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A Comparative Study between Flame Propagation Rate (FPR) and Oven Dry Density (ODD) as Fire Characteristics of Some Tropical Timbers

EI Okoye[1], AN Eboatu[2]

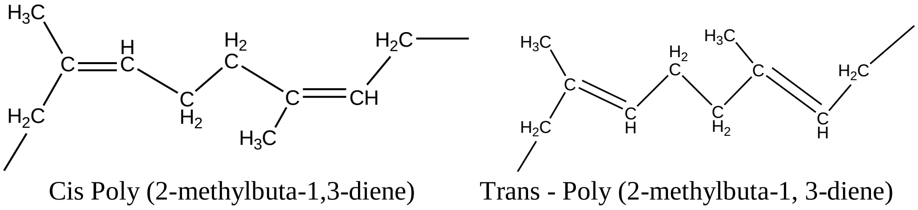
[1]Department of Pure and Industrial Chemistry ,Chukwuemeka Odumegwu Ojukwu University, Uli.
[2]Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka; Anambra State, Nigeria.

Abstract Timber is an essential raw material needed in constructing one thing or the other in all fields of human endevour. It is combustible. In this research, fire characteristics of fifty-seven (57) tropical timbers were investigated. The characteristics studied are: flame propagation rate and oven dry density. The tropical timbers with the highest FPR and ODD are P. Americana and Manilkara respectively while the ones with the least of these fire characteristics were *G. arborea* and *B. bonopozense* respectively. Although some tropical timbers with lower ODDs possess high flame propagation rate, some of the timber with higher ODDs possess lower flame propagation rate, it can be said that there is neither inverse nor direct relationship between the flame propagation rate of the tropical timbers and their oven dry densities. Though density is an important factor, in determining the fire characteristics of timber, the cellular structure, molecular composition, orientation of fiber (direction of grain) and timber extractives (*e.g.* resins) deserve a special attention in explaining the results. In this work, identification of the timbers that are fire resistant and otherwise are compared with respect to flame propagation rate (FPR) of these tropical timbers with their oven dry densities.

Keywords Tropical timbers, flame propagation rate, oven dry densities, fire characteristics, fire resistant and non-fire resistant timbers.

Introduction

A tree is a large, woody plant, with a main stem called a trunk, which does not usually branch until several feet from the ground. Trees are also perennials and are taller than shrubs. It is sometimes difficult to distinguish a shrub from a tree, for there are some plants like *Croton and Baphia nitida* which usually remain as shrubs but may occasionally grow as tall as a tree. The size of tree also varies with the climate and the depth and type of soil in which it grows [1]. Many bioactive compounds which are of biological, biochemical, industrial, commercial, agricultural and domestic importance had been derived from trees (plants). Trees are the main sources of beverages. Beverages are mild, agreeable and stimulating liquor meant for drinking. Examples of non-alcoholic beverages are tea, coffee and cocoa [2]. *Rubber is obtained* from the latex of *Hevea brasiliensis,* a big tree, which is the main source of commercial rubber. *Hevea brasiliensis* is a native of the Amazon Region of Brazil but it is nowadays grown in plantations in different parts of the world, *e.g.* Nigeria, Sri Lanka and Malaysia. Natural rubber is a type of hydrocarbon known as a polyterpene, $(C_5H_8)_n$, and exists in two isomeric forms.



Cis Poly (2-methylbuta-1,3-diene) Trans - Poly (2-methylbuta-1, 3-diene)
Cis –Polyisoprene (Elastic form) Trans – Polyisoprene (Nonelastic form)

Cellulose is the basic constituent of paper. It is obtained from the wood of various trees. Wood is used in the manufacture of these materials: printing paper, writing paper, newsprint, wrapping paper, cardboard and poster paper. Alcohol, known as ethanol is extracted from palm trees. It can also be synthesized from wood (saw dust) by fermentation process; saw dust is a cellulosic material. It can be hydrolyzed to glucose by the addition of dil. H_2SO_4 and steam at about a pressure of 6 atmospheres.

Ethanol is a good solvent used to dissolve soaps, perfumes, flavouring extracts, dyes, varnishes, drugs etc. It is also used in the manufacturing of alcoholic drinks such as wines, beers and spirits (*e.g.* gin, whisky, rum, brandy etc). Ply wood is made of a number of veneers (laminations) which are glued together with the grain of each at right angles to its neighbour and then placed in a press. A variety of timbers is used in making plywood.

