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TREATABILITY INDICES OF SOME PLANT SPECIES OF FABACEAE IN NIGERIA

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ABSTRACT

The hydraulic conductance as estimated by Hagen Poiseuille equation was tested on five Nigerian timber species: *Brachystegia nigerica, Afzelia africana, Periscopsis elata, Erythrophleum suaveolens*, and *Daniella oliveri* using spent-engine oil (SAE 40), diesel, kerosene and solignum. The wood of *Brachystegia nigerica* and *Afzelia africana* gave more conductance (penetrability) to kerosene, diesel, solignum and spent-engine oil than the other three. The wood of *Brachystegia nigerica* and *Afzelia africana* gave the highest vessel lumen radius of 0.18±0.06 mm and 0.12±0.01 mm respectively, while *Daniella oliveri, Erythrophleum suaveolens* and *Pericopsis elata* gave the lowest vessel lumen radius 0.09 ± 0.01 mm, 0.07±0.01 mm and 0.05±0.002 mm respectively. The less viscous oils: kerosene, solignum and diesel with viscosities 0.015, 0.019, and 0.043 centipoises respectively at 28°C showed more penetrability than the more viscous spent-engine oil of 2.92 centipoises. There is a positive correlation between the vessel lumen radius and hydraulic conductivities of the four treatment fluids ($P \geq 0.05$).

KEYWORDS: Hydraulic conductance, Hagen-Poiseuille equation, treatability indices, viscosity.

INTRODUCTION

Wood is an excellent renewable building material. When a wood product is used in contact with the ground or exposed to high moisture conditions, it may be subjected to biological deterioration. As a result, huge economic losses are incurred annually to termite and fungi attacks. Wood from most timber species can be destroyed within five to eight years of involvement in constructional works (Richardson 1993 , Tsoumis 1991, Jakub et al. 2015).

To extend the service life of wood to twenty-five or thirty years in moist environments, it is important to use preservative chemicals. The most effective method of application of these preservatives is the pressure treatment method (Richardson 1993). The permeability of wood is a measure of the ease with which fluids flow through it. Longitudinally the permeability of coniferous wood is controlled almost exclusively by the bordered pits. In the sapwood the pits are quite permeable and permit easy passage of fluids and small suspended particles (Dinwoodie 1996). According to Zimmer et al. (2014), the treatability of wood is a function of anatomical properties under certain growing conditions.

Movement of water takes place in the vessel (passage ways) in any direction, longitudinally in the cells, as well as laterally from cell to cell until it reaches the lateral drying surfaces of the wood. The higher longitudinal permeability of sapwood of hardwood is generally caused by the presence of vessels. The lateral permeability and transverse flow is often very low in hardwoods because The vessels in hardwoods are sometimes blocked by the presence of tyloses and or by secreting gums and resins in some other species, The presence of gum veins, the formation of which is often a result of natural protective response of trees to injury, is commonly observed on the surface of sawn boards of most eucalyptus plants. Despite the generally higher volume fraction of rays in hardwoods (typically 15% of wood volume), the rays are not particularly effective in radial flow, nor are the pits on the radial surfaces of fibres effective in tangential flow (Langrish and Walker 1993). Capillary forces determine the movements (or absence of movement) of free water. It is due to both adhesion and cohesion.

As wood dries, evaporation of water from the surface sets up capillary forces that exert a pull on the free water in the zones of wood beneath the surfaces. When there is no free water in the wood, capillary forces are no longer of importance (Uwe 2014).

During drying, the wood pits become aspirated resulting in marked reduction in permeability of the wood. In hardwood species, the number of vessels and their lumen diameter play a major role in the ability of woods to absorb preservatives (Richardson 1993).)

The viscosity of a liquid is due to the friction between neighbouring particles in a fluid that are moving at different velocities. When the fluid is forced through a tube, the fluid generally moves faster near the axis and very slowly near the walls; therefore, some stress (such as a pressure difference between the two ends of the tube) is needed to overcome the friction between layers and keep the fluid moving. For the same velocity pattern, the stress required is proportional to the fluid's viscosity. A liquid's viscosity depends on the size and shape of its particles and the attractions between the particles (Plumb and Robert 1989).

A fluid that has no resistance to shear stress is known as an ideal fluid or in viscid fluid. Zero viscosity is observed only at very low temperatures, in super fluids. Otherwise all fluids have positive viscosity. If the viscosity is very high, for instance in pitch (bitumen), the fluid will appear to be a solid in the short term. A liquid whose viscosity is less than that of water is sometimes known as a mobile liquid, while a substance with a viscosity substantially greater than water is called a viscous liquid (Bank 1981).

