difference test (LSD –test) was conducted for mean separation in that respect.

The total amount of water in a given piece of wood is called its moisture content (MC). Although we are accustomed to the fact that 100 % signifies the total amount of something, the MC percent of wood can be greater than 100 % (Stamm, 1964). This occurs because the water can weigh more than the wood, and the MC of wood is usually based on the ratio of the weight of the water to the weight of the wood after it has been dried.

$$\% \textbf{ Moisture content} = \frac{\text{weight of water in wood}}{\text{weight of kiln dried wood}} \quad 1$$

$$\%\textbf{MC} = \frac{\text{weight of wood before drying} - \text{weight of kiln dried wood}}{\text{weight of kiln dried wood}} \quad 2$$

Current % **MC** = (wet weight/ est. OD weight) – 1 × 100 3

Drawing, and plan of the solar kiln

The drawing of solar kiln was accomplished using Auto CAD software (version 10).

Solar kiln drawing

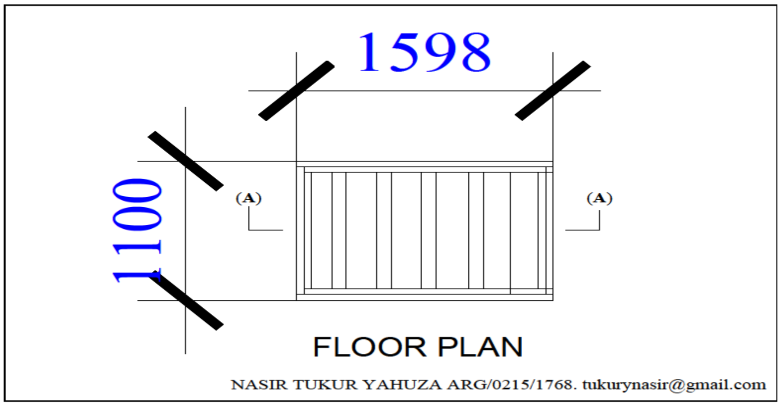

Figure II: Floor Plan

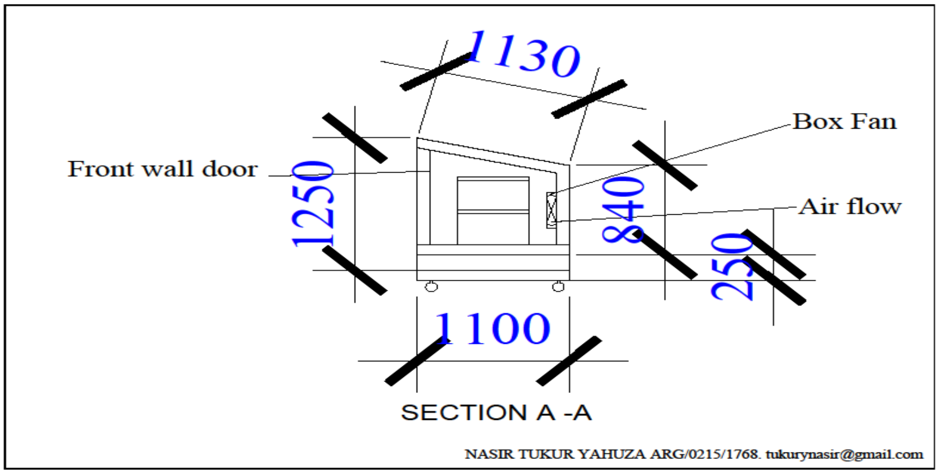

Figure III: Section A - A

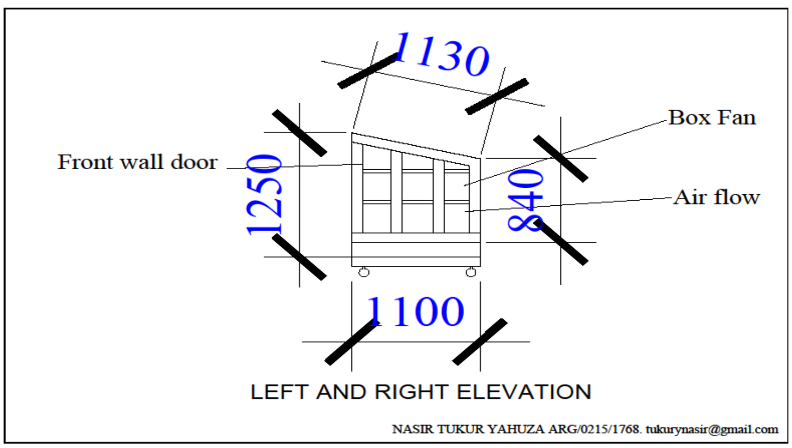

Figure IV: Left and Right Elevation