Trees are of paramount importance worldwide in that they are both biologically and economically important to man. Biologically, plants (trees) and animals (including man) live an interdependent life. This can be seen in the area of: (i) Taking in of carbon (iv) oxide and giving out oxygen, (ii) Synthesis of food, (iii) Animals die and decay to form plant food [3].

$$\mathbf{6CO_2 + 6H_2O + Energy \longrightarrow C_6H_{12}O_6 + 6O_2}$$

Trees manufacture food by the process of photosynthesis. Trees are indispensable sources of both coarse and fine fibres used in the manufacture of cloths or garments.

Camphor is obtained from the wood and leaf of *Cinnamomum camphora,* a tall tree of China, Japan and Taiwan origin. It has a characteristic strong but agreeable odour and is widely used in very small quantities in perfumery and medicines [4]. Cinnamon is the dried brown bark peeled off from *Cinnamomum zeylanicum,* a small tree of Ceylon. It is aromatic and tastes sweet. It is extensively used for flavouring foods and vegetables. Cinnamon oil is extracted from the bark and leaf of *cinnanomum* tree. It is used in combination with certain drugs as an intestinal antiseptic [2].

Experimental Procedures: Sample collection and preparation: The fifty-seven (57) tree species samples were collected from eleven states in Nigeria. The states are: Anambra, Imo, Enugu, Sokoto, Katsina, Kano, Kebbi, Yobe, Edo, Zamfara and Gombe. The map showing the states in Nigeria are shown in Fig.1.

Figure 1: Map showing the thirty-six (36) states in Nigeria

Some of the tree species were living trees cut down. Some were the already felled trees. Dulmer machine was used to cut out part of the tree drunk. Thirty-two timbers were obtained from the timber sheds or saw mills at Onitsha, Nnewi and Awka. The states from where these timbers were collected were ascertained from the timber dealers. The tree species were authenticated by the Forest Officer in each of the State or the Local Government

Area where the timbers were collected. The timber dealers or the saw millers were able to say the botanical names of few timbers collected from the timber shed. Most of the timbers collected there were taken to the Forest Officer in that Local Government Area where the tree species were got. By mentioning the local or common name of tree species and by having a look at the parts of tree species, the Forest Officers were able to say the botanical names of the tree or timber species.

After the collection and authentification, they were occasionally conveyed to the saw mill where each timber was cut into two different shapes and sizes; these are:

(i) Splints of dimensions of 30cm x 2.5cm x 0.6cm

(ii) Cubes of dimensions of 2.5cm x2.5cm x 2.5cm. The splints of timber were dried in an oven at 105^0C for 48hours before the experiment. American Standard for Testing and Materials (ASTM) was employed in the analysis. The picture of the saw mill used is in Figure 2.

Figure 2: Photograph of saw mill at Ihiala

Determination of the Flame Propagation Rates (FPR) of the timber

The splints of the timbers were used. They were dried in an oven at 105 ^{o}C for 48 hours. Three splints of timbers were selected from each of the tree species. Each splint was clamped vertically. Cigarette lighter was used to supply a steady flame at the base in a draught-free room. Immediately the splint was ignited, the cigarette lighter was withdrawn. The splint was allowed to burn for sometime till the flame was off. If the flame did not quench on its own, air was blown to it in order to quench it. The distance travelled by the char front along the surface of the splint was recorded. The distance travelled was obtained by subtracting the remaining length of the splint from the original length. The time interval from the ignition time till the time when the flame was off was also read in second. The rate of flame propagation or spread or linear surface flame velocity was calculated as the vertical distance traversed per second. For each tree species, three readings were obtained. The average of the three readings was recorded as the flame propagation rate. The results obtained were in Tables and Figures.

$$Flame\ velociey = \frac{\text{Distance traveled by the char front (cm)}}{Time\ \text{(sec)}}$$

Determination of Oven Dry Density (ODD)

