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Effect of Density on Flame Characteristics of Some Tropical Timbers

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Abstract: *Timber has always played an influencing role in the lives of humans. At high temperature and in the presence of air, it burns or decomposes exothermically. The flame characteristics studied were the ignition time, flame duration, flame propagation rate and after-glow time. Wet and oven-dry densities, moisture content and porosity index of these timbers were also measured. The oven-dry density range was 0.256 0.008 g/cm^3 to 1.111 0.039 g/cm ^{3} in which most of the timbers were of medium density (0.400 - 0.750 g/cm ^{3}). Most of the timbers can be described as being fire-tolerant since they have flame propagation rate values below 0.28cm/s. There was somewhat direct relationship between oven-dry density and ignition time, flame duration and afterglow time of these timbers, while an inverse trend exists with flame propagation rate. The use of alternative hardwoods with high density is recommended with its attendant flame characteristics.*

Keywords: *Tropical timbers, ignition time, flame duration, flame propagation rate, after-glow time.*

I. Introduction:

Fire climate in Nigeria is categorized into four zones, namely the Mangrove and Swamp vegetation; the Rain **forest; the Guinea Savanna; and the Sudan and Sahel Savanna vegetation. The first and last zones are the least** affected by fire due to too much water and extreme aridity in the respective zones [Balogun & Ajayi, 2006]. Timber/wood is a thermally degradable and combustible material [LeVan, 1984]. It is the most important natural and endlessly renewable source of energy with a complex chemical structure made up of cellulose (40-50%) and hemicelluloses (15-25%) impregnated with lignin (15-30%) [Beall & Eickner, 1970]. When a flammable and/or combustible material with an adequate supply of oxygen or another oxidizer is subjected to enough heat, fire starts.

Forest fires and building fires, e.g. homes, offices and markets, are now threatening communities in different parts of Nigeria, nay the world, leading to deforestation and desertification in the Northern belt as well as erosion and soil degradation in the Southern region. Fire has been and is still a major environmental factor, contributing to global warming and destroying the rich forest resources of the world. Little has been reported on the flammability properties of most tropical timbers [Eboatu & Altine, 1991; Momoh et al, 1996; Eboatu et al, 1997].

The main aim of this work is to study the flammability characteristics of these tropical timbers obtained from the Rainforest and Guinea Savanna regions of Nigeria. These timbers are classified with respect to their density and porosity indices which give a guide to their strength and permeability properties. This study will provide a pivotal database for the flammability characteristics of these Nigerian timbers. It will establish alternative (lesser-used) tropical hardwoods with high density that could be recommended for building and furniture, with **its attendant flame characteristics.**

II. Materials And Method

Tropical timbers were sourced from the Rain Forest and Guinea Savanna regions of Nigeria, particularly from Enugu, Kogi, Anambra and Edo States. Each of the timber species was cut into cubes and splints. Dry and wet densities, moisture content, ignition time, flame duration, flame propagating rate and after-glow time were determined as described elsewhere[Momoh et al, 1996; Eboatu & Altine, 1991; Eboatu et al, 1995]. Each experiment was repeated five times and the results averaged.

III. Results And Discussion

Of the fifty-three timbers, arranged in increasing order of denisty (Table 1), thirty-one were of medium density (0.403 ± 0.020to 0.715 ± 0.011 g/cm^3) , nine were of low density (0.256 ± 0.008 to 0.380 ± 0.012 g/cm^3) and thirteen were quite dense (0.784 ± 0.020 to 1.111 ± 0.039 g/cm^3).

