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THERMAL TRANSPORT OF NATURALLY SEASON DRIED ELAEIS GUINEENSIS (OIL PLAM) TREE TRUNK

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Abstract

Thermal conductivity, thermal diffusivity and thermal absorptivity of dry Elaeis guineensis (Oil palm) tree trunk have been determined at temperature range between 28 and 80°C using Bruel and Kjaer rapid thermal conductivity machine under the steady-state heat flow. Results show a mean thermal conductivity $\lambda = (0.0613 \pm 0.0009)\,\text{Wm}^{-1}\text{K}^{-1}$, thermal diffusivity $D = (8.96 \pm 0.71) \times 10^{-8}\,\text{m}^2\text{s}^{-1}$ and thermal absorptivity $\alpha = (20.24 \pm 1.61)\,\text{m}^{-1}$ with a mean percentage porosity of $(35.5 \pm 3.1)\%$ and specific heat capacity $c = (2164.2 \pm 33.6)\,\text{Jkg}^{-1}\text{K}^{-1}$. The low thermal conductivity, which is attributed to the high percentage

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of dead air space in the samples, leading to low density, makes this material a potential thermal insulator for thermal envelope, especially for building design.

1. Introduction

Thermal transport in porous materials is governed by thermophysical properties, such as thermal conductivity and heat capacity [33, 34]. The knowledge of thermal conductivity is very necessary for the computation of transient and steady temperature fields in a material, while heat capacity is useful for the calculation of transient temperature distribution and heat flux [33].

Thermal conductivity, a phenomenological transport coefficient, is complexly related to chemical and physical structure of the material. For porous materials, thermal conductivity depends upon many other parameters, such as the volume of fractions of the constituent phases, geometrical distribution of the phases, the size distribution of the particles and the geometry of the pore structure, and it is strongly influenced by moisture content (deVries [10], de Vries [11], de Vries [9], Bouguerra et al. [33], de Vries [12]). This phenomenological coefficient is the heat flux through a unit surface produced in the bulk material by the unit temperature gradient. A complete empirical measurement of thermal conductivity is possible at low or moderate temperatures with a variety of power input techniques and different geometrical configurations, but it becomes very difficult at higher temperatures to control and measure the heat flux and the local temperature gradients in the sample. It has been reported that many materials at high temperatures undergo uncontrolled structural and geometrical changes (Cocorullo et al. [8], Lysenko et al. [23]), a condition that affects both the thermal conductivity and the accuracy of measurement (Bouguerra et al. [33]). It is better, for these reasons, to obtain the thermal conductivity at high temperatures from the products of the heat capacity c, the thermal diffusivity α, and the density ρ (Bouguerra et al. [33]).

In the report of Beck et al. [5], the total thermal conductivity λ in highly porous insulation materials such as foams, fibre-boards or compressed powder boards has been described as the sum of gaseous conductivity λ_{gas}, solid conductivity λ_{sol}, radiative conductivity λ_{rad} and a coupling term λ_{coupl}, thus:

$$\lambda = \lambda_{gas} + \lambda_{sol} + \lambda_{rad} + \lambda_{coupl}. \tag{1}$$

According to Beck and his co-researchers [5], λ_{coupl} takes into account that gas conduction thermally short circuits the high thermal resistance between the contact points between the fibers. Conduction due to gas is believed to contribute significantly to the thermal transport in insulation materials. Solid conduction, on the other hand, correlates with density ρ, such that the higher the density of materials, the higher the solid conductivity values. Their report also asserts that the temperature dependence of the thermal conductivity of the bulk material is considered to be negligible at the temperature range $T = 0$ - 100°C.

Several materials such as asbestos, compressed cork, granulated cork wood, among others are used for thermal insulations. Some of these materials are reported to have health hazards. For example, asbestos which is a popular insulating material is reported to cause three lung diseases: mesostheliona, asbestos and chongenic carcinoma - lung cancer (BAMCWA, 1995), while the raw material for the production of the other effective heat insulators are being extinct in some areas due to high demand for such materials especially plants products which posses potential for energy conservation, but attempts have not been made to establish their suitability.