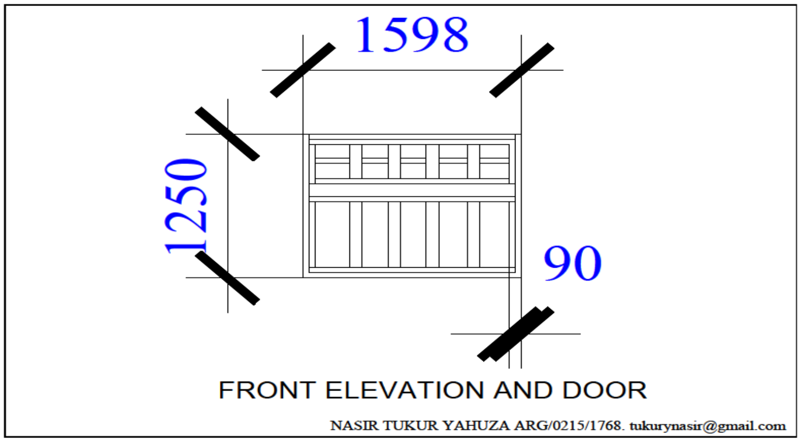

Figure V: Front Elevation and Door

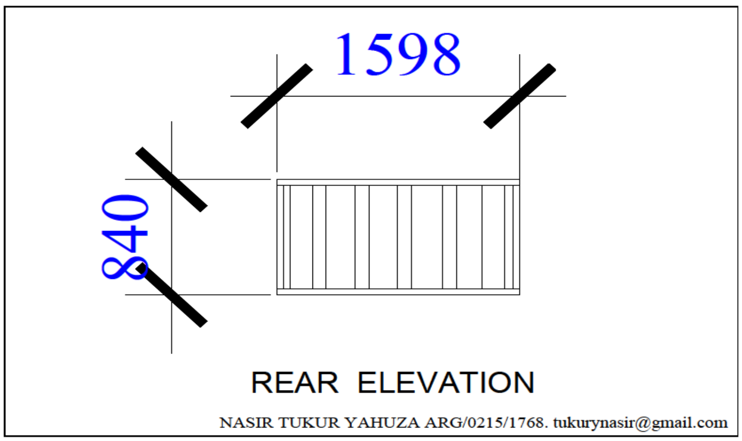

Figure VI: Rear Elevation

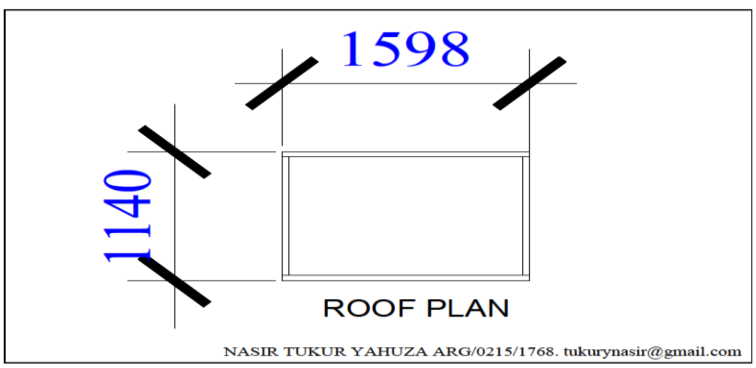

Figure VI1: Roof Plan

Experimental procedure

A total 18 wood samples 20 mm × 20 mm × 300 mm (3 each) of *Khaya ivorensis*, *Milicia excelsa* and *Triplochiton screloxylon for* both Air and Kiln respectively. They were labeled 1 – 3 for each of the species for proper identification. The experimental designed employed for the study was completely randomized blocked design (RCBD). Analysis of variance was conducted and followed up test was done on the data collected for drying rate of wood.

Determination of moisture content of the samples

The initial weight (W1) of the samples was recorded before subjected to their respective methods using an electronic scale (sensitive). Subsequently, samples were dried in the solar kiln and under shed until constant reading was obtained (W2). The average moisture content of the two sections was used to obtain the estimated percentage moisture content of the samples. This was expressed as a percentage of the dry weight of the samples.