***Table 1:** Correlation of density with the family and nature of timbers*

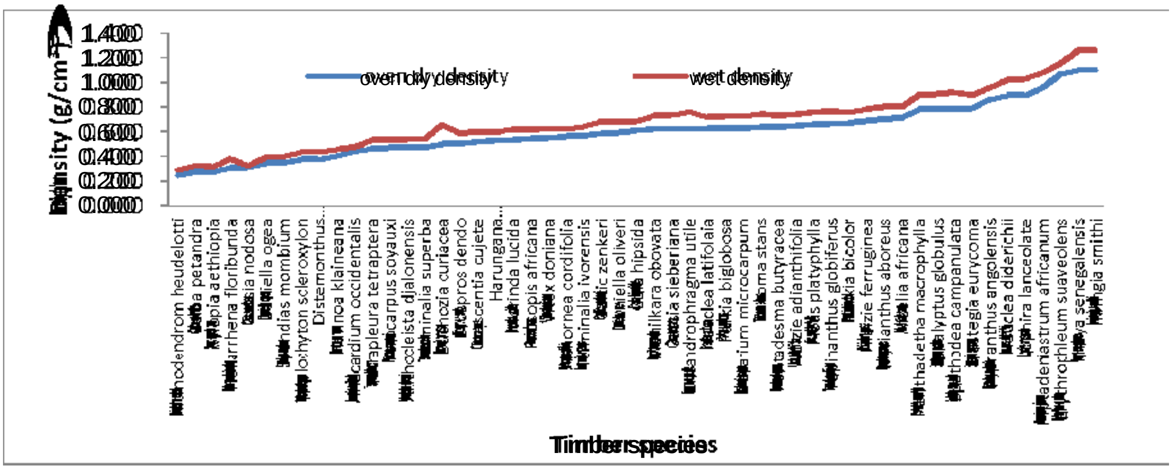
Botanic name	Oven dry density(g/cm^3)	Family of timber species	Nature of wood
Ricinodendrom heudelotti	0.256 ± 0.008	Euphorbiaceae	Wood white, very soft
Ceiba pentandra	0.281 ± 0.019	Bombacaceae	Wood white, very light, brittle when **dry.**
Xylopia aethiopica	0.283 ± 0.032	Annonaceae	White to pale yellowish
Hollarrhenafloribunda	0.308 ± 0.020	Apocynaceaae	White and soft
Cassia nodosa	0.311 ± 0.021	Caesalpinioideae	Reddish-brown, very hard and heavy
Daniella ogea	0.344 ± 0.048	Caesalpinioideae	Sapwood white and ripple- marked
Spondias mombium	0.350 ± 0.025	Anacardiaceae	Whitish and soft
Triplochyton scleroxylon	0.3 80 ±.007	Sterculiacease	
Distemonthus benthamiamus	0.380 ± 0.012	Caesalpinioideae	Wood yellowish
Hannoa klaineana	0.403 ± 0.020	Irvingiaceae	Wood white, soft, very light.
Anacardium occidentalis	0.443 ± 0.043	Anacardiaceae	Yellowish in colour
Tetrapleura tetraptera	0.467 ± 0.018	Minniosoideae	Wood reddish to brown , heartwood fairly hard, sapwood white
Pterocarpus soyauxi	0.470 ± 0.0 14	Papilionoideae	Wood brownish-yellow sapwood, red heartwood.
Anthocleista djalonensis	0.470 ± 0.073	Loganiaceae	Whitish and soft
Terminalia superba	0.478 ± 0.024	Combretaceae	Wood greyish-white, turning pale yellowish-brown, often with dark streaks: strong but easily worked.
Buchozia curiacea	0.503 ± 0.02 1	Capparaceae	Yellowish-white, soft and somewhat fibrous
Diosprosdendo	**0.504 ± 0.027**	**Ebenaceae**	
Crescentia cujete	0.520 ± 0.0 19	Bignoniaceae	Wood is light brown with darker veins, soft, tough and flexible.
Harungana madagasceriensis	0.532 ± 0.066	Guttiferae	
Morinda lucida	0.535 ± 0.005	Rubiaceae	Yellow and hard
Prosopis africana	0.547 ± 0.027	Mimosoideae	Very hard and tough, rich red-brown with grey sapwood
Vitex doniana	0.554 ± 0.031	Verbinceae	Whitish to light brown, soft
Alchornea cordifolia	0.564 ± 0.048	Euphorbiaceae	
Terminalia ivorensis	0.571 ±0.036	Myrtaceae	Yellow, working easily
Celtic zenkeri	0.592 ±0.024	Ulmaceae	Yellow, hard and close grained
Daniella oliveri	0.598 ± 0.014	Caesalpinioideae	Sapwood whitish, heatwood red brown with dark streaks, sweetly scented
Cola hipsida	0.611 ±0.098	Sterculiaceae	
Manilkara obovata	0.623 ± 0.031	Sapotaceade	Deep red wood, hard, heavy, durable, resistant
Cassia sieberiana	0.625 ± 0.0 17	Caesalpinioideae	Hard and heavy
Entandrophragma utile	**0.625 ± 0.110**	**Meliaceae**	**Useful mahogany**
Nauclealatifolia	0.627 ± 0.028	Rubiaceae	Darker yellow and hard
Parkia biglobosa	0.629 ± 0.0 13	Mimosoideae	
Detarium microcarpum	0.629 ± 0.037	Caesalpinioideae	Dark brown, tough and hard
Tecoma stans	0.641 ± 0.146	Bignoniaceae	Wood light brown with darker vein
Pentadesma butyracea	0.642 ± 0.032	Guttiferae	Fairly hard, sapwood pale heartwood dark brown
Albizie adianthifolia	0.649 ± 0.040	Mimosoideae	Wood rather soft, heartwood yellow- brown, sapwood whitish
Ficusplatyphylla	0.664 ± 0.0 15	Moraceae	
Topinanthus globiferus	0.668 ± 0.064		
Parkia bicolor	0.670 ± 0.024	Mimosoideae	Dirty yellow, very light in weight
Albizieferruginea	0.687 ± 0.026	Mimosoideae	Wood reddish-brown
Myrianthus aboreus	0.706 ± 0.076	Moraceae	Wood yellowish white, soft and fibrous
Afzeliaafricana	0.715 ± 0.011	Caesalpinioideae	Wood hard, tough and heavy
Penthaclethra macrophylla	0.784 ± 0.020	Mimosoideae	Reddish brown, very hard
Eucalyptus globules	0.786 ± 0.021	Myrtacae	
Spathodea campanulata	0.786 ± 0.101	Bignoniaceae	White or pale, soft and fibrous