It is in consideration of the above that this work, which involves measurement of heat flow in Elaeis guineensis (oil palm) tree trunks, naturally seasoned to dryness, is predicated upon, with the aim of sourcing for available plant product with suitable substitute to asbestos and other good but scarce insulation materials.

2. Related Model

Many models have been proposed for the prediction of thermal conductivity of materials, hence, thermal transfer. Some of such models include; that postulated by Pande and Gori as reported in Bouguerra et al. [34], Maxwell's model for determination of thermal conductivity - valid for materials with low porosity (Fricke [35]), Pande and Chaudhary theory based on lattice model with effective continuous medium approximation (Bouguerra et al. [33]), a generalized model based on the fact that statistical self-similarity exists in porous media (Bouguerra et al. [33]). Zumbrunnen et al. [32] in their model assume that heat transfer in solid with randomly distributed pores of complex geometry can be idealized as a structure in which all pores have a single characteristic size, evenly spaced and are randomly oriented with respect to their neighbors only in the direction of the heat flow. The assumption also used in their model is that conduction across the fluid in the pores can be related to the characteristic size of the pores by the parameters. That heat transfer by thermal radiation occurs only across the pores. The pores surfaces are gray diffuse emitters and reflectors and the fluid in the pores is radiatively nonparticipating. That the geometry as well as the dimensions of the material, do not depend on temperature, and that the transfer is one-dimensional.

The above assumptions led to their expression for the effective thermal conductivity λ_e for a porous solid of fraction porosity *P* and with λ_s and λ_f being the conductivities of the solid and of the fluid phases, respectively, thus, (Zumbrunnen et al. [32], Kimani and Aduda [21]);

$$\lambda_e = \left[x + \Lambda\left\{\frac{\beta + 1}{\beta}\right\} + 1\right]\left[\frac{1}{\lambda_s}\left(\frac{\Lambda\phi}{\beta} + x\right) + (1 + \Lambda)\left(Vh_{rr} + \frac{\lambda_f}{\varphi}\right)^{-1}\right]^{-1},$$

where

$$x = \frac{(1 + \beta)\left[\left(\frac{2 + \beta}{1 + \beta}\right)\ln(1 + \beta) + 1\right]}{\beta \ln(1 + \beta)}, \quad \beta = \frac{\rho^{1/3}}{1 - \rho^{1/3}} \quad \text{and} \quad \Lambda = 1 + \left[\ln\left(\frac{\beta + 1}{\beta}\right)\right]^{-1}.$$

ϕ is taken to be 1 for solids with closed pores and 0 for solid with interconnected pores. Λ defines the number of pores contained in a path of heat flow that begins on a pore surface, φ is an adjustable parameter. The heat transfer coefficient for thermal radiation across the pores is given by

$$h_{rV} = 4\varepsilon\sigma T^3,$$

where *T* is the average temperature of the pore surface, ε is the emissivity of the material and σ is the Stephan-Boltzmann constant.

In the face of all these models, the knowledge of certain related parameters is essential for the prediction of the required parameters. As Bouguerra et al. [33], rightly expressed, that the main difficulty in using the corresponding analytical expressions of these models stems from the fact that these expressions, generally require the knowledge of several parameters. However, there abound several experimental methods or techniques for determination of the necessary parameters. Such includes method developed by Ki-Iti Horai as reported in Bouguerra et al. [33] for the determination of the thermal conductivity of mineral, at ordinary temperature and pressure; Gustafsson developed method for measuring the thermal properties of materials, known as transient plane source (TPS) techniques; others are Calorimetry method (Kimbal and Jackson [22]), Thermo time domain reflectometry (Therm - TDR) probe method (Ochsner et al. [28], Moon et al. [25], McCammon et al. [24]), and of course, steady state determination of temperature gradient technique for the determination of the thermal flux (Steffen et al. [29], Kersten et al. [20], Ekpe and Dew [14]). Some techniques require physical contact between the measuring devices and the sample, while others are non-contact methods, such as radiometry and luminescence (Nishino et al. [27]).

Focusing on the techniques of our choice for this work, the steady state technique, it has been postulated that the temperature of porous material at any depth depends on the thermal conductivity of material, which is expressed mathematically as (Yong et al. [31])

$$Q = \frac{\lambda A(T_h - T_c)}{x}, \tag{2}$$

where T_h is the temperature of the hot face, T_c is the temperature of the cold face, x is the coordinate through the thickness of the material sample, and Q is the heat flow.