Three 2.5 cm cubes of each timber were randomly selected from one hundred and eighty cubes of the tree species. Each was weighed with Top loading balance, Model: PL 203, Make: Mettler Toledo. After recording the initial weight, the sample was transferred into the drying oven at the temperature of 105 ^{o}C. The sample was left in the oven for three hours. After the heating, the oven was switched off, and the sample left overnight to cool. The sample was re-weighed after twelve hours. Care was taken to ensure that sample did not absorb moisture before and during weighing. After recording the second weight for each, the samples were taken back into the oven for another 3 hrs at that same temperature. This was repeated until any two subsequent weights were equal i.e. constant weight attained. Three cubes of each tree species were tied together with a copper wire and weighed as a single entity. Cu wire was removed and the three samples re-weighed. The weight of a cube was obtained by calculating the average of the three samples of each tree species. The dimensions of the three 2.5 cm cubes were measured and the volume of each was calculated. The average volume of the three samples was recorded as the volume of each sample of the timbers. Finally the oven dry density of each tree species was determined by dividing the average dry weight of the three samples by the average volume of three samples.

$$ODD = \frac{\text{Average dry wt of samples g/dm}^3}{\text{Average volume of samples}}$$

Results and Discussion

The results of the investigations carried out in this work are given in Tables 1 and 2, and Figures 3 and 4.

Discussion

The thermal characteristics of tropical timbers investigated in this research include; flame propagation rate **(FPR)** and oven dry density **(ODD)**.

Table 1: Names of the selected fifty-seven (57) tropical timbers from Nigeria

Tree species No	Botanical name	Common name	Vernacular names
1.	*Cola nitida*	Colanut	Ibo - oji, Hausa – goro Yoruba - obi gbanja, Nupe – Chigban'bi
2.	*Newboldia levis*		Ibo – Ogilisi, Hausa – aduruku, Yoruba – akoko,Benin – Ikhimi
3.	*Crysophyllum albidium*	White Star apple	Ibo – udala Yoruba-Agbalumo,Edo-Otien
4.	*Treculia africana*	African bread fruit	Ibo – ukwa
5.	*Psidium guajava*	Guava	Ibo – gova
6.	*Citrus sinensis*	Sweet orange	Ibo – oloma
7.	*Dacroydes edulis*	Native pear	Ibo – ube
8.	*Chlorophoro exelsa*	Iroko	Ibo – orji, Hausa – loko, Yoruba – iroko, Benin – uloko Nupe – rook,Ijwa – olokpata
9.	*Gaeis guineensis*	Oil palm tree	Ibo – nkwu
10.	*Cocus nucifera*	Coconut tree	Ibo – aku oyibo
11.	*Persea Americana*	Avocado pear	Ibo – ube oyibo
12.	*Irvingia smithii*		Ibo – ogbono
13.	*Irvingia gabanensis*		Ibo – ugiri, Yoruba – Oro, Benin – Ogwe, Efik – Oyo Nupe – pekpeara,Ijaw – ogboin
14.	*Caesalpina pulcherima*	Pride of Barbadose	
15.	*Terminalia catappa*	Umbrella tree or Indian Almond	
16.	*Spathodea campanulala*		Ibo – echichii
17.	*Ricinovenvron heudenocii*		Ibo – okwe
18.	*Ficu natalensis*		Ibo – ogbu
19.	*Banbax bonopozense*		Ibo – Akpu ,Yoruba – Puopola,Benin – oboidia Ijaw – idoundu
20.	*Ceiba petandra*	Silk cotton plant	Ibo – akpu ogwu,Yoruba –