Brastegia eurycoma	0.794 ± 0.05 1	Caesalpinioideae	Wood pinkish-brown, with rather vague bands and distantly spaced fine streaks; hard and fairly heavy.
Pycnanthus angolensis	0.864 ± 0.038	Myristicaceae	
Nauclea diderichii	0.896 ± 0.074	Rubaiceae	Wood golden yellow, hard and durable.
Lophira lanceolate	0.897 ± 0.018	Ochnaceae	Reddish, tough, very durable
Piptadeniastrum africanum	**0.963 ± 0.069**	**Mimosoideae**	**Golden brown with coarse open grain**
Erythrophleum suaveolens	1.069 ± 0.04 1	Caesalpinioideae	Reddish, very hard and heavy
Khaya senegalensis	1.106 ± 0.036	Meliaceae	Typical reddish brown mahogany
Irvingia smithi	1.111 ± 0.039	Irvingiaceae	Wood pale brown, very hard and fine- grained.

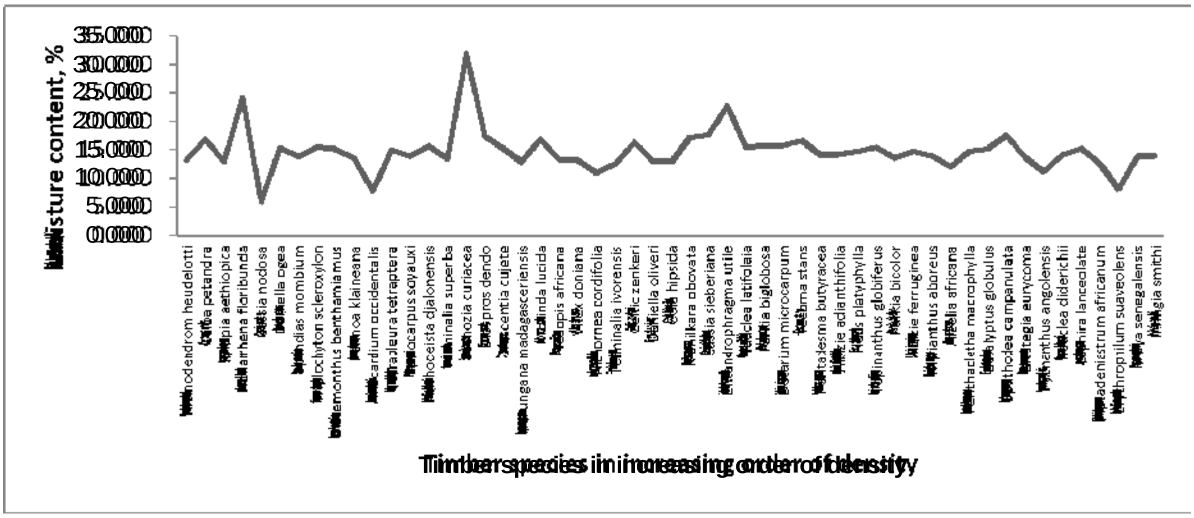
Figure1: *Plot of the oven dry and wet densities of the timber species studied.*

Figure 2: *Plot of moisture content vs. oven-dry density of timber species.*

It is observed that the moisture contents of the timbers were relatively similar(Figure 2), with an average value of 14.8 19 ± 3.710% which is higher than moisture value of air dry wood i.e.12%. The equilibrium moisture content a wood attains is dependent on the relative humidity and



temperature of the surrounding environment. Timbers such as *Cassia nodosa* (6.019%), *Anacardium* occidentalis (7.848%), and Erythrophilum *suaveolens*



(8.230%) had MC values much lower than air dry wood while those for *Entandrophragma utile* (22.83%), *Hollarrhena floribunda* (24.25%) and *Buchozia curiacea* (31.95%) were much higher. This may be attributed to the chemical composition of the individual wood and the void volumes [Siau, 1971]. Oily parchewere visible on the ovev-dried cubes of *Buchozia curiacea, Celtic zenkeri,* *Daniella oliveri* and *Entandrophragma utile*.