In the present work, efforts have been made to find the penetrability (treatability) indices of five members of the Fabaceae family to fluids of different viscosities.

MATERIALS AND METHODS

The wood materials used in this work include five Nigerian timber species of the family Fabaceae. The species are listed with their sub-families in Tab. 1.

Tab. 1: Plant species and their sub-families.

Plant species	sub-family
Alfzelia africana Sm.	caesalpinoidae
Brachystegia nigerica (Hoyle&A.PJones)	caesalpinoidae
Erythrophleum sualveolens (Guill. & Perr.)	caesalpinoidae
Daniella oliveri (Rolfe)Hutch. & dalz.	caesalpinoidae
Pericopsis elata Harms.	papilionoidae

Wood samples were collected with the help of the Forest Ranger attached to the Nsukka timber market. A preliminary identification of the samples was made following the guidelines of Desch and Dinwoodie (1981). A confirmatory identification of the samples was made through the microscopic studies of their section and the features observed were compared to those of Desch and Dinwoodie (1981).

The transverse sections (TS) of the samples were made with the aid of a Reichert sledge microtome. Each of the section was about 18-30u thick. These sections were stained with phloroglucinol and conc. HCL, and photomicrographs taken.

Small blocks of the heart wood of each of the wood species were oven-dried to remove moisture in readiness for maceration process. The Schultz's method of maceration as adopted by Kpikpi and Olatunji (1990) was used. Chips of wood of the five species about the size of half match sticks were placed differently in long labelled test-tubes. Two grammes of 2% potassium chlorate crystals were added to each of the test tubes. 10 mls of concentrated Nitric acid (conc. HNO_3) was carefully introduced into the test-tubes through the side. The set-up was allowed to react in fume cupboard, while standing on test-tube rack until the chips are softened and bleached.

Potassium chlorate being a strong oxidizing agent causes an instant reaction with conc. nitric acid to effect maceration. In tubes when the reactions were slow, the racks were put in an oven and heated to 60°C until the maceration of the chips occurred.

Distilled water was poured in each of the tubes, covered and shaken and allowed to stand in a rack till the pulp settles. Excess solutions were decanted from the test-tubes and the softened bleached chips were washed several times with distilled water till they become clear. The resultant pulps were then separately transferred into well labelled specimen bottles. A drop of formalin was added to each bottle to prevent fungal attack, while a drop of glycerine was added to removes air bubbles from the mass. The bottles were stained with safranine. The stained fibres and vessels were mounted on slide in 30% glycerine, carefully covered with cover slide, and then examined and measured under calibrated light microscope.

The vessel dimensions were measured using Kyowa Japan monocular microscope to which an ocular micrometer was fitted in the ocular tube. The ocular micrometer was first calibrated using a stage micrometer placed on the stage of the microscope by aligning its zero mark with that of the ocular. The number of units of the ocular which aligns with a given unit of the stage micrometer, in a given magnifications was noted. This was used as the conversion factor in the subsequent measurements. The conversion was worked out as follows:

At 40x magnification,

- 45 units of ocular =1.6 mm of stage, 1 unit ocular = 1.6/45 = 0.04
- Conversion factor at 40x magnification = 0.04
- At 100x magnification, 50 units of ocular = 0.74 mm of stage, 1 unit of ocular = 0.74/50 = 0.015 mm, conversion factor at 100x = 0.015 mm
- At 400x magnification, 71 units of the ocular = 0.25 m of stage, 1 unit of the ocular = 0.25/71 = 0.004, at 400 x magnification is 0.004.

The dimensions measured were: vessel length, vessel diameter, vessel lumen radius (calculated as half of lumen diameter) fifteen different xylem vessel members were measured in each of the five wood species from various dimensions as stated above. The conductivities of the samples were estimated using the Hagen-Poiseuille equation.

$$\text{Hagen-Poiseuille: (K)} = K = \frac{\pi r^4}{8 l \eta}$$

where: K - conductivity,
r - radius of vessel lumen,
l - length of vessel member,
η - viscosity (Newman 1976).

The viscosities of the four liquids were tested using the Ferranti portable viscometer model VL. Two cylinder combinations: VHL and VLA were used depending on the rate of viscosity of the liquid. Five gears/ speeds were obtained and the average taken.

The viscosity in poises at given speeds and cylinder combinations were obtained by multiplying the instrument's reading by appropriate multiplying factor as given and certified by the manufacturer of the instrument. The viscosities in Poises were converted to centipoises as follows: Centipoises = poises x 102. Correlations were run between the vessel dimensions and their conductivities to the wood treatment chemicals.