3. Palm Oil (Elaeis guineensis) Tree Description

Palm oil (Elaeis guineensis) tree is a soft and pored monocotyledonous plant, having solid unbranched trunk, crowned with fan-shaped bipinnate leaves. It belongs to a class of trees known as endogenous trees (Ajibola and Falade [3]). According to Hodge [19], it does not have cambila activities, which are responsible for annual rings and trunk thickness of trees. This is responsible for the slender and graceful form but non-massive diameter of palms. Palms that grow under favourable conditions produce large cells, which lead to bigger trunks as observed in the African oil palms. Local brooms are made from midribs of the leaflet of Elaeis guineensis. The fruit is often used for oil and kernel production (Hodge [19]). Most researchers on palm are mainly on taxonomy, botanical structure and determination of structural or mechanical properties of palm timbers (Hodge [19], Moore [26] and Essiama [17]).

4. Materials and Experimental Methods

Five different Elaeis guineensis trunk were obtained from sites cleared for building at Uyo in Akwa Ibom State, Nigeria, located at latitude $05°03'$ N and longitude $07°57'$ E. After felling the trees, the trunks were cut into logs and sawed into planks of portable lengths. The planks were labeled and stored separately at oblong position in a dry environment for three years. The seasoned planks were afterward weighed at intervals for a constant mass to ensure complete dryness at ordinary atmospheric temperature. They were subsequently and separately joined and shaped to the required samples of approximately $0.300\,\text{m} \times 0.300\,\text{m} \times 0.026\,\text{m}$ needed by the test equipment for the determination of thermal conductivity of the material.

The method described by Ajibola and Onabanjo [4], which is in accordance with the British standard 874, (1973), that is "method for determining thermal properties with definition of thermal insulating term" using Bruel and Kjaer rapid thermal conductivity machine was used for the determination of thermal conductivity of the material. The equipment is a compact self-contained instrument for the determination of thermal conductivity of materials of insulation.

The test section comprises a stationary upper section and can be adjusted to accommodate various sample thickness not exceeding 0.1m maximum. The upper section comprises a heat sink plate with coils separated by insulation from a controller heater and aluminum surface plate. This surface is often maintained at a higher temperature than the lower plate. A thermocouple consisting of chromel-alumel is at the centre of the upper surface plate to measure the temperature.

The lower section has a movable base plate mounted on the four guide rods with ball bushing. A heat sink plate, aluminum plate and controlled heater are parts of the movable base plate. Also attached to the lower surface plate is a heat flow transducer. Chromel alumel thermocouple is also attached to the top surface of the lower plate for the measurement of the temperature. The instrument has $39.99\,\text{mV}$ full-scale digital panel meter located on the front panel where the output of the various thermocouples and the heat flow transducer can be displayed. Thermal conductivity of the sample in the test section was allowed to attend a steady state of thermal equilibrium by observing that the two controlling temperatures on the front panel of the equipment had reached and maintained constant temperature readings. Dry samples were used to avoid the problem of redistribution of water under the influence of temperature gradient (Ekpe and Akpabio [15]).

In order to determine thermal conductivity for the samples, fibre glass used as a calibration sample was first inserted into the appropriate section of the instrument. It was firmly held between the hot and cold faces. The test section was allowed to reach a steady state of thermal equilibrium, observing that the temperatures on the front panel of the instrument remained constant without any change irrespective of increase in duration of the experiment. Data for heat flow meter output for the calibration sample Q_c; hot surface temperature T_{hc} for the calibration sample in mV; calibration sample thickness x_c; and cold surface temperature T_{cc} for the calibration sample in mV were read directly from the Bruel and Kjaer rapid thermal conductivity equipment and recorded. The test sample was then placed in the machine and the procedure repeated and allowed temperatures at both the upper and lower sections to attend constant reading as in the case of calibration sample. Corresponding data Q, T_h, x and T_c, for five test samples were also obtained. Temperature differences $\Delta T = T_h - T_c$ and $\Delta T_c = T_{hc} - T_{cc}$ were calculated, respectively, for the test and calibration samples in mV. The following relation, given by Ajibola and Onabanjo [4] as

$$\lambda = \frac{Ax\Delta T_c \lambda_c}{Q_c x_c \Delta T}, \tag{3}$$

where λ_c is the thermal conductivity for the calibration sample, was used for the calculation of the thermal conductivity values for the test samples, at ambient temperature of $28°\text{C}$. Thermal conductivity values were also determined at different ambient temperatures up to $80°\text{C}$.