Determination of Temperature (c) and Relative humidity (%)

Temperature and relative humidity (drying factors) of the environments (shed and solar kiln) were determined in accordance to WMO (1974). The data was collected five (5) times a day; 8:00 am, 10 am, 12 pm, 2 pm and 4 pm. Readings were taken 15 mins after the instruments were introduced in to the kiln. Mean daily Temperature and relative humidity were evaluated as follows

Ti = ti+t2+t3+t4+t5+t6/6

Ti = Mean Temperature of the drying period

ti = Hourly temperature

RHi = (rhi)1 + (rhi)2 + (rhi)3 + (rhi)4 + (rhi)5 + (rhi)6/6 (As adopted by Amoo-Onidundu *et al.* (2016)

Where

RHi = Relative humidity of the drying period

rhi= Relative humidity on hourly basis

Consequently, the correlation between mean of the daily drying factors and the drying rate was carried out.

RESULT AND DISCUSSION

Solar kiln evaluation

Table 1 presents the mean values of initial and periodic moisture content of the wood samples (*Khaya ivorensis, Triplichiton scleroxylon* and *Milicia excelsa*). The initial moisture content (IMC) of *Khaya ivorensis* under Kiln drying method was 53.98 %, dropped to 28.5 % after 48hrs, 18.80 % at 96hrs and 14.06 % after 144hrs as presented in Table 1.

Triplochiton scleroxylon IMC was 45.90 %, decreased to 24.75 % after 48hrs, 18.03 % at 96hrs and 13.03 % at 144hrs time. Similarly, *Milicia excelsa* initial moisture content was 66.83 dropped to 27.78 % after 48hrs, 19.84 % at 96hrs and 13.17 % after 144hrs as presented in the Table.

Likewise the samples under the shed (air drying) the initial moisture content of *Khaya ivorensis* was 51.13 %, decreased to 30 % after 48hrs, 25.26 % at 96hrs and 21.88 % after 144hrs, for *Triplochiton scleroxylon* the initial moisture content was 45.74 %, dropped to 35.74 % after 48hrs, 24.51 % at 96hrs and 21.15 % as the final moisture content at 144hrs. *Milicia excelsa* with initial moisture content of 65.08 %, dropped to 37.38 % in 48hrs time, 29.37 % after 96hrs and 25.40 % after 144hrs.

Table 1: Mean values of initial moisture content (IMC) of the wood samples and moisture contents change over the drying period

Drying methods	Wood samples	IMC (%)	drying Period (hours)		
Kiln drying			48hrs	96hrs	144hrs
	Khaya senegalensis	53.98	28.5	18.30	14.06
	Triplochiton scleroxylon	45.90	24.75	18.03	13.03
	Milicia excels	66.83	27.78	19.84	13.17
Air drying					
	Khaya senegalensis	51.13	30.0	25.26	21.88
	Triplochiton scleroxylon	45.74	35.74	24.51	21.15
	Milicia excels	65.08	37.38	29.37	25.40

Table 2 shows the **e**ffect of wood drying methods, wood species and period of drying on wood seasoning the results showed that wood seasoning was significantly (P<0.05) influenced by the drying methods. The lowest moisture content (19.77 %) was observed in wood seasoned in kiln.

Whereas the wood seasoned under shed had higher moisture content with the mean value of 27.41 %. With respect to wood species, the result show that *Triplochiton scleroxylon* had the lowest moisture content (22.87 %), followed by *Khaya ivorensis* (23.08 %) and *Milicia excelsa* had the highest moisture content of 24.87 %. The effect of drying rate indicated that the lowest moisture content was attained after 144 hours with mean value of 18.11%, followed by 96 hours (21.97 %) and 30.69 % at 48 hours respectively.

Table 2: Effect of wood drying methods, wood species and period of drying on wood seasoning

Variables	Mean	S.E ±
Drying method		
Air drying	27.41a	1.06
Kiln drying	19.77b	1.11
Wood species		
Milicia excels	24.87a	1.79
Khaya ivorensis	23.08b	1.34
Triplochiton scleroxylon	22.87c	1.70
Drying periods (hours)		
48	30.69a	1.10
96	21.97b	0.76
144	18.11c	1.18

abc Means with different letters along the column differ significantly at P<0.05, S.E: Standard error

Table 3 indicated the mean value of Temperature and relative humidity over the drying period. In kiln 25.66^{0}C was the temperature with R/H of 52.55 % at 8am, 44^{0}C and 22.73 % at 10am, 57.83^{0}C and 18.93 % at 12pm, 60.16^{0}C and 11.87 % at 2pm, and 52.66^{0}C and 9.63 % relative humidity respectively. Under the shade the temperature of 26.16^{0}C and 49.75 % relative humidity was recorded at 8am, 31.83^{0}C and 35.25 % at 10am, 33.66^{0}C and 25 % at 12pm, 34.33^{0}C and 19.18 % at 2pm, and 34^{0}C and 19.86 % respectively.