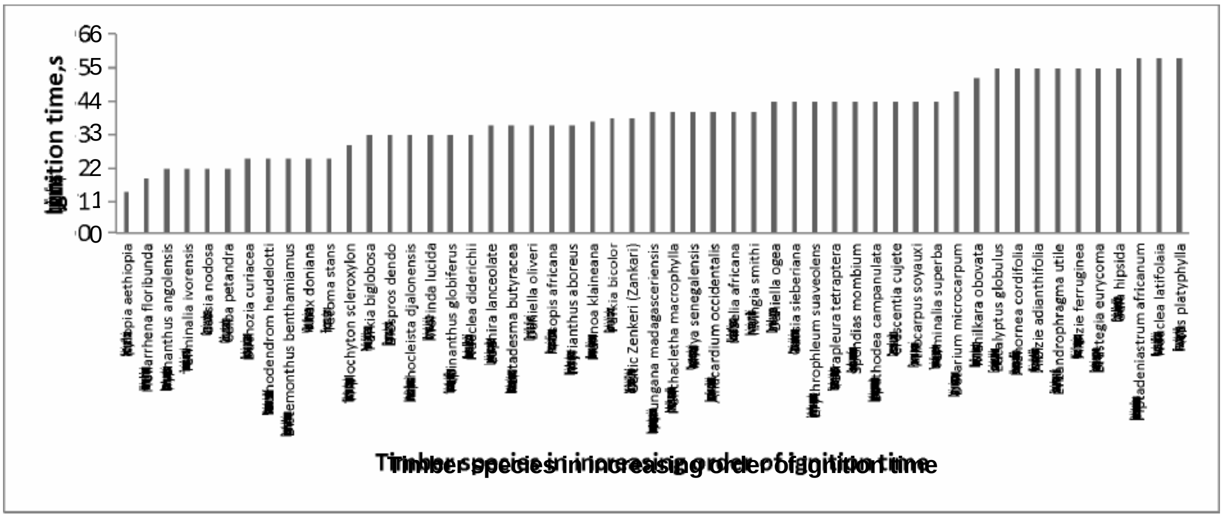


Figure 3: *Plot of the ignition time for various timber species.*

On the average the timbers have the ignition time of 3.6 1.0 s. The general observation that the ignition of light wood species is quicker than heavy species is evident (Figure 3), though a very weak positive correlation (0.152) is indicated. It is observed that there was somewhat direct relationship between oven-dry density (ODD) and ignition time (Figure 4).