Bulk densities, as well as particle densities, were determined for the test samples using Archimedes principle. The percentage of "dead air space" was determined using the expression given by Blake and Hartge [7], as

$$P = \left[1 - \frac{\text{bulk density}}{\text{particle density}}\right] \times 100\%. \tag{4}$$

Specific heat capacity was determined for each test sample using calorimetry method, with cooling correction to reduce the amount of heat lost to the surrounding. In this method, a well lagged copper calorimeter was weighed empty. It was half filled with cold distilled water and the temperature of the inner calorimeter environment with the water taken using thermocouple, and re-weighed. The sample, cut into a size of $0.045\,\text{m} \times 0.045\,\text{m} \times 0.020\,\text{m}$, with a thermocouple attached was placed in an oven pre-heated at $100°\text{C}$. The temperature of the sample was monitored until it reached a value of $88°\text{C}$. The hot sample was quickly transferred into the calorimeter with water placed on a shaker system. The shaker was turned on to ensure uniform temperature distribution. The maximum steady temperature was measured. The temperature was also measured as it cooled, until it was about $5°\text{C}$ below the maximum temperature. The calorimeter with its contents was then weighed, and the mass of the sample as well as the mass of the distilled water used were deduced for the calculation of the specific heat capacity of the sample. To compensate for the heat loss to the surrounding, cooling correction was made from a temperature time curve. The specific heat capacity was calculated from a heat balance equation, expressed by several authors, including Ekpe and Akpabio [15] as

Heat loss by the hot sample = heat gained by calorimeter and cold water.

Thermal diffusivity D was determined using the relationship (Ekpe and Akpabio [15])

$$D = \frac{\lambda}{\rho c}, \tag{5}$$

where ρ is the density and c the specific heat capacity of the sample. Thermal absorptivity α was then calculated from the following expression:

$$\alpha = \left(\frac{\omega \rho c}{2\lambda}\right)^{1/2} = \left(\frac{\omega}{2D}\right)^{1/2}, \tag{6}$$

where ω is the angular frequency.

5. Results and Discussions

5.1. Results

Table 1 shows typical result as recorded from Bruel and Kjaer rapid thermal conductivity machine, while Table 2 shows the experimental results for thermal conductivity values and other related thermophysical properties of naturally dry Elaeis guineensis timber used in this study. The result shows a mean thermal conductivity value of $(0.0613 \pm 0.0009)\,\text{Wm}^{-1}\text{K}^{-1}$ with a mean bulk density of $(316.1 \pm 15.9)\,\text{kgm}^{-3}$ and the mean particle density of $(489.3 \pm 18.3)\,\text{kgm}^{-3}$, resulting in $35.5 \pm 3.1\%$ as the mean percentage porosity. Table 3 shows thermal conductivity and density values expressed by others for wood from other plants (Diamant [13], Twidell and Weir [30]), for comparison. Figure 1 shows the relationship between thermal conductivity and temperature for dry oil palm trunk.

5.2. Discussions

The result in Table 2 indicates a low thermal conductivity value for dry palm oil trunk. This is plausibly due to the high volume of dead or still air space in the cell cavities of the plant samples used for this work (high porosity of about 35.5%). This also accounts for the low bulk density of about $316\,\text{kgm}^{-3}$ relative to the particle density of $489\,\text{kgm}^{-3}$. The result compares favourably with those of insulation materials shown in Table 3. The low thermal conductivity value coupled with low bulk density value favours the choice of dry Elaeis guineensis timber as insulation material.

Figure 1 shows the temperature dependence of thermal conductivity of Elaeis guineensis timber. It increases slightly with temperature. The trend suggests that it increases linearly with temperature given the temperature range under study. This slight but negligible increase is supported by the report of Beck et al. [5], which stated that, for a temperature range of $0 - 100°\text{C}$, the temperature dependence of thermal conductivity of the bulk material is considered to be negligible.