Table 3: The mean value of Temperature and relative humidity of the drying period

Drying methods	8am		10am		12pm		2pm		4pm	
	T^0C	RH (%)	T^0C	RH (%)	T^0C	RH (%)	T^0C	RH (%)	T^0C	RH (%)
Kiln drying	25.66	52.55	44.00	22.73	57.83	18.93	60.16	11.87	52.66	9.63
Air drying	26.16	49.75	31.83	35.25	33.66	25.00	34.33	19.18	34.00	19.86

T^0C-: Temperature in degree Celsius, **RH (%) -:** Relative humidity in percentage

DISCUSSION

The results depict the trend of changes in moisture content of the wood samples over the drying periods of both the kiln and air drying method. *Khaya ivorensis* seasoned in the kiln was from initial moisture content (IMC) of 53.98 % to final moisture content (FMC) of 14.06 %, whereas *K. ivorensis* under shed was from IMC of 51.13 % to final moisture content of 21.88 %.

Similarly *Triplochiton scleroxylon* of kiln was from initial moisture content of 45.90 % to FMC of 13.03, where the same species under shade dried from initial moisture content of 45.74 % to FMC of 21.15 %. Likewise *Milicia excelsa* with initial MC of 65.83 % dried to 13.17%, where the *M. excelsa* under shed dried from initial moisture content of 65.08 % to 25.40 %. The moisture content loss of Solar drier was more compare to air drying samples.

This could be attributed to variations in the dying factors (Temperature and relative humidity). This observation is in line with the submissions of previous researchers (Gan and Choo, 2001; Haque and Langrish, 2003; Owoyemi, 2013) who reported that drying rate of wood is faster in solar kiln drying than air drying method. It was observed that 19.77% moisture content was obtained when kiln solar dryer was used, at this value it will be difficult for bio deterioration agents and other insect activities to attack the wood. This could be apparently attributed to the difference in the drying factors as asserted by several researchers (Bond, 2011, Langrish 2003 and Oweyemi, 2015).

Species would also count as drying schedule as its effectiveness portrayed in this research. *Triplochiton scleroxylon* had the lowest moisture content (22.87 %), followed by *Khaya ivorensis* with 23.08 % and *Milicia excelsa* had the highest moisture content (24.87 %). It could be connected to the differences in the anatomical and physiological properties of the species. In addition, time was effective in the drying operation as the lowest moisture content (18.11 %) was achieved at 144 hours, followed by 21.97 % and 30.69 % at 96 hours and 48 hours respectively. This indicates that the longer the duration of drying the lower the moisture content attained.

Subsequently, the results revealed the relationship between the Temperature and Relative humidity (the drying factors) over the period of seasoning. The relationship between the Temperature and Relative humidity was inversely related, whenever Temperature increased the Relative humidity decreased and vice versa. For solar kiln the highest temperature (60.16^0C) was recorded at 2 pm with relative humidity of 11.87 % where the least temperature was 25.66^0C with the highest relative humidity of 52.55 %. This could be connected with the fact that sun which was the source of the heat energy was not high at 8am, it normally reaches its peak at 12:30 pm in the research area and the kiln absorbed more heat around these hours which might be the reason to have the highest temperature (60.16^0C) at 2pm in the kiln.

While it was air- the highest temperature value of 34. 33^0C was recorded at 2 pm with relative humidity of 19.18 %, while the least temperature value of 26.16^0C with highest Relative humidity of 49.75 %. It could be infer from this research that the kiln attained higher Temperature and lower Relative humidity than air drying environ. This could the reason that the solar kiln seasoned wood faster than natural air drying method as asserted by several researchers (Ogunsanwo and Amoo-Onidundu (2011); Owoyemi, *et al.* (2015) and Amoo-Onidundu *et al.* (2016)).

Conclusion

The proto-type solar powered Kiln was constructed using low cost materials and was compared with air drying method. From the results obtained, it was evident that the Solar kiln seasoned wood faster when compared to natural air drying. Information on drying factors (Temperature and Relative humidity) forms one of the proofs that established the reasons for the better result obtained for solar kiln seasoning.

From the outcome of this research it is obvious that solar kiln season wood faster than the natural air drying method. I t was also discovered from different wood species used in the experiment *Triplochiton scleroxylon* dries fast.

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