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Experimental Investigation of Thermal Conductivity of Woods by Linear Regression Approach

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ABSTRACT: *This research tries to study the experimental investigation on thermal conductivity of Melina and wall nut woods using linear regression approach .From the thermal conductivity investigation of woods by linear regression approach , test results show that the values of thermal conductivity for Melina wood falls in the range of K between 0.002w/mk^{-1} to 0.007w/mk^{-1} which is on the low side and the wall nut between 0.0001w/mk^{-1} to 0.041w/mk^{-1} which is on the high side .It therefore depicts that Melina has a better thermal conductivity than wall nut since thermal conductivity of it (Melina) agrees with the literature that thermal conductivity is better with lower values of K.*

KEYWORDS*: Linear-regression, Modified Lee Disc, thermal conductivity.*

INTRODUCTION

Wood is hard fibrous tissue and organic material found in many plants. Natural composite of cellulose fibers -with strong tension capability rooted in a matrix of lignin which repels compressive force. Wood also may be stated as other plant materials that has equivalent properties, and to any other material gotten from wood, or wood panels, chips and fiber. The conduction of heat across Nigerian woods is less understood, especially since this phenomenon has received little attention until investigations to alternative building materials starts to develop as a result of high cost of concrete and iron based materials.

Wood is resilient and has a good strength. This blend of strength and resilient attribute gives wood its knack to hold the shock that comes from heavy loads offering larger boundary of safety than many other engineering materials. Talking about cost, the alteration cost of wood - manufacturing cost of the products starting from the raw material level to finished product - wood is far much less than any other engineering materials. Using wood for energy conversion is also much lower. In engineering material selection the two factors are very vital for decision making. In building construction and installations, engineers and architects consider the insulating capacity of wood to steel or aluminum, since wood has 10 times better insulating capacity than the mentioned other materials and also 5 times more effective as an insulator than concrete or cinder blocks.

The most vital of nature's gift to man is wood and wood based materials: because of three main reasons which includes. First, wood is worldwide: wood is everywhere, a raw

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material that can fulfill almost every requirement on life. Wood makes available food for man and animals. Wood finds its way in the textile industry. Wood is also in the automobile industries as it is capable of producing motor fuels (biofuel) and lubricants. In building sector, wood is the chief raw material of any building from start to finish. Engineers have no substitute for wood in building. Secondly, wood is copious, Forest is more than eight billion acres, which is one quarter of the total earth's surface. The availability of wood cannot be compared with other natural resources like oil, iron ore, coal and others. It can be argued that soon deforestation will take over the forestation, but only a small segment of the world's forest is being utilized. Also an acre of good forest can grow, annually, as several times as much wood fiber is pulled down so much wood fiber is planted immediately for replacement: afforestation.

Finally, the wood resources are inexhaustible, forest is not a mine that will be depleted, but a crop - provided that trees are harvested as a crop and the forest is sustained by proper management. The submission here, therefore, is that one of man's highest natural gifts is wood. There is no other material that has given engineers so much to work with through these centuries. Its renewable ability stands out because not only does wood gives us food, shelter, energy for warmth and cooking, clothing, tools, and 10,000 other products, but it renews itself naturally. Afforestation is encouraged because trees take our waste carbon-dioxide and gives man the much needed oxygen to stay alive.

LITERATURE/THEORETICAL UNDERPINNING

Exact measurement of steady state thermal property of moist wood and wood particles does not necessarily lead to better thermal conductivity values. They evaluated two hypotheses (a) thermal conductivity of solid wood is a linear function of density and MC of the form of equation below.MacLean, (1941) and Wilkes, (1981) postulated that from the equation above that K_0 should equal roughly the thermal conductivity of air (approximately 0.024 w/m-k). After fitting the above to the equation, MacLean arrives at the following equation for moisture content below and above 40% respectively.

Hankalin et al, (2009), reviewed this contact conductance as it effects the thermal conductivity of solid bodies. The answer to the question of air density and lumen space and geometry in case of Hunt et al, (2008) and TenWolde *et al*, (1988) to their work seemed answered. The study of two surfaces in contact with one hotter that the other and heat is conducted to the cooler one is called thermal contact conductance. Like the diagram below body A and body B in contact. Figure1. From our normal heat flow gradient, heat flows from hotter to colder body, also from experience; the temperature profile along the two bodies varies, approximately, a temperature drop is observed at the interface between the two surfaces in contact. This phenomenon is as a result of the opposites of thermal contact conductance, which is thermal contact resistance, existing between the contacting surfaces. Contact resistance is the inverse of contact conductance.