			araba,Benin – okha, Efik – ukem Ijaw – afalafase
21.	*Cola gigantia*		Ibo – ebenebe, Hausa – bokoko, Yorubo – ogugu, Benin – ukpokpo, Efik – dikir, Ishan – abolo
22.	*Acacia nilotica*	Cacia	Hausa – bagaruwa, Kanuri – kangari,Fulani – gaudi
23.	*Nauclea diderrichii*		Ibo – uburu mmiri, Yoruba – opepe, Benin – obiakhe, Ijaw – owoso,Urhobo – urherekor
24.	*Gmelina arborea*	Bushbeech or Meligna	Ibo – malina,
25.	*Pteracarpus soyauxi*		Ibo – oha
26.	*Annoa senegalensis*		Ibo – oghulu, uburu ocha, Yoruba – abo,Hausa – Swandar daji,
27.	*Canarium schwanfurthii*		Ibo – ube okpoko
28.	*Pinus carribean*	Whispering pine	
29.	*Albizia ferruginea*	Albizia	Ibo- Ngwu or ngu Yoruba – Ayinre oga, Benin – uwowe
30.	*Brachystegia Nigeria*		Ibo – ufi, Yoruba – akolodo,Benin – okwen, Ishan – eku Ijaw – akpakpa, Efik – ukung,Boki – kpeunik, Ekoi – etare
31.	*Dialuim guineensis*		Ibo – icheku
32.	*Napoliana vogelii*		Ibo – nkpodu
33.	*Accio bateri*		Ibo – araba
34.	*Brachystigia eurecomya*		Ibo – achi mkpuru,Yoruba – akolodo,Benin – okwen Ijaw – akpakpa,Ishan – eku,Ekoi – etare, Boki – kepuruk Efik – ukung
35.	*Pluneria africana*		
36.	*Walteria americana*		
37.	*Azadirachta indica*	Neem plant	Hausa – dogonyaro
38.	*Khaya senegalensis*	Mahogany	Hausa – madacu
39.	*Manilkara*		Ibo – ukpi
40.	*Alstonia congensis*		Ibo – egbu
41.	*Tectona grandis*	Teak	
42.	*Mansonia altissima*	Mansonia Iron tree	Yoruba-ofun
43.	*Isoberlinia tomentosa*	Berlinia	Ibo – uboba, Hausa – faradoka (white doka) Nupe – baba
44.	*Isoberlinia doka*	Berlinia	Ibo – ububra ibu, Hausa – doka Nupe – babarochii bokun, Tiv – mkovol
45.	*Garcinia kola*	Bitter kola	Ibo – ugolo/adi, Yoruba – orogbo Benin –edun, Efik – efiari,

			Ijaw – okan Ibibio – efiat
46.	*Garcinia gnetoides*	Wild ugolo	Ibo – ugolo agho
47.	*Baphia nitida*		Ibo – aboshi ojii, Yoruba – irosun,Benin – otun, Efik – ubara Ijaw – abodi, Itsekiri – orosun, Urhobo – arhua
48.	*Baphia gracilipes*		Ibo – aboshi ocha
49.	*Terminalia brownie*	Congo afara	Ibo – edo, Hausa – baushe,Yoruba – idiodan
50.	*Terminalia superba*	Akmond tree (white afara)	Ibo – edo, Yoruba – afara,Benin – egboin nofua, Efik – afia eto,Ijaw – gbarada, Nupe –eji,Urhobo – unwonron
51.	*Terminalia glaucescens*	Black afara	Ibo –edo, Hausa – baushe,Yoruba – idiodan
52.	*Mangifera callina*	Kerosene mango	
53.	*Mangifera banganpalli*	Ordinary mango	Ibo – mango nkiti
54.	*Mangifera indica*	Mango with fibre	Ibo – opiolo mango
55.	*Mangifera indica*	Gernan mango	
56.	*Pentaclethra macrophyllum*	Oil bean tree	Ibo – ukpaka
57.	*Nauclea popeguinii*		Yoruba – opepe

Table 2: Flame propagation rate and ODD of fifty-seven (57) tropical timbers.

Tree species No	**Botanical name**	**FPR Flame Propagation Rate x 10^{-2} cm/Sec**	**ODD Oven dry density x 10^{-2} g/cm^3**
1.	*Cola nitida*	4.5	66.6
2.	*Newboldia levis*	0.8	68.1
3.	*Crysophyllum albidium*	0.9	62.7
4.	*Treculia africana*	3.2	58.8
5.	*Psidium guajava*	1.4	**85.5**
6.	*Citrus sinensis*	1.3	86.5
7	*Dacroydes edulis*	0.6	51.1
8.	*Chlorophoro exelsa*	1.6	58.4
9.	*Gaeis guineensis*	2.8	59.9
10.	*Cocus nucifera*	1.6	60.1
11.	*Persea Americana*	10.4	43.4
12.	*Irvingia smithii*	0.5	81.7
13.	*Irvingia gabanensis*	0.5	87.8
14.	*Caesalpina pulcherima*	1.2	46.5
15.	*Terminalia catappa*	0.4	65.4
16.	*Spathodea campanulala*	2.2	32.0
17.	*Ricinovenvron heudenocii*	1.6	34.2
18.	*Ficu natalensis*	1.3	48.5
19.	*Banbax*	2.1	24.0

