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INVESTIGATION OF *MUSANGA CECROPIOIDES* HEARTWOOD AS A POTENTIAL THERMAL INSULATOR FOR REFRIGERATORS, COOLERS AND FOOD FLASK

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Abstract

Thermal conductivity, specific heat capacity and density were measured for *Musanga cecropioides* (Corkwood) heartwood sample obtained from a bush at Afaha Oku in Uyo, Akwa Ibom State, Nigeria. Thermal resistivity, diffusivity and absorptivity were also determined for the sample to establish its suitability as construction material for cooler, food flask and refrigerator, from an energy conservation point of view. Results showed that the thermal properties of *Musanga cecropioides* heartwood compared favourably with those of similar construction materials. In fact, *Musanga cecropioides* heartwood is a better thermal insulator than most known resources. The material could be used as an efficient heat insulator in various interior spaces, if properly harnessed.

Résumé

ETUK E. SUNDAY, AKPABIO E. LOUISE & ESSIEN E. KUFREABASI.: *Enquête de* Musanga cecropioides *Brois de Cœue comme insulateur thermique potentiel pour les réfrigérateurs, les glacières et les thermos.* La conductivité thermique, la capacité de chaleur spécifique et la densité étaient mesurées pour *Musanga cecropioides* (bois de liège) échantillon de bois cœur obtenu d'une buisson à Afaha Oku dans l'état Uyo, Akwa Ibom du Nigeria. Resistivité, diffusivité et absorptivité etaient également déterminées pour l'échantillon pour vérifier s'il est convenable en tant que matériel de construction pour le glacier, la thermos et le réfrigérateur du point de vue de la conservation d'énergie. Les resultats montrent que les propriétés thermiques de *Musanga cecropioides* bois de cœur se comparent favorablement avec ceux de matériel de construction semblable. En fait, *Musanga cecropioides* bois de cœur est un meilleur insulateur thermique que la plupart de resources connues. Le matériel pourrait être utilisé comme un insulateur de chaleur efficace dans les différents espaces intérieurs, s'il est convenablement exploité.

Introduction

One of the problems people face is how to maintain the temperature of their foodstuff, water, research samples, vegetable and others at the required temperature for a required length of time. One of the factors causing change in the temperature of food or sample is the heat transmitted in or out through the walls of the containing vessel by the process of conduction and radiation. The heat gain or loss can be minimized if good insulating material is used to finish the walls of the container. The application of the refrigeration principles makes preservation of food and research samples possible. The use of portable cooler and food flask also helps in maintaining the temperature of food and preserving food for a long time. Various attempts are now being made to develop local materials with suitable structural and energy-conserving properties. Various types of timber and clay are also being examined for energy conserving properties for passively cooled building design (Ajibola & Onabanjo, 1995; Marsh & Olivo, 1979; Ekpe & Akpabio, 1994; Akpabio & Ekpe 1998).

At present, most insulating materials that can be used for refrigerator, cooler and food flask, like polystyrene (expanded), polyurethane (rigid foam), mineral wood (batts), glass fibre etc., are very expensive to acquire. Alternative sources of plant-based energy-conserving materials have been examined. Akpabio, Etuk, Ekpe & Essien (2001) established that parts of some plants especially the palm family are suitable for insulation.

The study is aimed at determining some thermal properties of *Musanga cecropioides* heartwood as a potential insulator for cooler, food flask and refrigerator production. *Musanga cecropioides* (Corkwood) is one of the trees that grow wild in the bush. It is characterized by soft branched trunk crowned by compound leaves. It is used in match sticks and pulp production. A typical *Musanga cecropioides* reaches a height of 10 m or more. It takes a short time to grow; the rate of growth, however, depends on the condition of the soil. Other applications include xylophone production. Juice from *Musanga cecropioides* root is used as solvent in many herbal preparations, while the leaves are fed to animals. The heartwood of *Musanga cecropioides* is brown or light yellow in colour (Etukudo, 1991; Etukudo, 2000).

Some properties of insulation materials include thermal conductivity, specific heat capacity, specific thermal resistance, thermal resistivity, thermal diffusivity and absorptivity and density (Ekpe & Akpabio, 1994; Twidell & Weber, 1990). Other properties include affinity for moisture absorption, insect infestation and mechanical strength in case of building insulator.