The low thermal diffusivity value of $8.9 \times 10^{-8}\,\text{m}^2\text{s}^{-1}$ is due to the low thermal conductivity and moderate density, which is traceable to the large volume of dead air space in the material and the specific heat capacity value. This argument is supported by the Forest Product Laboratory [18] definition of thermal diffusivity as the ratio of thermal conductivity to the product of specific heat capacity and density. The low diffusivity indicates very low vibration of the material particles of the sample as a result of increased temperature. This results in a reduced rate of flow of heat through unit cross sectional area per unit temperature gradient.

6. Conclusions

The thermal conductivity value measured for seasoned (dry) oil palm trunk (timber) of $0.0613\,\text{Wm}^{-1}\text{K}^{-1}$ at temperature of $28°\text{C}$ is close to those of commonly used insulation materials (shown in Table 3). Within the temperature range considered in the study, thermal conductivity values of dried oil palm trunks show negligible temperature effect. Thus, trunks of oil palm trees would make an interesting material for building insulation, which is yet to be utilized by building industries despite the fact that it is readily available and commonly found in some parts of the world. This is probably because of lack of adequate data on its thermal properties to inform potential users of the effectiveness of the material for insulation. Insulation boards of conventional insulation sizes from oil palm tree trunk could be produced for building applications.

7. Recommendations

Having provided research data on thermal properties of dry oil palm tree trunk which places the trunk (timber) favourably in the list of insulation materials, it is therefore recommended that the use of old unproductive oil palm tree trunk for insulation in buildings be encouraged. Individuals as well as government agencies responsible for drop science and forestry should embark on massive planting of oil palm trees for the purpose of oil and kernel at the productive age and, of course, trunk (timber) of the tree at its old unproductive age for insulation boards. Building industries are encouraged to patronize the material for insulation.

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References

[1] N. Abedinov, P. Grabiec, T. Gotszaik, T. Ivanov, J. Voigt and I. W. Rangelow, Micromachined piezoresistive cantilever array with integrated resistive microheater for calorimetry and mass detection, J. Vac. Sci. Technol. A4 19(6) (2001), 2884.

[2] B. O. Aduda, Effective thermal conductivity of loose particulate systems, J. Mater. Sci. 31(1) (1996), 6441.

[3] K. Ajibola and F. Falade, Determination of some structural properties of African palm timber (Elaeis quineensis), Ife Technol. 1(2) (1990), 24.

[4] K. Ajibola and B. O. Onabanjo, Investigation of cocos nucifera as a potential insulator for buildings, Renewable Energy 6(1) (1995), 81.

[5] A. Beck, U. Heinemann, Reidinger and J. Fricke, Thermal transport in straw insulation, J. Therm. Env. Bldg. Sci. 27(3) (2004), 227.

[6] Black Allied Mining and Construction Workers Union (BAMCWU) position paper, Workers protest against the use of asbestos, Clavion 1(2) (1985), 2.

[7] C. R. Blake and K. H. Hartge, Bulk density, Methods of Soil Analysis, A. Klute, ed., Part 1, Agron Monogr, 2nd ed., 9 ASA and SSSSA, Madison, W1, 1986, pp. 363-375.

[8] G. Cocorullo, F. G. Della Corte and I. Rendina, Temperature dependence of thermo-optic coefficient in crystalline silicon between room temperature and 550 K at the wavelength of 1523 nm, Appl. Phys. Lett. 74(22) (1999), 3338.

[9] D. A. de Vries, Thermal properties of soil, Physics of Plant Environment, W. R. Vin Wijk, ed., Amsterdam, North Hollands, 1963, pp. 210-235.

[10] D. A. de Vries, A critical analysis of the calorimetric method for determining the heat

flux in soils, Proc. 8th Int. Heat Transfer Conf., Hemisphen Publication Corporation, Washington, Vol 2, 1986, pp. 473-476.

[11] D. A. de Vries, Soil heat flux, thermal conductivity and the null-alignment method Soil Sci. Soc. Am. J. 50 (1986), 12.

[12] D. A. de Vries, The theory of heat and moisture transfer in porous media revisited, Int. J. Heat Mass Transfer 30(7) (1987), 1343.