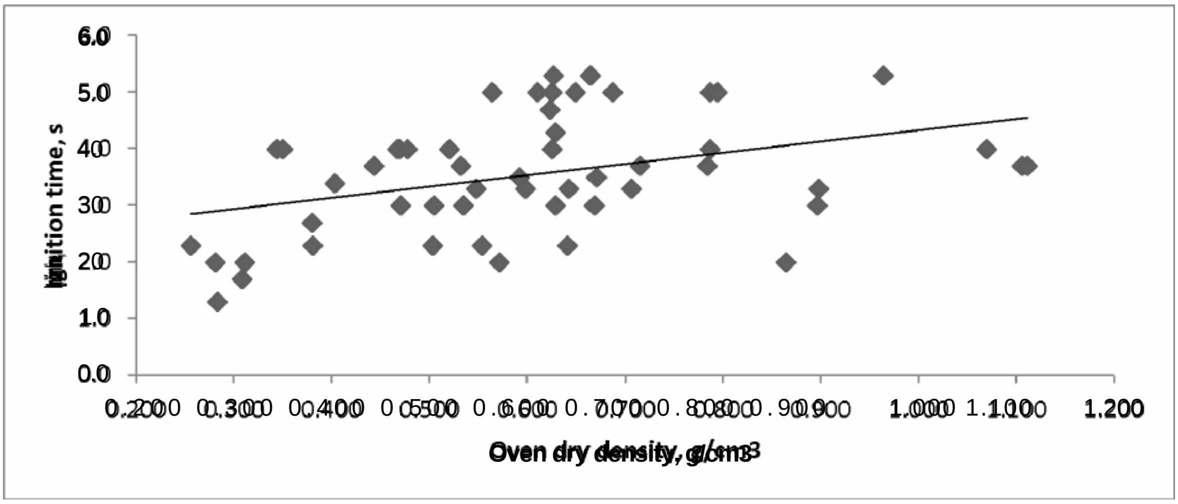


Figure 4: *Plot of ignition time vs. ovendry density of variuos timber species.*

This effect of density on ignition time has been widely reported [Babrauskas, 2001; White, 2000]. In this work,some species, however, have similar densities but different ignition times e.g. *Alchornea cordifolia* (0.564 g/cm^3, 5.0s) and *Terminalia ivorensis* (0.571 g/cm^3, 2.0s) *as well as Parkia biglobosa* (0.629 g/cm^3, 4.3s) and *Detarium microcarpum* (0.629 g/cm^3, 3.0s). This may be attributed to effects of morphological differences such as chemical composition, void volume within the cell walls, early wood: late wood ratios and resin contents. Low density woods theoretically burn more rapidly than denser woods because the high insulation value (as internal voids) reduce the heat loss from the burning zone, resulting in lower surface temperatures [Momoh et al, 1996].

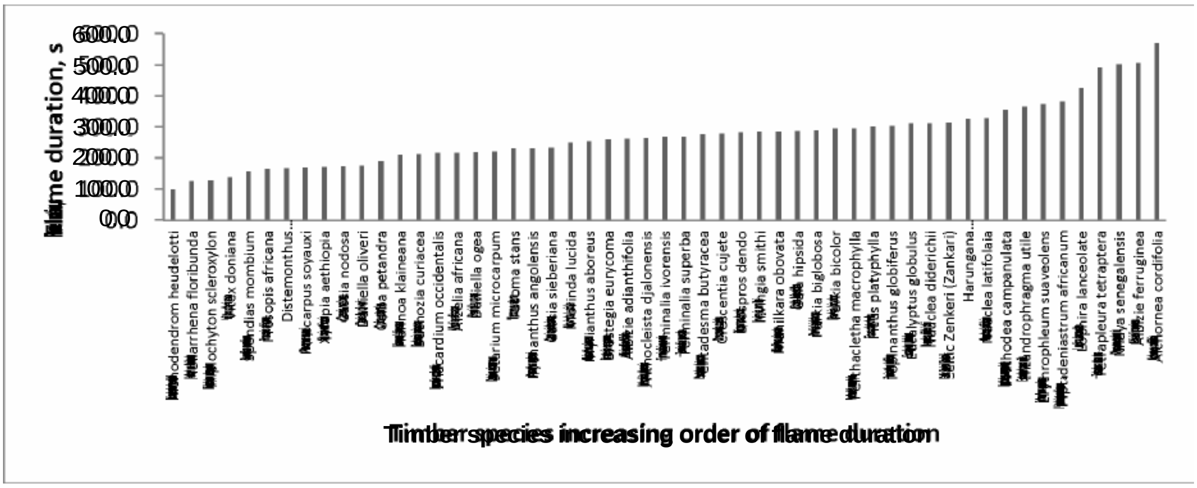
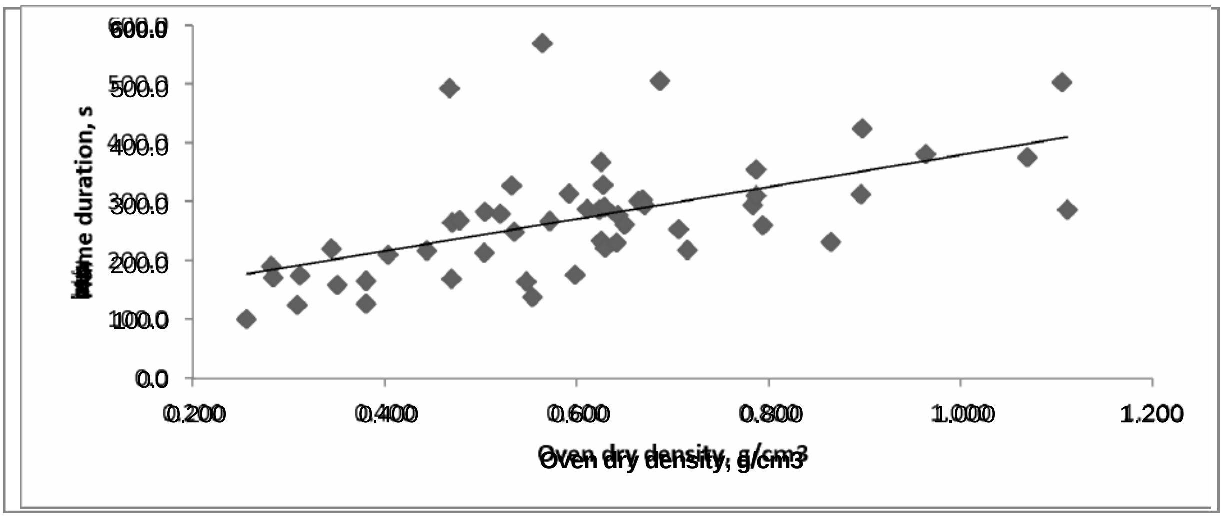