RESULTS

The results of the measured parameters of the plant species and those of the treatment fluids are presented in Tabs. 2 and 3 respectively.

Tab. 2: Some mean dimensional characteristics of vessel members in the five plant species measured in millimeters (mm).

Species	Vessel- members length	Vessel-members diameter	Vessel lumen radius
B.nigerica	0.2 ± 0.01	0.2 ± 0.01	0.18 ± 0.06
E. suaveolens	0.15 ± 0.01	0.19 ± 0.01	0.07 ± 0.01
A. africana	0.17 ± 0.011	0.24 ± 0.02	0.12± 0.01
D. oliveri	0.22 ± 0.01	0.21 ± 0.01	0.09± 0.01
P.elata	0.14 ± 0.09	0.1 ± 0.002	0.05 ± 0.002

B.nigerica = Brachystegianigerica, E. Suaveolens = Erythrophleum suaveolens , A.africana = Afzelia africana
D.oliveri = Daniela oliveri, P.elata= Periscopsis elata

Tab. 3: Hydraulic conductance and viscosities of vessels members in the five plant species in Centipoises.

Oils	Viscosity (28°C)	Conductivity (x 10^{-3} Centipoises)				
		Brachystagia	*Erythrophleum*	*Afzelia*	*Daniella*	*Periscopsis*
Spent engine oil	2.92 ± 0.032	0.68	0.023	0.16	0.039	0.0041
Kerosene	0.015 ±0.003	135	4.60	32.51	7.79	0.81
Diesel	0.043 ±0.001	46.7	1.59	11.2	2.69	0.28
Solignum	0.019 ±0.002	107	3.64	25.7	6.17	0.0064

Tab. 2 shows the mean dimensional characteristics of vessel members of the five studied plant species. The result shows that *Bn* and *Do* have the highest vessel members length (0.2 and 0.22 mm, respectively) which are significantly higher than Es (0.15 mm), Aa (0.17 mm) and Pe (0.14). The vessel members diameters were comparable for Bn, Es, Aa, and Do, while Pe was significantly lower (0.1 mm). Further, vessel lumen radius was found to be 0.18 mm for Bn, which is significantly higher than Aa (0.12 mm), Do (0.09 mm), Es (0.07 mm) and Pe (0.05 mm).

Tab. 3 shows the viscosities of the four treatment fluids and conductivity of the vessels of the wood species to them(the four treatment fluids). Tab. 4 shows significant positive correlations between the vessel lumen radii of the wood species and the four treatment fluids.

Tab. 4: Correlation matrix of the vessel dimensions and their conductivities to the treatment wood chemicals.

	Vessel length	Vessel diameter	Vessel lumen radius	Spent engine oil	Kerosene	Diesel	Solignum
Vessel length	1						
Vessel diameter	.524	1					
Vessel lumen radius	.544	.573	1				
Spent engine oil	.389	.242	.931*	1			
Kerosene	.389	.246	.933*	1.000**	1		
Diesel	.389	.245	.933*	1.000**	1.000**	1	
Solignum	.392	.251	.934*	1.000**	1.000**	1.000**	1

** Correlation is significant at the 0.01 level (2 -tailed), *Correlation is significant at the 0.05 level (2 -tailed).

Conductance/penetrability of vessel members is shows in Fig. 1

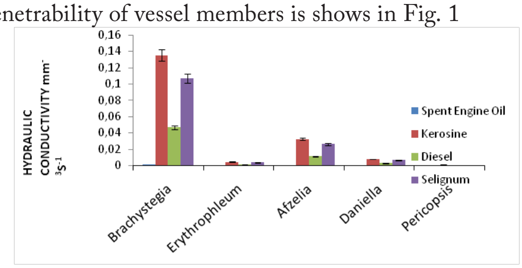

Fig. 1: Conductance/penetrability of vessel members in Brachystegia, Erythrophleum, Afzelia, Daniella and Periscopsis to spent engine oil, kerosene, diesel and solignum.

Figs. 2, 3, 4, 5 and 6 the transverse sections of the heartwood of the various wood species.

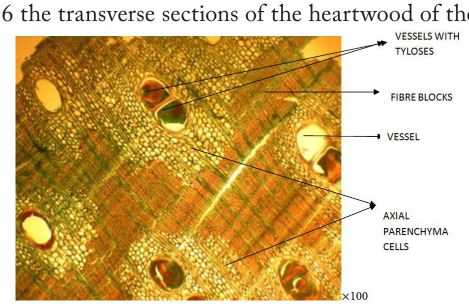

Fig. 2: Transverse section (T.S.) of Brachystegia nigerica showing vessels with aliform confluent parenchyma and presence of tyloses.