To date, no study has been conducted on the thermal properties of *Musanga cecropioides*. This study focuses on the thermal properties of *Musanga cecropioides* (Corkwood) heartwood. The study is necessary because the fibre composition of the heartwood of *Musanga cecropioides* differs considerably from that of other wood types. For this reason it may have different thermal properties from those of other wood species. The properties to be examined are the thermal conductivity, thermal resistivity, specific thermal resistance, specific heat capacity, thermal diffusivity, absorptivity and density. The rationale is that if the material has high resistance to heat, it could be successfully used either singly or as a composite material to prevent heat conduction through walls into or out of interior spaces in the vessel.

It is necessary to know the thermal properties of refrigerator, cooler and food flask lagging materials because they determine the amount of heat that is transferred into a space from external sources and how much is transferred out of the space from interior content. A knowledge of the thermal properties assists in a rational choice of lagging materials for production of refrigerator, cooler and food flask. Hence, it will help in the preservation of food and samples.

Thermal conductivity

Thermal conductivity is really a physical property of the substance, which indicates the number of heat units ($Wm^{-1}K^{-1}$), that will be conducted per unit surface area and unit time across a slab of the substance of unit thickness for every degree of difference in temperature between the two surfaces. Moisture content, temperature, density, porosity and particle size are some of the factors affecting it. It is represented by the following equation (Ajibola & Onabanjo, 1995; Marsh & Olivo, 1979; Ekpe & Akpabio, 1994; Van Straaten, 1961; Collieu & Powney, 1977; Zemansky & Dittman, 1982).

$$q = kA(\theta_h - \theta_c)/L \qquad (1)$$

where θ_h = temperature of the hotter face (°C); θ_c = temperature of the cooler face (°C); A = unit area (m^2); L = thickness of the material slab with plane parallel faces measured (m); k = thermal conductivity of the material ($Wm^{-1}C^{-1}$ or $Wm^{-1}K^{-1}$); and q = rate of heat flow (W). Equation (1) indicates that heat flow is directly proportional to the area and the temperature difference = ($\theta_h - \theta_c$) between the parallel faces, and inversely proportional to the thickness. Materials with thermal conductivities below 0.25 $Wm^{-1}K^{-1}$ are commonly used for thermal insulation (Isachenko *et al.*, 1987).

Thermal resistivity

The reciprocal of thermal conductivity is referred to as thermal resistivity. It indicates the ability of a material irrespective of its thickness, to resist the passage of heat and the unit is $m°CW^{-1}$ or mKW^{-1} (Ajibola & Onabanjo, 1995; Etuukudo, 2000). Equation (2)gives the mathematical formula for thermal resistivity (r)

$$r = 1/k \quad (2)$$

where r = thermal resistivity in $m°CW^{-1}$ or mKW^{-1} and k = thermal conductivity.

Specific thermal resistance

The specific themal resistance R of a material is defined as the quotient of thickness of the material to its thermal conductivity, as the actual heat flowing across a given material depends on the thermal conductivity k as well as the thickness (L) of the material. The unit of specific thermal resistance is $m^2\ °CW^{-1}$ or $m^2\ KW^{-1}$ (Ajibola & Onàbanjo, 1995). It is represented by the equation.

$$R = L/k \quad (3)$$

where R = specific thermal resistance; L= thickness (m); k = thermal conductivity.

Thermal diffusivity

Thermal diffusivity is another property closely related to the thermal conductivity which indicates how quickly changes in temperature diffuse through a material. It is mathematically represented thus:

$$\lambda = k/\rho c \quad (4)$$

where ρ is the density of the material in Kg/m^3 and c is the specific heat capacity at constant pressure. λ has the unit m^2s^{-1} (Marsh & Olivo, 1979; Ekpe & Akpabio, 1994; Twidell and Weir, 1990).

Thermal absorptivity

Thermal absorptivity α of a material is defined by

$$\alpha = (\omega/2\lambda)^{1/2} \quad (5)$$

where ω = angular frequency; λ = diffusivity. The more heat that a material absorbs, the less it reflects and *vice versa* Akpabio *et al.* (2001).

Thermal insulator

This refers to any material that effectively reduces the transfer of heat. Any material that traps air in small holes is useful as an insulator (Marsh & Olivo, 1979; Twidell & Weir, 1990).

Experimental

The *Musanga cecropioides* plant of approximately 4 years old, obtained from a bush at Afaha Oku in Uyo, Akwa Ibom State, Nigeria was used for the analysis. After cutting the tree, the trunk was cut into portable lengths. The heartwood, a brown or light yellow cork was removed and shaped.