Figure 5: *Plot of the flame duration for various timber species.*

Figure 5 indicates that the flame duration of the species were within the range of 100.7s to 569.9s, with an average value of 273.0 99.9 s. Timbers having the least flame duration are *Ricinodendrom heudelotti* (100.7s), *Hollarhena floribunda* (125.3s), *Triplochyton scleroxylon* (127.7s) and *Vitex doniana* (138.3s) while *Alchornea cordifolia* (569.9s), *Albizie ferruginea* (506.7s), *Khaya senegalensis* (503 .7s) and *Tetrapluera tetraptera* (493.5s) had higher capacity of retaining the flames. A direct relationship was evident between ODD of timbers and flame duration (Figure 6). The timber species that had the highest flame duration values were mostly of medium density except for *Khaya senegalensis* which is quite dense. This shows that though the effect of density cannot be overlooked in determining the fire characteristics of timber, other factors such cellular structure, molecular composition and timber extractives deserve special attention in explaining these results [White, 2000; Eboatu & Altine, 1991; Babrauskas, 2001].

Figure 6: *Plot of flame duration vs. ovendry density of variuos timber species.*



The following timbers: *Spondias mombium* (0.30 cm/s), *Vitex doniana* (0.34 cm/s), *Triplochyton scleroxylon* (0.37 cm/s), *Hollarrhena floribunda* (0.38 cm/s) and *Ricinodendrom huedelotti* (0.47 cm/s) which had high FPRs showed ready ignitability (Figure 7).

White [2000] observed that the same factors govern ignition and flame spread such as the internal structure concentration of the materials, the direction of flame travel, and the intensity of the external heat source and air flow, amongst others. Low FPRs is attributable to many factors such as the ability of the wood sample to exude non-combustible or flame retardant liquid on heating and evolution of pyrolysates that are difficultly ignitable.

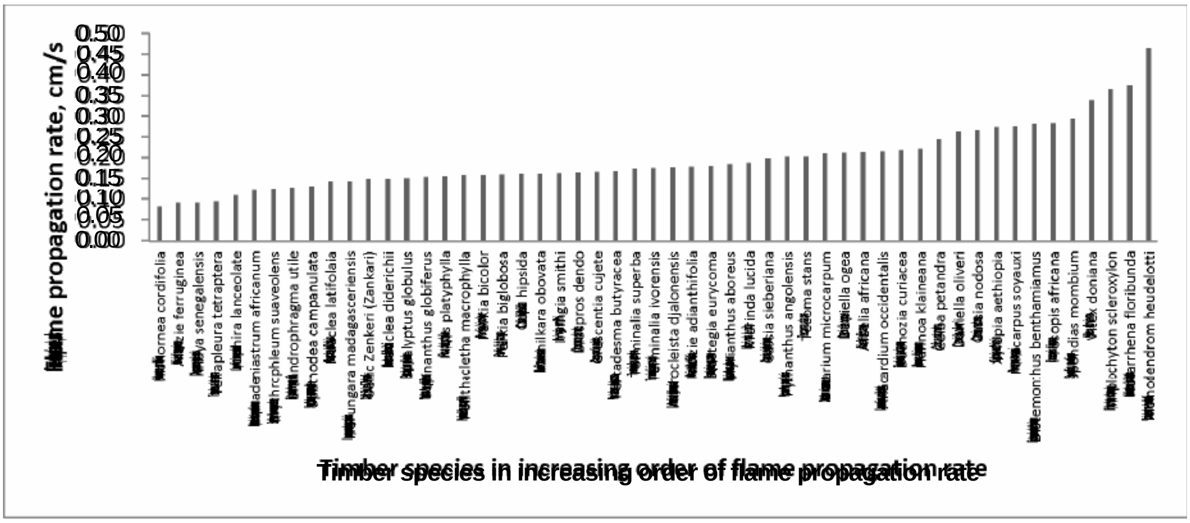
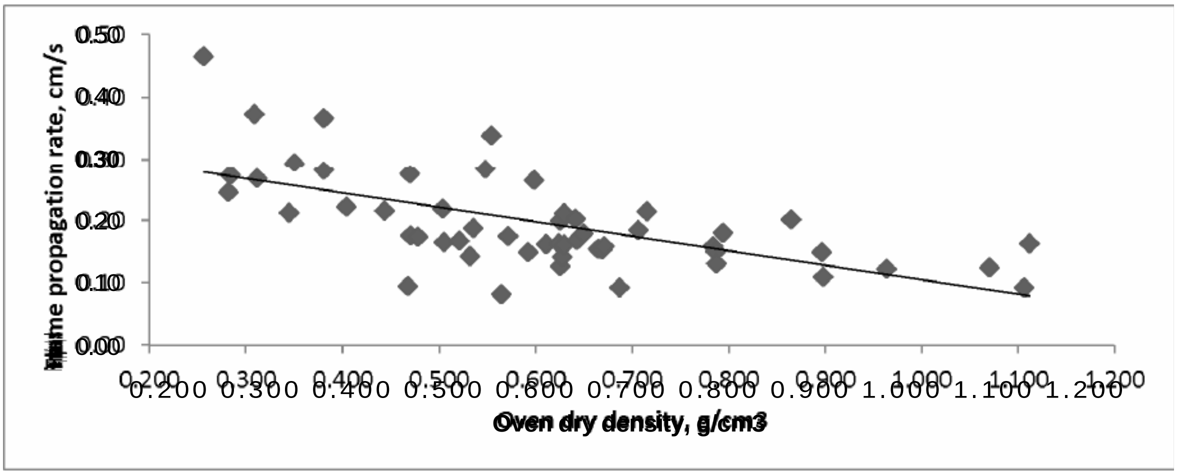