[13] R. M. E. Diamant, Thermal and Acoustic Insulation, Butterworth, England, 1986, p. 3.

[14] S. D. Ekpe and S. K. Dew, Investigation of thermal flux to the substrate during sputter deposition of aluminum, J. Vac. Sci. Technol. A 20(6) (2002), 1877.

[15] S. D. Ekpe and G. T. Akpabio, Comparison of the thermal properties of soil samples for a passively cooled building design, Turkish J. Phys. 18 (1994), 117.

[16] S. D. Ekpe, Study of energy flux in magnetron sputter deposition system, Ph.D. Thesis, University of Alberta, Edmonton, 2005, pp 54-70.

[17] S. K. Essiamah, The utilization of palms in West Africa, Plant Research and Development 21(1) (1985), 45.

[18] Forest Products Laboratory, Wood as an engineering material, Agriculture Handbook No. 72, US Government Printing Office, Washington D. C., 1974.

[19] W. H. Hodge, The world of Palms, J. American Horticultural Society, Special issue 40(1) (1961), 17.

[20] H. Kersten, H. Steffen, D. Vender and H. E. Wagner, On the ion energy transfer to the substrate during titanium deposition in a hollow cathode arc discharge, Vacuum 46(3) (1995), 305.

[21] J. N. Kimani and B. O. Aduda, Temperature dependence of the thermal conductivity of a Grog modified Kenyan kaolinite refractory, African J. Sci. Technol.: Science and Engineering series 5(1) (2004), 6.

[22] B. A. Kimball and R. D. Jackson, Soil heat flux determination: Temperature gradient method with computed thermal conductivities, Soil Sci. Soc. Am. J. 40 (1996), 26.

[23] V. Lysenko, S. Perichon, B. Remaki, D. Barbier and B. Champagnon, Thermal conductivity of thick mesoporous silicon layers by micro-Raman scattering, J. Appl. Phys. 86(12) (1999), 6841.

[24] D. McCammon, R. Almy, E. Apodaca, S. Deoker, M. Galeazzi, S.-I. Han, A. Lesser, W. Sanders, R. L. Kelley, S. H. Moseley, F. S. Porter, C. K. Stahle and A. E. Szymkowiak, High-resolution calorimetry: Limitations of doped semiconductor thermometers, Nucl. Instrum. Methods Phys. Res. A 436 (1999), 205.

[25] I. K. Moon, D. H. Jung, K. B. Lee and Y. H. Jeong, Peltier microcalorimeter, Appl. Phys. Lett. 76(17) (2000), 2451.

[26] J. H. E. Moore, Botany and classification of palms, J. American Hort. Soc., Special issue 40(1) (1961), 17.

[27] H. Nishino, W. Yang, Z. Dohnalek, V. A. Ukraintsev, W. J. Choyke and J. T. Yates Jr., Silicon crystal heating and thermocouple mounting using pulsed photothermal radiometry and silver halide infra red optical fibres, Appl. Phys. Lett. 70(12) (1979), 150.

[28] T. E. Ochsner, R. Horton and T. Ren, A new perspective on soil thermal properties, Soil Sci. Soc. Am. J. 65 (2001), 1641.

[29] H. Steffen, H. Kersten and H. Wuff, Investigation of the energy transfer to the substrate during the titanium deposition in a hollow cathode arc, J. Vac. Sci. Technol. A 12(5) (1994), 2781.

[30] J. Twidell and T. Weir, Energy Resources, E. and F. N. Spon, London, 1990, pp. 416-418.

[31] P. L. Yong, M. W. Anyakoha and P. N. Okeke, University Physics, Africana-FEB Publishers Ltd., Onitsha, Vol. 1, 2002. p. 451.

[32] D. A. Zumbremen, R. Viskanta and F. P. Incropora, Heat transfer through porus solids with complex internal geometries, J. Heat and Mass Transfer 29(2) (1986), 275.

[33] A. Bouguerra, H. Salle, F. De Barquin and M. Queneudec, Cement Concrete Res. 29 (1999), 339.

[34] A. Bouguerra, M. B. Diop, J. P. Laurent, M. L. Benmalek and M. Queneudec, J. Phys. D: Appl. Phys. 31 (1998), 3457.