Fig. 3: Transverse section (T.S.) of Daniella showing vessels pores with aliform and banded parenchyma arrangements and presece of tylosis.

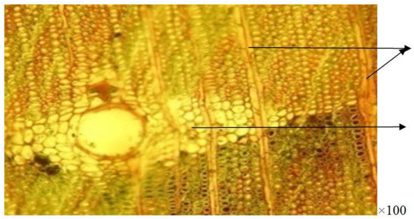

Fig. 4: Transverse section (T.S.) of Afzelia africana showing large vessel pores with aliform axial parenchyma with on tylosis in the vessel.

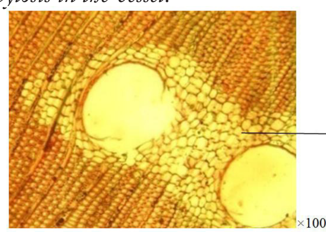

Fig. 5: Transverse section (T.S.) of Erthrophleum showing vessel pores with aliform confluent paratracheal axial parenchyma and no tylosis.

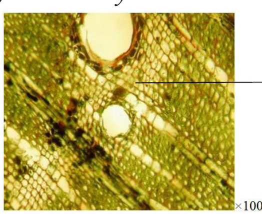

Fig. 6: Transverse section (T.S.) of Pericopsis elata showing banded paratracheal axial parenchyma and no tylosis

DISCUSSION

The wood samples from the five timber species studied showed the characteristic features of the angiosperms (hardwoods). All posses vessel elements joined end to end and fibres with tapering ends, ray parenchyma tissues that ran horizontally and vertical axial parenchyma tissues.

Oladele (1991), considered the possession of vessels and fibres as advancement over *Gymnosperm* and *Pteridophytes*, where the tracheids performed the dual functions of mechanical support and water conduction. In the angiosperms, the thick walled fibres perform the function of mechanical support while the vessels conduct water and dissolved mineral salt. The parenchyma tissues mainly for storage (e.g. starch), and lie either horizontally to the trunk (ray cells) or parallel to the trunk (axial parenchyma cells) (Chen et al. 2010, Evert 2006, Simpson 2006, Schweingruber et al. 2006 and Oladele 1991).

According to Richardson (1993), the porous nature of the vessels in angiosperms gives them an added advantage over the gymnosperms whose tracheids are imperforate to movement fluids.

In the present work, *Brachystegia* vessels gave more penetrability to the fluids than the other plant species used, its vessels lumen radius (0.178 ± 0.064 mm) are relatively wider than the other four plants used. Moreover, the vessel members of the five plants are more penetrable to kerosene, solignum and diesel. The species gave the highest resistance to the most viscous oil (spent engine oil), with the viscosity of 2.916792 centipoises and most penetrable to the least viscous oil (kerosene) followed by diesel and then solignum. According to Uwe 2014, a key factor in determining hydraulic conductance is the vessel lumen radius, *Pericopsis* wood had the narrowest vessel lumen radius, and it appeared less penetrable to the fluids than those of other four species. This is reflected in the correlation table (Tab. 4), where significant positive correlations exist between vessel lumen radius and the conductivity to the four treatment fluids. Lumen resistance and pit resistance were said to be limiting factors for flow of fluid in tracheides elements (Zimmerman and Brown, 1971, Gibson et al. 1985). Penetrability may, however be enhanced by application of vacuum in the treatment wood (Oladele 1994).

CONCLUSIONS

In conclusion, the more viscous liquid (spent engine oil) has the least penetrability in the vessel members of the five plants, while the least viscous has a high penetrability through the vessel members. In this study, it has been shown that *Brachystegia nigerica* vessels having the largest of lumen radius are more penetrable to the fluids, while the *Pericopsis elata* with the smallest vessel lumen radius gave the least permeability. The presence of tyloses in vessel lumen can reduce or impede the flow of fluids through the vessels (Richardson 1993, Beck 2010). In the present study, tyloses were observed in the vessel lumina of *Brachystagia nigerica* and *Daniella oliveri* (Figs. 2 and 3). It is noteworthy that predicted hydraulic conductivities show inverse relationships to the oil viscosities.

Therefore, in treatment of wood species whose vessel lumen radii are as low as 0.05 mm, pesticides, fungicides and other chemicals to be used should be made to be of low viscosity about 0.015 centipoises and below for easy treatment or penetrability of wood. Also wood with small vessel lumen radii should be treated with high pressure equipment to force the preservatives into the wood or be incised to create more channels for preservatives to enter.

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