Figure 7: *Plot of the flame propagation rate for timber species.*

Also the effect of density on FPR (Figure 8) proposes that as the porosity index of the timber species decreased with increase in density, the rate of flame spread was reduced accordingly. These timbers can be termed as being fire-tolerant since they have FPR values below 0.28cm/s [Momoh et al, 1996].

Figure 8: *Plot of flame propagation rate vs. ovendry density of variuos timber species.*

The porous structure of wood allows moisture to transfer heat by evaporation and condensation through the system, acting as a biological heat pipe. In addition, cracking plays a major role in



exposing new surfaces, while ash formation acts as an insulator and radiation shield. All these factors, amongst others, affect the duration of smouldering fires [Fristom, 1995].

Glow is a heterogeneous surface oxidative process and is potentially as dangerous as naked flame. The very low **after-glow time for *Erythrophleum suaveolens* (12s) implies it is not a good charcoal former but less a danger** than, say *Irvingia smithii* (425s), another high density timber (Figure 9). Worthy of note is the high after-glow time values of *Cassia sieberiana* (969.3s) and *Buchozia curiacea* (557.3s).

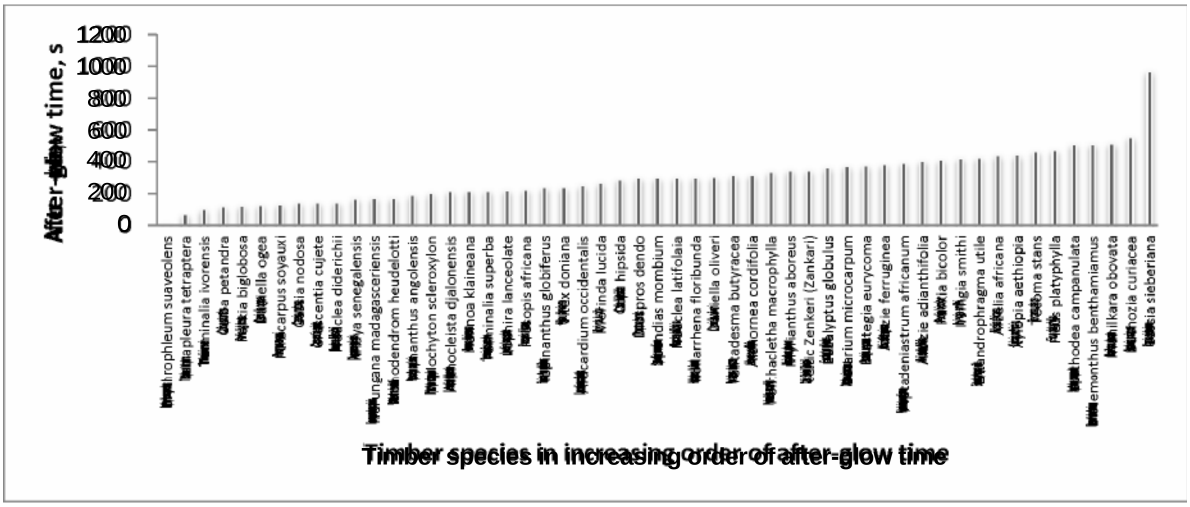
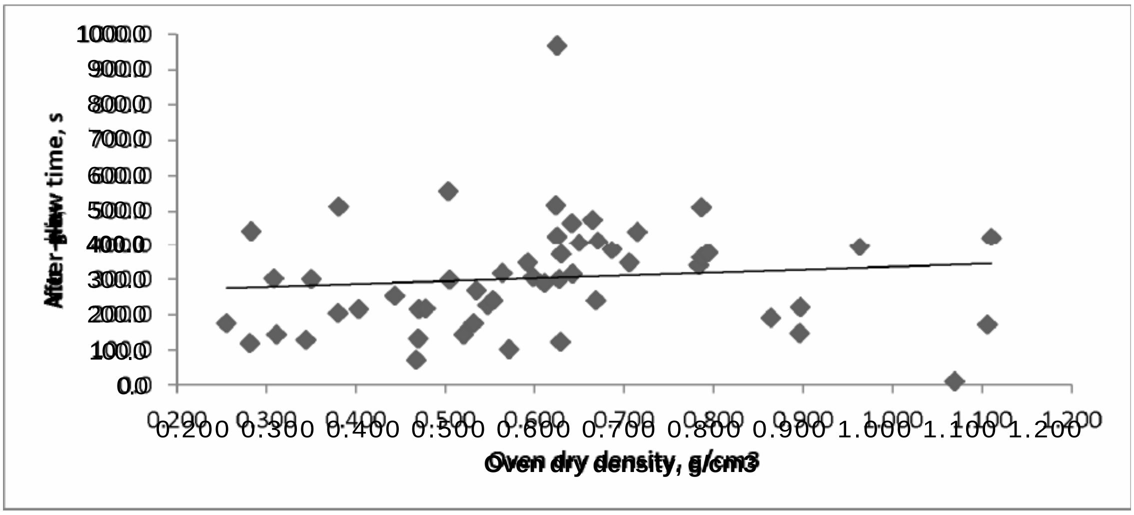


