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Research Article

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Failure Analysis of Timber (Wood) in Constructional Work for Engineering Application (Thermal Conductivity (TC) and the Oven Dry Densities of Some Tropical Timbers)

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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: thermal conductivity (TC) and oven dry density (ODD). The tropical timbers with the highest of these characteristics are *C. schwanfurithii* and Manilkara respectively while the ones with the least of these fire characteristics were *F. natalensis* and *B. bonopozense* respectively. Although some tropical timbers with lower ODDs possess high TC, some of the timber with higher ODDs possesses lower TC. It can be said that there is neither inverse nor direct relationship between the TC 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 (eg resins) deserve a special attention in explaining the results. The aims and objectives of this work is to identify the timbers that are fire resistant and those that are not and to compare the TC of these tropical timbers with their oven dry densities.

Keywords Tropical timbers, thermal conductivity, oven dry densities, fire characteristics, fire resistant and non-fire resistant timbers

Introduction

In many situations the ability of a substance to resist the passage of heat, electricity, or sound, is of the greatest importance. Dry wood is one of the poorest conductors of heat, and this characteristic renders it eminently suitable for many of the uses to which it is put every day, e.g. as a building material, as internal wall paneling, sheathing in timber-frame house construction, or external wall cladding, and as handles of cooking utensils.

The transmission or conduction of heat depends on two factors: (a) the specific conductivity and (b) the specific heat of the intervening material. Although the specific conductivity of dry wood substance is low, that of timber is even lower. Wood is a cellular substance, and in the dry state the cell cavities are filled with air, which is one of the poorest conductors known. Green timber conducts heat much more quickly than dry timber of the same species because of the water present, which is a much better conductor than air. One effect of applying heat to a substance is to expand. Allowances to permit of expansion and contraction, with changes in atmospheric temperature, are made in all-metal structures such as bridges, rails, and steel-work structures generally. Woody tissue also expands with heat, but timber in use tends to shrink when heated. This apparent contradiction is easily explained. Timber in use always contains a varying quantity of moisture in the cell walls, which, on being heated, is lost to the atmosphere and, loss of moisture is accompanied by shrinkage. In consequence, although heat would cause the cell walls to expand, the loss of moisture from the walls results in shrinkage, which more than counteracts any increase in volume caused by the expansion of the woody tissue. In effect, it is not that the expansion of wood substance is low but that shrinkage is high; actually, in linear expansion along the grain, ash is almost identical with cast iron and steel, although the linear expansion of most other species is considerably less; across the grain, the linear expansion of beech is about six time as great as that of iron or steel.

The reaction of timber to heat has an important bearing on its suitability as a fire-resistant material. Because of the relatively high specific heat and poor conductivity of wood, wooden doors are often effective in preventing the spread of a fire for a considerable period. Wooden doors fail when shrinkage causes the different parts, e.g. panels, styles, and mouldings, to pull apart, leaving gaps through which flames can penetrate. Failure through shrinkage usually causes a breakdown of wooden doors long before the flames have been able to penetrate by combustion or heat by conduction. Metal doors, on the other hand, conduct heat to the opposite side so quickly, and absorb so little heat themselves in the process that they tend to pass on a fire from chamber with great rapidity unless constructed with an insulating core. In a light fire, papers filed in a steel cabinet will char and burn whereas under the same conditions those in a wooden cabinet might well come through unharmed. In spite of eventual failure, because of shrinkage, it has been shown that a well- constructed wooden structure is often efficient in retarding the progress of a fire: the distinction between retarding and resisting fire is important – wood is highly combustible, but is not highly inflammable.

Eboatu *et al* [1] studied the thermal characteristics of some tropical woods. Here, the surface flame spread rate, the afterglow time and degradation patterns of some tropical timbers found in Nigeria were investigated. Results from their studies showed that the oven dry densities of the timbers and their flame spread rates were inversely proportional. It was also found that the surface flame velocity was dependent upon the orientation of the timbers. Thermogravimetic analysis showed that all the timbers degrade in three discrete stages, the bulk of the weight losses did not appear to depend on timber density. Garba and Eboatu studied the effect of an alum-potassium aluminum sulphate, as a fire retardant on some Nigerian timbers. It was observed that flame spread rate and after-glow time were drastically reduced. Thermogravimetric analysis of those timbers showed that alum functions as a flame retardant (FR) by a complex process that entails the dehydration, condensed phase and the vapour phase mechanisms.