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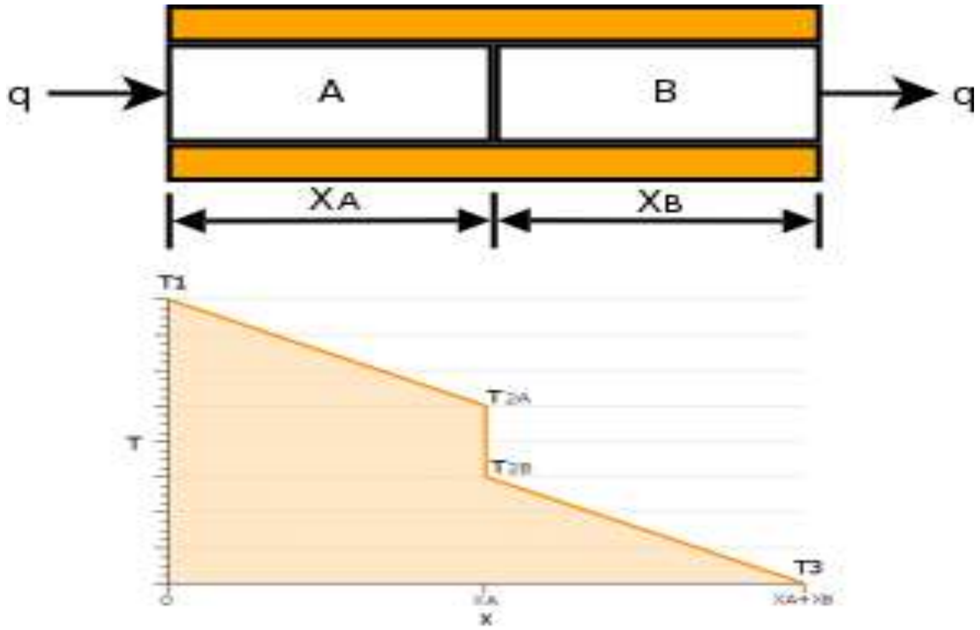

Figure 1: **Heat flow between two bodies in contact and the temperature distribution**.

This encyclopedia still took us to the theory we are working on; Fourier's law.
The heat flow between the two bodies is found by bringing in the energy conservation theory in the equation and expanding it to give us the thermal contact conductance of a solid body.
Heat flow between two bodies is found as;

$$q = \frac{T1 - T3}{\Delta X_A / (K_A A) + 1/(h_C A) + \Delta X_B / K_B A} \qquad (1)$$

q = applied heat (w)
$T_1 - T_3$ = the temperature difference including the contacting area.
K_A = thermal conductivity of body A (w/mk)
K_B = thermal conductivity of body B (w/mk)
X_A and X_B = the distances from the probe of bodies A and B (m)
A = area of the contacting area (m^2)
$1/h_c$ = the contact resistivity the inverse of contact conductance.

From the above it was witnessed that the heat flow is directly connected to thermal conductivity of the bodies in contact, K_A and K_B, the contact area, A and the thermal resistance, 1/hc, which is the inverse of the thermal conductivity coefficient h_c.

Ayers *et al.*, (1995) in their thermal contact conductance highlighted the importance of thermal contact conductance. Also Holman, (1997) and Fletcher, (1988), brought us closer to what we use to have in this century. In electronics; electronics packaging, heat sinks and brackets needs the theory of contact conductance. This analysis is needed in industry areas like nuclear reactor cooling, gas turbine cooling, internal combustion engines, heat exchangers and thermal insulation, contact conductance theory is needed to be able to

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analyze the heat transfer well. In researches; the theory is highly needed as it is the chief source of information for the other applications. The air, density and space issues that seem unsolved in the two reviewed literatures above can be handled with the contact conductance theory. we have electric iron as our heat source and the sample wood to be in contact with the iron, two different materials in contact their will be some things happening at the contact surface which is contact conductance. From our physics, no surface is smooth not even mirror, so therefore, there is space left even at the point of contact, air and water are trap in it, which was the problem of Hunt et al, (2008) and TenWolde et al, (1988) in their literature of properties effecting thermal conductivity. In the cause of this work we found that there are some factors influencing the contact conductance of two bodies in contact, even experience shows these factors as follows; contact pressure; this is the most influential of the other factors. Increase in contact pressure of the two surfaces brings about also increase in the contact conductance, automatically, contact resistance becomes smaller. This is accredited to the fact that the contact surfaces between the bodies increases as more force is applied to it which is the contact pressure increase. Most studies and correlation and mathematical models measurement on contact conductance are done using contact pressure. Again there are defects in the surfaces this constitute another influence in conductance, since to smooth surface actually exist; contact of the two surfaces is only achieved in predictable number points, which are detached by fairly large cavities. This brings to bear another resistance to heat flow since the total surface area in contact is reduced. These cavities are filled with gasses/fluids, yet another different material is introduced and heat flow is influenced as well. The two mentioned defects - Contact conductance interstitial defects and contact pressure are governing properties that influences the thermal conductivity of wood as well. This particular property of thermal conductivity was neglected or was not properly understood by the old researcher on this topic, but due to the emerging usage of wood more work on the topic was done, better findings and application were made.