Thermal conductivity was determined for the sample using the steady state method (Duncan, 1981). Lees disc apparatus was modified and adapted for use. Dry *Musanga cecropioides* heartwood was used to avoid the problem of redistribution of water under the influence of a temperature gradient (Ekpe &Akpabio, 1994; Akpabio & Ekpe, 1998; Jackson & Taylor, 1965).

At the steady state, the rate at which heat is conducted across the sample is equal to the rate at which it is emitted from the exposed surface.

Specific heat capacity was measured for the sample using the cooling correction method. This was done to take care of any heat, which might be lost by radiation, since the heartwood sample requires considerable time for heating.

Density was also measured for the sample. Thermal diffusivity ($\lambda = k/\rho c$) and absorptivity, $\alpha = (\omega/2\lambda)^{1/2}$ were calculated. Also calculated were the specific thermal resistance and resistivity for the sample. The procedure was repeated for two other test samples of *Musanga cecropioides* for average values.

Results

Results for the thermal conductivity k, specific heat capacity c, thermal diffusivity λ and absorbtivity α, specific thermal resistance R and thermal resistivity ρ for the sample are shown in Table 1. The thermal conductivity of the sample is 0.04 $Wm^{-1}K^{-1}$ which is compared to those of other thermal insulators like mineral wool (0.035 $Wm^{-1}K^{-1}$); polysterene expanded (0.042 $Wm^{-1}K^{-1}$), which are all compared to those of still air (0.03 $Wm^{-1}K^{-1}$). Table 1 also shows the calculated value of the thermal resistivity of the sample to be 25.22 mKW^{-1} and specific resistance value of (0.31m^2KW^{-1}). It has a density of 53 Kgm^{-3}, thermal diffusivity of 3.72 × 10^{-7} m^2s^{-1} and absorptivity of 9.88 m^{-1}.

TABLE 1

Experimental result for the thermal properties of Musanga cecropioides *heartwood.*

Sample	*Conductivityk* $Wm^{-1}K^{-1}$	*Density* $rKgm^{-3}$	*Absorptivity* α m^{-1}	*Diffusivity* $\lambda m^2s^{-1} \times 10^{-7}$	*Resistivity* $rmKW^{-1}$	*Specific thermal resistance* Rm^2KW^{-1}	*Specific heat capacity* $JKg^{-1}K^{-1}x\ 10^3$
Test sample 1	0.039	53.0	9.97	3.66	25.64	0.310	2.01
Test sample 2	0.041	53.1	9.73	3.84	24.39	0.295	2.01
Test sample 3	0.039	53.0	9.95	3.67	25.64	0.310	2.00
Average ≅	0.04	53	9.88	3.72	25.22	0.31	2.00

The values of the thermal conductivity and density obtained are compared with the values of thermal conductivity and densities of other known thermal insulators used for lagging refrigerators, coolers and food flask. As shown in Table 2, *Musanga cecropioides* heartwood has

TABLE 2

Density and thermal conductivity of some insulating materials (Twidell & Weir 1990).

Material	*Density r* Kgm^{-3}	*Thermal conductivity k* $Wm^{-1}K^{-1}$
Corkboard (dry, 18 °C)	144	0.042
Mineral wool, batts	32	0.035
Polyurethane (rigid foam)	24	0.025
Polystyrene expanded	16	0.035
Still air (27 °C, 1 atmos.)	1.18	0.026

thermal conductivity and density values lower than those of corkboard and thermal conductivity very close to those of mineral wool, fibre glass and polystyrene. This means that it offers more resistance to the passage of heat through it than corkboard (Rosenberg, 1978). A gradual release of air bubbles was observed when the heartwood sample was totally immersed in water using heavier mass to push it down the water. The immersed sample floated immediately after the mass that pushed it down the water was removed after 24 hours of total immersion. It indicated that *Musanga cecropioides* heartwood traps air in small holes as its thermal conductvity is comparable to that of still air, indicating that it incorporates small pockets of air. According to Twidell & Weir (1990), almost any material that traps air in small holes is useful as an insulator, giving fibre glass with $k = 0.035\ Wm^{-1}K^{-1}$ as an example. This is further supported by March & Olivo (1979) that the effectiveness of any thermal insulator is due to the trapped air spaces. Twidell & Weir (1990) attest that still air is one of the best insulators available and all natural and commercial insulating materials rely on it.