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.

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 authentication, they were occasionally conveyed to the saw mill where each timber was cut into two different shapes and sizes; They 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 i.e. 15.625 cubic centimeter. The splints of timber were dried in an oven at 105°C for 48hours before the experiment. American Standard for Testing and Materials (ASTM) was employed in the analysis. The

Determination of thermal conductivity of timbers by the ash method

Each clean crucible was weighed and 2.0 gram of each of the ground samples were taken in the weighed crucible. The samples were burnt on an electric plate for four hours, allowed to cool at room temperature and then reweighed. The weight of the ash was obtained by subtracting the weight of the empty crucible from the weight of the crucible and ash. The result obtained was divided by 2 gram to get the actual fraction of the ash in the weighed sample.

Weight of ash = Wt of crucible + ash – Wt of crucible

$$\text{Fraction of the ash} = \frac{\text{Wt of crucible + ash – Wt of crucible (g)}}{2g}$$

If fraction of the ash is multiplied by 100, percentage ash content is obtained.

By comparing the fraction of the ash obtained with "the Conductance Ash Table for low conductivity cells," (6) the thermal conductivity of the timber sample was obtained.

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Determination of Oven Dry Density (ODD)

Three 2.5cm 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 specie 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 specie. The dimensions of the three 2.5cm cubes were measured and the volume of each was calculated. The average volume of the three samples was recorded as the volume of each samples 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.

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

Results and Discussion

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

Table1: 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*		Ibo – ugiri, Yoruba – Oro, Benin – Ogwe, Efik –

	gabanensis		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.	*Terminaia 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: Thermal Conductivity and ODD of fifty-seven (57) tropical timbers

Tree species No	Botanical name	TC Thermal Conductivity x 10^0 µmho/cm	ODD Oven dry density x 10^{-2} g/cm^3
1.	*Cola nitida*	40.11	66.6
2.	*Newboldia levis*	435.81	68.1
3.	*Crysophyllum albidium*	1025.51	62.7
4.	*Treculia africana*	40.11	58.8
5.	*Psidium guajava*	40.11	**85.5**
6.	*Citrus sinensis*	48.12	86.5
7	*Dacroydes edulis*	21.06	51.1
8.	*Chlorophoro exelsa*	578.40	58.4
9.	*Gaeis guineensis*	32.11	59.9
10.	*Cocus nucifera*	72.18	60.1
11.	*Persea Americana*	64.16	43.4