There are other factors like surface roughness, waviness and flatness, surface cleanliness and surface deformation, Williamson *et al*., (1992) wrote on the surface deformation in their paper surface deformation in contact conductance.

METHODOLOGY

In order to evaluate the thermal conductivity of Nigerian woods, through a triangular interface and pyramid volume, a known thermal conductivity apparatus was modified - lee disc was re-designed to obtain data over a temperature range of Nigerian wood samples and under some certain thermal conditions. Heat was supplied to the assembly by Q-link manufacturing company with a triangular shaped 210 x110mm electric iron of 1100w capacity, Too avoid heat loss; the wood samples were cut in the same shape with the electric iron of triangular shape and coated with fiber glass heat insulator, with a little dimensional difference. The heat source is from mains of supposedly 240v.

$$P = IV \tag{2}$$

Where P (w) is equal to the applied heat Q (w).

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Instrumentation

The calculation of thermal conductivity of woods and other materials involves the use of some instruments to acquire some vital data needed for the calculation. Some of the instruments used are

Thermocouple

Type K thermocouple was used. The range is -323k to 1573k with tolerance of ±0.75%. K-Type is described as 3.24x150mm metal sheath 100cm compensating wire. This gives us the temperature difference (dt) in the Fourier's law with a digital thermometer displaying the data. Type K (chromel – alumel) is the most commonly general purpose thermocouple, as we have described above.

Thermometer

TES- 1303 digital thermometer for the thermocouple (probe) above was used. This digital temperature sensor used follows NBS and IEC 584 temperature /voltage standard tables for K-type thermocouple. Dimension of the temperature sensor includes; 135(L) x 72(W) x 31(H) mm and 235g weight with battery and has a display rate of approximately 2.5 times per second. The thermometer should be calibrated once a year to ensure its accuracy is within specifications. This gives us a dual display for both thermocouples at the distance x at once.

Ammeter

Analog AC ammeter of 0- 25amps measurement ranges was used to measure the current that is supplied to the heater. This gives us the, I value in equation 2 above, for the calculation of power (heat applied).

Voltmeter

Also an analog AC voltmeter range of 0- 500volts was used to measure the voltage coming to the heater. Again this gives us the value of V in equation 2 for the heat applied to the whole assembly.

Meter Rule

This was used to measure the distance of the two probes (thermocouples) and also helped in measuring the width and the height, for the calculation of the wood samples area A (m^2). Two out of the five woods were further selected for the linear regression model of predicting thermal conductivity over the entire body of a solid material like wood. These two woods are Melina and wall-nut, four holes were drilled in the direction of the applied heat with different distances. Using a straight line linear regression equation, prediction can be made at any distance around the body of the wood sample. These holes drilled will accommodate four thermocouples at a time for the temperature reading for at least fifteen minute or less. Prior to installation within the test load up, the contacting surfaces of each specimen was cleaned and coated with thermally conductive grease and they were placed between the contacting surface of the heat source and the wood samples. The thermally conductive grease reduces the power required by the heater to maintain the test specimen at a desired temperature by reducing the temperature discontinuities at the interfaces between the

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specimens. Alignment of the specimens with the heat flow source was meticulously checked to avoid uncertainty and tighten very firm for the test to start.

Thermal Conductivity

The thermal conductivity of the materials used in this investigation was determined by means of the modified lee disc method. This method, as employed in this investigation, imposes a flow of heat through a triangular shaped wood samples. The samples and the heat source are placed together, and heat is introduced at one end of the surface of the samples and removed at the other end of the sample. The heat applied, the temperature difference and the thermal conductivity were calculated using linear regression equation for two samples prediction of thermal conductivity at any distance on the sample. Fourier's Law was used to determine the thermal conductivity of the samples for the anisotropic behavior of wood. Each sample has two pieces each of different grain direction.