	bonopozense		
20.	*Ceiba petandra*	0.8	35.5
21.	*Cola gigantia*	1.3	54.0
22.	*Acacia nilotica*	2.2	64.6
23.	*Nauclea diderrichii*	0.5	54.1
24.	*Gmelina arborea*	0.3	58.6
25.	*Pteracarpus soyauxi*	1.3	47,5
26.	*Annoa senegalensis*	1.2	37.0
27.	*Canarium schwanfurthii*	1.0	41.3
28.	*Pinus carribean*	3.0	40.7
29.	*Albizia ferruginea*	0.8	66.8
30.	*Brachystegia Nigeria*	0.7	72.1
31.	*Dialuim guineensis*	0.8	73.1
32.	*Napoliana vogelii*	1.1	74.3
33.	*Accio bateri*	1.6	97.5
34.	*Brachystigia eurecomya*	1.1	77.2
35.	*Pluneria africana*	0.7	60.3
36.	*Walteria americana*	1.5	50.1
37.	*Azadirachta indica*	1.7	79.0
38.	*Khaya senegalensis*	0.7	77.5
39.	*Manilkara*	0.6	109.7
40.	*Alstonia congensis*	1.0	40.1
41.	*Tectona grandis*	5.0	55.1
42.	*Mansonia altissima*	0.8	59.6
43.	*Isoberlinia tomentosa*	3.0	49.6
44.	*Isoberlinia doka*	0.8	45.1
45.	*Garcinia kola*	2.6	92.1
46.	*Garcinia gnetoides*	0.5	68.3
47.	*Baphia nitida*	0.9	88.6
48.	*Baphia gracilipes*	1.6	79.2
49.	*Terminalia brownie*	1.0	69.3
50.	*Terminalia superba*	0.3	55.6
51.	*Terminalia glaucescens*	0.8	56.2
52.	*Mangifera callina*	0.9	60.9
53.	*Mangifera banganpalli*	0.9	65.3
54.	*Mangifera indica*	2.4	74.8
55.	*Mangifera indica*	5.5	44.4
56.	*Pentaclethra macrophyllum*	2.3	78.8
57.	*Nauclea popeguinii*	1.2	63.2

Figure 3 portrays the bar graph of flame propagation rate of fifty-seven tropical timbers. The flame propagation rate of these fifty-seven tropical timbers were represented in their increasing order of magnitude. It can easily be seen that the timbers with the least and highest flame propagation rates (FPR) are *G. arborea* (0.3x10^{-2}cm/sec) and *P. americana* (10.4x10^{-2}cm/sec) respectively. It is futher observed that a good number of these timbers have equal flame propagation rate. These include*; G. arborea and T. superba (0.3x*10^{-2} *cm/sec), I. smithii, I.gabanensis, N. diderrichii and G. gnetoides (0.5x*10^{-2}*cm/sec). D. edulis and Manilkara (0.6x*10^{-2}*cm/sec), B. nigeria, P. Africana and K. senegalensis (0.7x*10^{-2}*cm/sec), N. levis, C. pentandra, A. ferruginea, D. guineensis, M. altissima, I. doka and T. glacescens, (0.8x*10^{-2}*cm/sec), C. albidwn, B. nitida* and two varieties of *M. indica: kerosene mango and ordinary mango* (0.9x10^{-2}cm/sec), *C. schwanfurithii, A. congensis and T. brownie* (1.0x10^{-2}cm/sec), *N. vogelii and B. eurecomya* (1.1x10^{-2}cm/sec) etc. As pointed out earlier, the work of Panshin and coworkers held the view that there is an inverse relationship between these two characteristics [5].