Figure 9: *Plot of the after-glow time for various timber species.*

Figure 10 shows a very weak correlation between the after-glow time of timbers and their densities. The positive correlation of after-glow time to ODD is more highly inferred when considering only the medium density timbers species than the whole timbers (R^2 = 0.198 for only medium density and R^2 = 0.10 for all others).

Figure 10*: Plot of after-glow time vs. ovendry density of variuos timber species.*



IV. Conclusions

This study investigated the flammability characteristics of fifty-three Nigerian timbers and the following conclusions could be drawn:

- Most of the timbers are of medium density; *Ricinodendrom huedelotti* is least dense (0.256 g/cm^3) while *Irvinga smithii* is the most dense (1.111 g/cm^3*).*

Variations in density are also observed between species of a given genus.

- The low density timbers are whitish in colour and got darker to yellowish and reddish brown to the denser timbers, though there were a few exceptions.
- The anisotropic character of wood was quite evident, though some general tenets were obeyed. There is somewhat direct relationship between oven-dry density and ignition time, flame duration, and afterglow time, while an inverse trend exists with flame propagation rate.
- Timbers such as *Cassia nodosa* (6.019%), *Anacardium* occidentalis (7.848%), and Erythrophilum *suaveolens* (8.230%) had low MC values while those for *Entandrophragma utile* (22.83%), *Hollarrhena floribunda* (24.25%) and *Buchozia curiacea* (31.95%) are much higher. Water imbibition capacity reduced as the density of timbers species increased.

- *Spondias mombium* (0.30 cm/s), *Vitex doniana* (0.34 cm/s), *Triplochyton scleroxylon* (0.37 cm/s), *Hollarrhena floribunda* (0.38 cm/s) and *Ricinodendrom huedelotti* (0.47 cm/s) have higher FPRs and show higher ignitability.
- Ignition time for these wood samples are similar, average of 3.6 1.0 s; the most easily ignited ones being *Xylopia aethiopia* and *Hollarhena floribunda* while *Piptadenastrum africanum,, Nauclea latifolia* and *Ficus platyphylla* were the least.
- Timbers having the least flame duration are *Ricinodendrom heudelotti, Hollarhena floribunda* and *Triplochyton scleroxylon* while *Alchornea cordifolia, Albizie ferruginea, Khaya senegalensis* and *Tetrapluera tetraptera* had higher capacity of retaining the flames.
- The very low after-glow time for *Erythrophleum suaveolens* (12s) implies it is not a good charcoal former but less a danger than, say *Irvingia smithii* (425s), another high density timber. Notably the high after-glow time values of *Cassia sieberiana* (969.3s) and *Buchozia curiacea* should be of concern to **the building safety (557.3s).**
- The recommended practice is that the quality needed for a particular function can be specified and timbers can then be selected from the orderly graded system developed to serve the interests of the users and the producers.
- A comprehensive understanding of the chemical composition of timber species is necessary for developing a database for flame properties of wood. The use of alternative hardwoods with high density is recommended with its attendant flame characteristics.

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