12.	*Irvingia smithii*	111.20	81.7
13.	*Irvingia gabanensis*	88.23	87.8
14.	*Caesalpina pulcherima*	16.01	46.5
15.	*Terminalia catappa*	48.12	65.4
16.	*Spathodea campanulala*	64.16	32.0
17.	*Ricinovenvron heudenocii*	96.15	34.2
18.	*Ficu natalensis*	8.01	48.5
19.	*Banbax bonopozense*	16.01	24.0
20.	*Ceiba petandra*	586.41	35.5
21.	*Cola gigantia*	32.11	54.0
22.	*Acacia nilotica*	993.41	64.6
23.	*Nauclea diderrichii*	1060.00	54.1
24.	*Gmelina arborea*	1068.01	58.6
25.	*Pteracarpus soyauxi*	473.00	47,5
26.	*Annoa senegalensis*	1076.01	37.0
27.	*Canarium schwanfurthii*	341076.01	41.3
28.	*Pinus carribean*	224.71	40.7
29.	*Albizia ferruginea*	823.46	66.8
30.	*Brachystegia nigeria*	61973.96	72.1
31.	*Dialuim guineensis*	24.06	73.1
32.	*Napoliana vogelii*	48.12	74.3
33.	*Accio bateri*	1068.01	97.5
34.	*Brachystigia eurecomya*	775.31	77.2
35.	*Pluneria africana*	729.20	60.3
36.	*Walteria americana*	21.06	50.1
37.	*Azadirachta indica*	40.11	79.0
38.	*Khaya senegalensis*	16.01	77.5
39.	*Manilkara*	985.40	109.7
40.	*Alstonia congensis*	834.60	40.1
41.	*Tectona grandis*	21.06	55.1
42.	*Mansonia altissima*	21.06	59.6
43.	*Isoberlinia tomentosa*	32.11	49.6
44.	*Isoberlinia doka*	608.40	45.1
45.	*Garcinia kola*	8.01	92.1
46.	*Garcinia gnetoides*	61.01	68.3
47.	*Baphia nitida*	32.11	88.6
48.	*Baphia gracilipes*	32.11	79.2
49.	*Terminalia brownie*	21.06	69.3
50.	*Terminalia superba*	80.22	55.6
51.	*Terminalia glaucescens*	149.31	56.2
52.	*Mangifera callina*	40.11	60.9
53.	*Mangifera banganpalli*	80.22	65.3
54.	*Mangifera indica*	57.21	74.8
55.	*Mangifera indica*	518.00	44.4
56.	*Pentaclethra macrophyllum*	111.20	78.8
57.	*Nauclea popeguinii*	1025.51	63.2