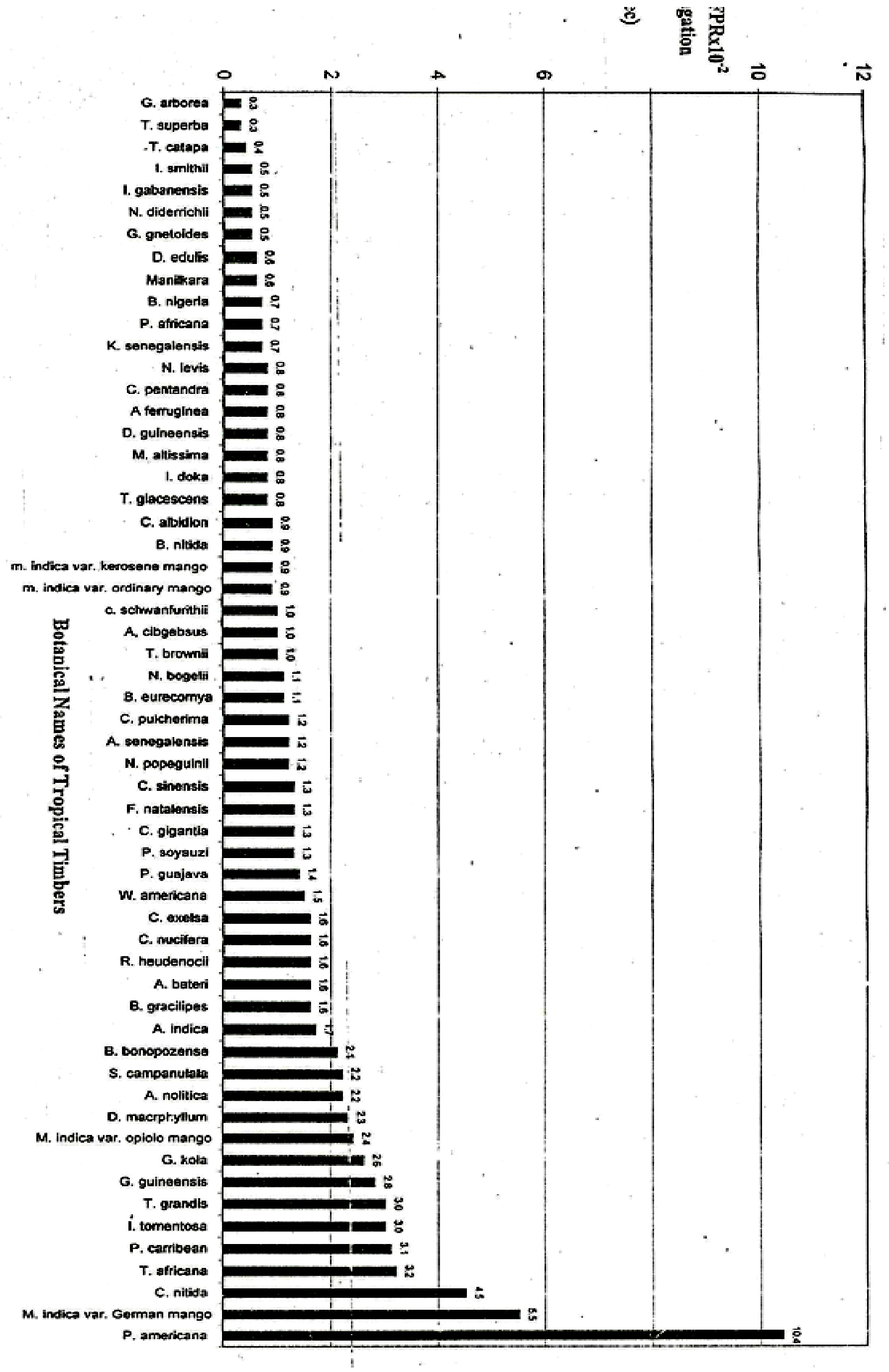


Figure 3: Graph of (FPR) Flame propagation rate of the 57 tropical timbers

In other words, heavy hardwoods takes more time to ignite than resinous softwoods. Considering the nature of arrangement of grains and the porosity nature of the heavy hard woods and light softwoods , one can see really that inverse relationship is also bound to exist between flame propagation rate and oven dry density. This means that in the absence of any other variable, the higher the ODD, the lower the flame propagation rate. The more porous the material, the greater the ease with which the material (wood) propagates flame. The thermal conductivity of the material also increases in that other. Hence increase in ODD should reduce flame-spread rate. Thus the more the density or cellular make up, the less the flame propagation rate. This is so since *dense timbers of large dimension do not burn easily as the light dimension* [6], *Dense woods burn more slowly and with less flame than light woods which tend to flare up and burn away quickly* [7].