[35] J. Fricke, Material research for the optimization of thermal insulations, High Temperature-High Pressures 25 (1993), 379-390.

Table 1. Details of experimental values measured from Bruel and Kjaer thermal conductivity machine for fibre glass (calibration sample) and five samples of naturally seasoned (dry) Elaeis guineensis

Sample	Q (mV)	T_c (mV)	T_h (mV)	x (cm)	ΔT	λ_c ($Wm^{-1}K^{-1}$) (Standard)	λ ($Wm^{-1}K^{-1}$)
Fibre Glass	0.924	2.116	2.501	2.47	0.385	0.035	
1	1.778	2.140	2.553	2.52	0.413		0.064
2	1.767	2.106	2.552	2.61	0.446		0.061
3	1.686	2.174	2.609	2.58	0.435		0.059
4	1.861	2.206	2.614	2.49	0.408		0.067
5	1.528	2.125	2.533	2.49	0.408		0.055

Table 2. Thermal properties of naturally seasoned (dry) Elaeis guineensis timber

Test Sample	Thermal Conductivity, λ ($Wm^{-1}K^{-1}$)	Density (kgm^{-3})		Porosity (%)	Specific heat capacity, c ($Jkg^{-1}K^{-1}$)	Thermal diffusivity, D (m^2s^{-1} x 10^{-8})	Thermal absorptivity, α (m^{-1})
		Bulk, ρ_B	Particle, ρ_P				
1	0.0641 ± 0.0009	318.2 ± 16.0	485.7 ± 18.0	34.4 ± 3.0	2170 ± 31	9.29 ± 0.73	19.88 ± 1.56
2	0.0611 ± 0.0009	320.0 ± 16.1	492.6 ± 18.5	35.0 ± 3.1	2204 ± 38	8.66 ± 0.71	20.56 ± 1.68
3	0.0590 ± 0.0008	313.3 ± 15.8	499.0 ± 18.5	37.2 ± 3.3	2148 ± 33	8.77 ± 0.69	20.39 ± 1.60
4	0.0671 ± 0.0010	322.0 ± 16.2	459.9 ± 18.0	31.2 ± 2.8	2095 ± 28	9.95 ± 0.78	19.17 ± 1.50
5	0.0551 ± 0.0008	307.2 ± 15.5	509.3 ± 18.6	39.7 ± 3.5	2204 ± 38	8.14 ± 0.66	21.19 ± 1.72
Mean	0.0613 ± 0.0009	316.1 ± 15.9	489.3 ± 18.3	35.5 ± 3.1	2164.2 ± 31.6	8.96 ± 0.71	20.24 ± 1.61

Table 3. Densities and thermal conductivities of some known insulation materials (Twidell and Weir [30], Diamant [13])

Material	Density (kgm^{-3})	Thermal conductivity ($Wm^{-1}K^{-1}$)
Oak wood	770	0.160
Pine wood	570	0.138
Pine fibreboard (25 °C)	256	9.952
Asbestos cement sheet (30 °C)	150	0.319
Corkboard (dry, 18 °C)	144	0.042
Cardboard	700	0.200
Mineral wood, Baths	32	0.035
Still air (27 °C, 1 atm)	1.18	0.026
Clay (dry)	1800	0.810
Rubber (soft)	1100	0.140
Rubber sponge	225	0.200
Balsa wood	113	0.046
California redwood	352	0.095
Spine (Scandinavian)	352	0.089

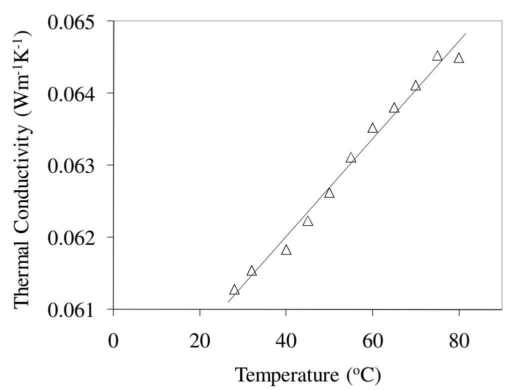

Figure 1. Variation in thermal conductivity of naturally seasoned (dry) Elaeis guineensis timber with temperature.