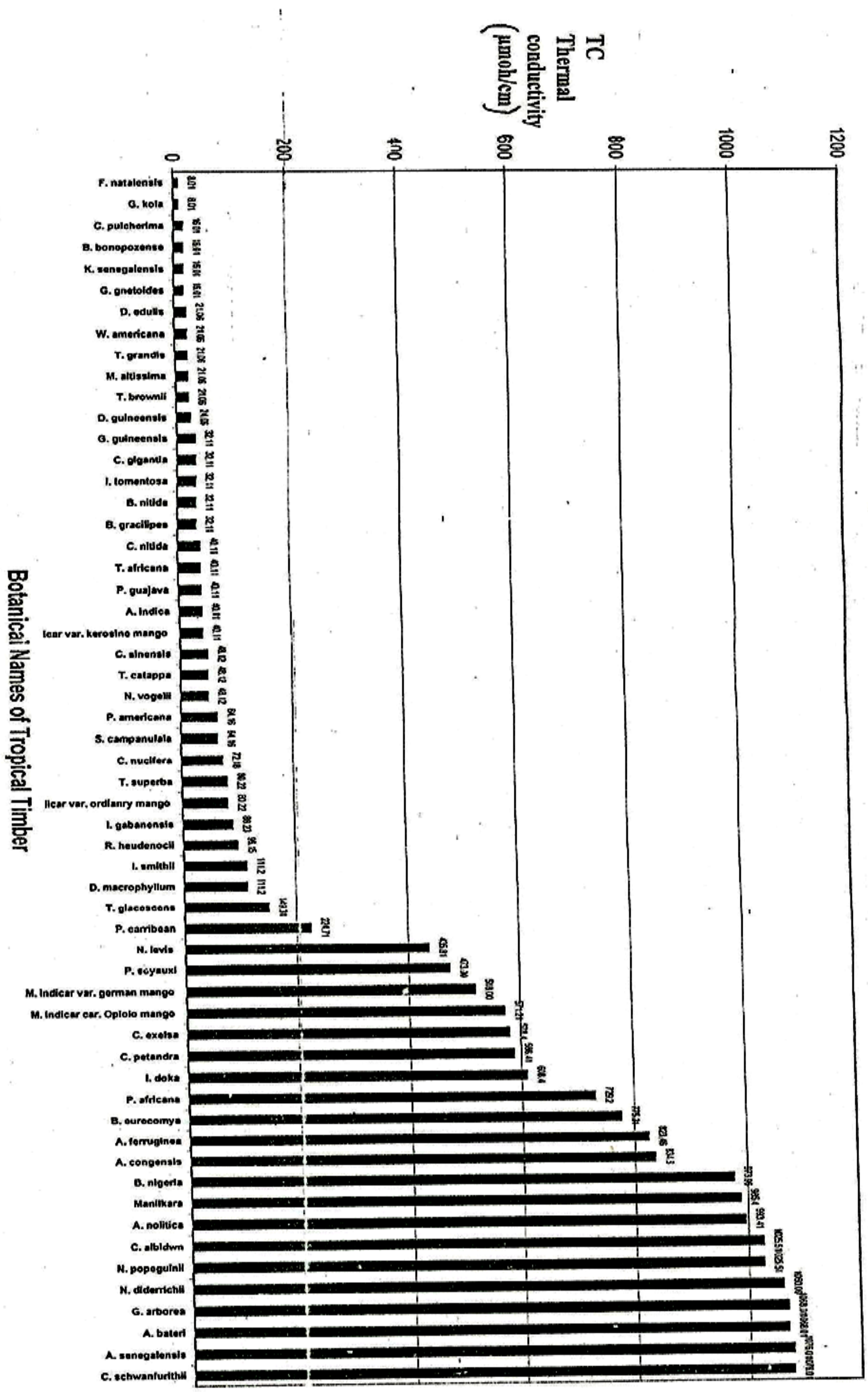
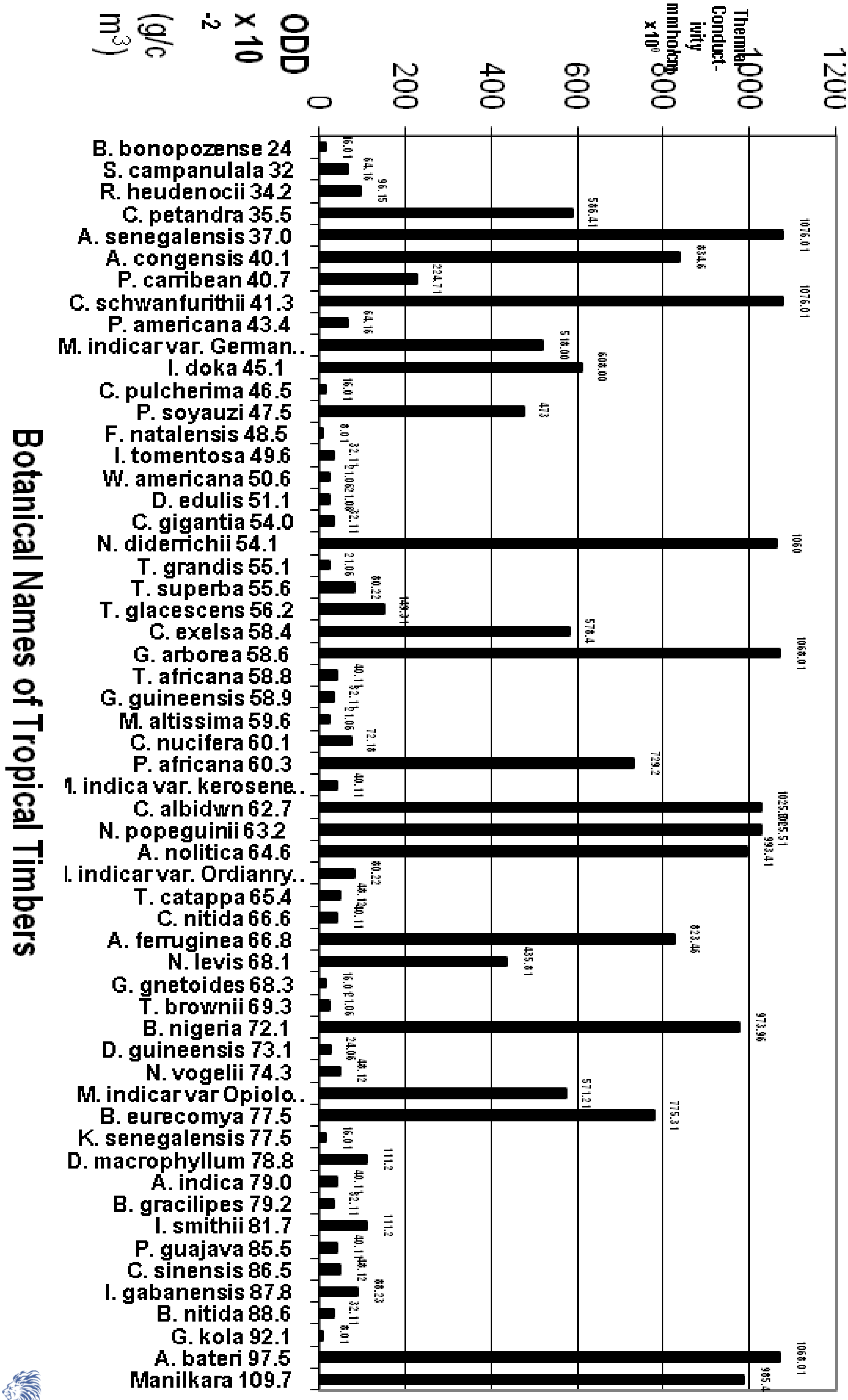