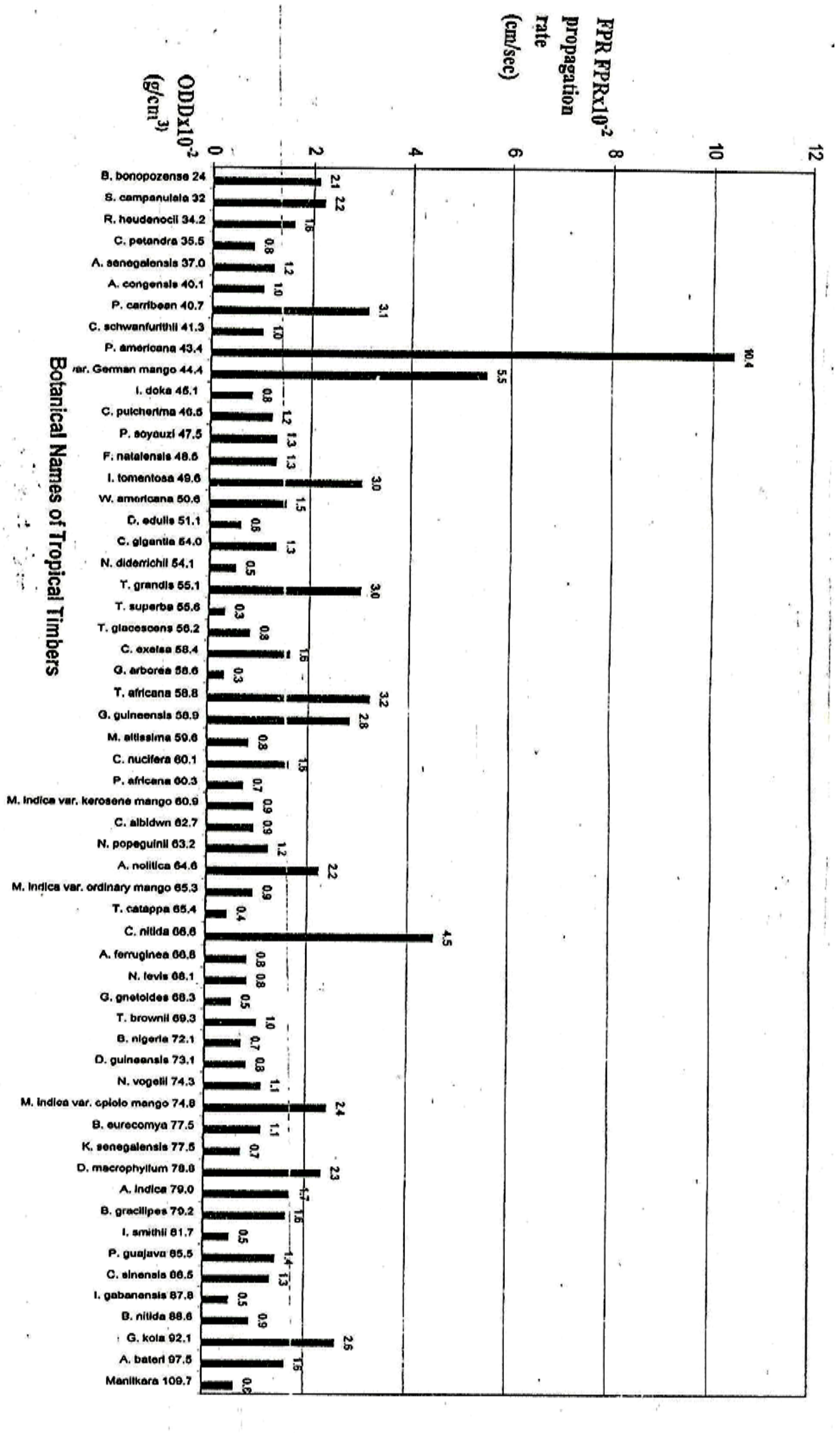


Figure 4: Graph of (FPR) vs(ODD) Oven dry density

In wood, the spread of flame generally takes place in the following manner: Heat from external source locally raises its temperature. As heat is gradually being absorbed by the wood, a stage is reached when pyrolysis starts, resulting in the production of volatile products. At appropriate oxygen-gas ratio and at the right temperature, combustion occurs. Some heat of combustion is lost to the surroundings while some heat is rechanneled back for further pyrolysis. *The rate of this pyrolysis or combustion process along the wood is the rate of flame propagation* [8]

Conclusion

Flame propagation rate of timbers should be put into consideration for one to make wise choice of timber and to guard against or minimize fire outbreak.

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