The value of thermal diffusivity of $3.72 \times 10^{-7}\ m^2s^{-1}$, a value which depends on the thermal conductivity, density and specific heat capacity indicates that *Musanga cecropioides* heartwood would not allow heat to move easily through the material and, hence, would impede temperature exchange.

The density of 53 kgm^{-3} determined for the heartwood of *Musanga cecropioides* further confirmed the assertions that the density of materials also influences their thermal conductivities (Gray, 1992). The low density of *Musanga cecropioides* heartwood gives an added advantage for employing the material in the production of portable cooler and food flask as it can be carried about with ease. Having thermal radiation absorptivity value of 9.88 m^{-1} which is less than 10.02 m^{-1} recorded by Ekpe & Akpabio (1994) for their choice of a good thermal insulator for passively cooled building design, makes *Musanga cecropioides* heartwood a better insulating material. Low thermal absorptivity value indicates that the material reflects more than it absorbs, a condition which is preferred in the choice of insulators for insulating houses, refrigerators and the like by sheeting them in materials called reflective insulation (Marsh & Olivo, 1979).

Conclusion

Based on the experimental result and comparison of *Musanga cecropioides* heartwood with materials of similar nature, the following conclusions and recommendations have been made.

Musanga cecropioides heartwood can be used as a thermal insulating material because of its low thermal conductivity, resulting in high thermal resistivity and high resistance to heat flow, with low density, thermal absorptivity and diffusivity values. The fact that it is not infested by insect is an added advantage.

Comparison with other similar materials and established insulators show that *Musanga cecropioides* heartwood has a lower thermal conductivity than similar wood insulators such as corkboard, wood fibres, plywood, chipboard, etc. It is, therefore, a better thermal insulator.

Recommendation

The study establishes that the *Musanga cecropioides* heartwood is useful in the insulation of refrigerator, cooler, food flask, and the like for the conservation of energy. Because of this the following recommendations were made:

(i) The use of *Musanga cecropioides* heartwood as insulating/lagging materials should be encouraged. This can be done by making the heartwood into boards suitable for use in the lining of the interior spaces of the cooler or heat energy conserving system.

(ii) The planting of *Musanga cecropioides* with the objective of using the heartwood as thermal insulator should be embarked upon, as this would augment our insulator resources.

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Reference

AJIBOLA, K. AND ONABANJO, B. O. (1995). Investigation of *Cocos nucifera* as a potential insulator for buildings, *Renewable Energy* **6** (1), 81 – 84.

AKPABIO, G. T. AND EKPE, S. D. (1998) Comparison of the thermal properties of brick samples for a passively cooled building design. *Global J. pure appl. Sci.* 4(4), 453 – 454.

AKPABIO, L. E., EKPE S. D, ETUK S. E. & ESSIEN, K. E. (2001). Thermal properties of oil and raffia palm fibres. *Global J. pure appl. Sci.* **7** (3).

COLLIEU, A. M. B. & POWNEY, J. (1977) *The mechanical and thermal properties of materials*. London: Edward Arnold.

DUNCAN, T., (1981) *Material and mechanics*, 2nd edn. London: John Murray.

EKPE, S. D. & AKPABIO, G. T. (1994) Comparison of the thermal properties of soil samples for a passively cooled building design. *Tr. J. Phys.* **18**, 117 – 122.

ETUKUDO, I. (1991) *Common plants of Akwa Ibom*, Ministry of Agriculture and Natural Resources, Uyo: Akwa Ibom State Publication.

ETUKUDO, I. (2000) *Forests our divine treasure*. Uyo: Dorand.

GRAY D. E. (1992). *American Institute of Physics Handbook*, 3rd edn. New York: McGraw-Hill.

JACKSON, R. D. & TAYLOR, S. A. (1965) *Heat transfer*, Method of soil analysis, *Agronomy Monograph*, **9** (1), 349 – 360.

MARSH, R. W. & OLIVO, C. T. (1979). *Basics of Refrigeration* (2nd edn). New York: Van Nostrand Reinhold.

ROSENBERG, H. M. (1978) *The Solid State* (2nd edn). Oxford: Clarendon.

TWIDELL, J.& WEIR, T. (1990) *Renewable Energy Resources*. Madras: Chapman and Hall.

VAN STRAATEN, J. F. (1961) *The Thermal performance characteristics of certain wall construction in warm climates*. Melbourne.

ZEMANSKY, M. W. & DITTMAN, R. H. (1982) *Heat and thermodynamics* (6th edn.). London: McGraw-Hill.

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