Figure 1: Graph of (TC) Thermal conductivity of 57 tropical timbers

Figure 2: Graph of Thermal Conductivity (TC) vs (ODD) Oven dry density



Discussion

Figure 1 depicts the graph of thermal conductivity of tropical timbers. The tropical timbers *F. natalensis and G. kola* have the least thermal conductivity of 8.01µmho/cm. *A. senegalensis and C. schwanfurithii* have the highest thermal conductivity of 11076µmoh/cm respectively. Again it is observed that the two tropical timbers *(B. eurecomya and K. senegalensis)* with equal ODDs of 77.5 x 10^{-2}g/cm^3 possess very wide variation in their thermal conductivities. *B. eurecomya* has the thermal conductivity of 77.31 µmoh/cm while *K. senegalensis* possess 16.01 µmoh/cm. Materials that conduct heat also conduct electricity. What applies to electrical conductors will also apply to heat or thermal conductors. This type of variations in thermal conductivity may be as a result of this assertion; It was said that: "The small difference in electrical conductivity of different woods of the same density can be explained by attributing such variations to *the effect of differences in anatomical structure of different woods and the possible influence of certain inorganic extractives present in some woods*. [2].

In Figure 2, it is clear that thermal conductivities of these tropical timbers increases occasionally as the ODD increases, sometimes, their thermal conductivities decrease as their ODDs increase. In other word, there is no steady increase in thermal conductivities of these tropical timbers as their ODDs increases. The graph fluntuates. This observation shows that there is no relationship between the thermal conductivities of these tropical timbers and their ODDs. The mechanism of conduction of thermal energy from one point to another through materials has been explained [3-6]. It involves the transfer of phonons and electrons. It is clear that the more the quantity of material, the greater the conductivity. In the absence of other variables; Figure 2 will show steady increase in thermal conductivities of these tropical timbers from the one with the least ODD to the one with the highest ODD. *'Heavy woods conduct heat more rapidly than light, porous one* [2]. The anomalous observation could be attributed to the following factors:

(i) The transmission or conduction of heat depends on two factors (a) the specific conductivity and (b) the specific heat of the intervening material.

(ii) Wood is a cellular substance and in the dry state, the cell cavities are filled with air, which is one of the poorest conductors known.

(iii) *The cellular structure of wood also partly explains why heat is conducted about two or three times as rapidly along, compared with across the grain* [2].

Since the researchers did not study the above mentioned factors, the expected observable positive relationship between the thermal conductivities of these tropical timbers and their ODDs may be proved negative.

Conclusion

There is no steady increase in thermal conductivities of these tropical timbers as their oven dry densities (ODDs) increases. Thermal conductivity of tropical timbers should be considered for one to make wise choice of timbers.

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