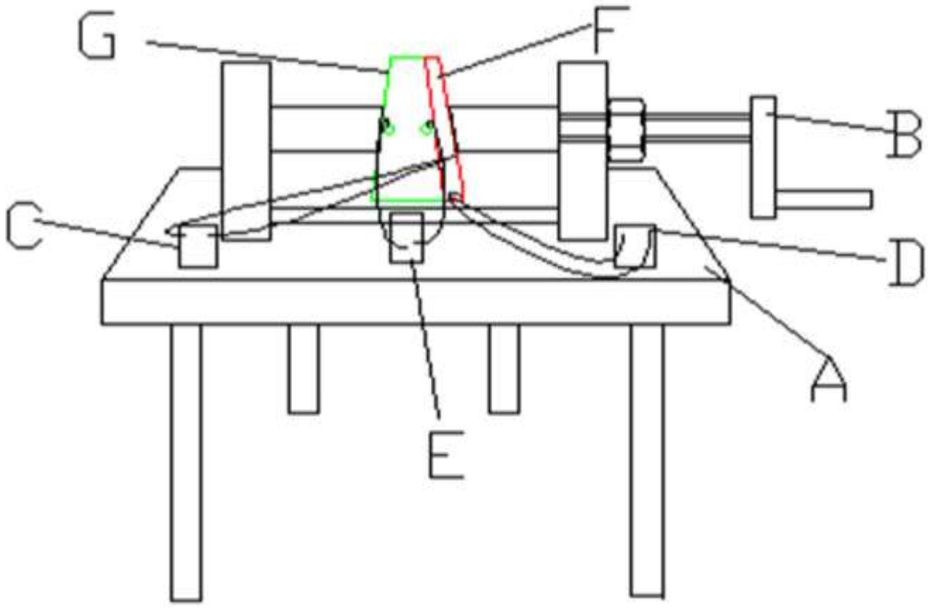

Figure 2. Schematic Diagram of modified lee disc apparatus

Keys to the Schematic diagram above

A – Laboratory Table
B – Modified Lee Disc Apparatus
C – Ammeter
D – Voltmeter
E – TES-1303 Digital Thermometer with Type-K Thermocouple
F – 1.5kw Power Source
G – Wood Sample

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Plate 1. Photo of the experimental set up of modified lee disc apparatus

Linear Regression Testing

Many engineering test results employ the use of the correlation of fitted curve of linear regression of the form;

F(X)= $a + bx$ (3)

This equation is of the form of a straight line equation of the form;

Y= $a + bx$ (4)

The gradient of the curve becomes the thermal conductivity of the wood sample. Likening the equation to temperature and distance, we have equation of the form;

T= $a + bx$ (5)

Where;

T is the temperature at the distance x.

X is the distance in meter.

Where 'a' and 'b' are variables to be obtained with the following equations below. They are used to test the fit of the curve to ascertain how fitted is the curve. After a and b had been gotten, they will be used in 'r' to obtain the fattiness of the curve which its gradient will serve as the thermal conductivity 'k'

$$b = (\sum x1y1 - (\sum x1 \sum y1/n)/(\sum x1^2 - (\sum x1)^2/n) \quad (6)$$

$$a = [\sum \frac{y1}{n} - b \sum x1/n] \quad (7)$$

Where; ∑x1 is the temperature values, ∑y1 is the values of the distance between probe to probe, n is the number of probes being worked on.

The table we have is for temperature of four probes and four distances from probe to probe.

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Table 1: Test values from the wood sample Melina

Temp. (K)	371.7	370.2	367.3	358.1
dx (m)	0.012	0.023	0.027	0.029

Table 2: Test values from the wood sample Wall-Nut

Temp. (K)	369.4	350.2	348.4	362.6
dx (m)	0.020	0.027	0.030	0.025

This test was gotten at the time interval of fifteen minutes; four probes are pointed directly to the direction of the applied heat. And we shall be plotting temperature against distance. We could check for the fitness of the curve with the formula below;

$$r^2 = [\sum x1y1 - (\sum x1 \sum y1/n)]/[\sum x1^2 - (\sum x1^2)/n]\,[\sum y1^2 - (\sum y1^2/n] \quad (8)$$

If the r^2 is 1.00 then the curve fit is a good fit, therefore interpreting with thermal conductivity then we must be talking of good gradient of the interpolation of temperature versus distance, invariably the thermal conductivity is at the expected range, while our is very close to 1.00.
From equations 4 and 5 the values of 'a' and 'b' using the data in the table above for each of the samples were obtained as:
For Melina

$b = 15,80$
$a = 90.23$

For Tick (wall nut)

$b = 0.154$
$a = 84.6$

For Melina the prediction of the thermal conductivity follows the substitution of the values of 'a' and 'b' in equation 3 for a known distance to get the temperature. The gradient of the equation becomes the thermal conductivity.

$$T = 90.23 + 15.80X \quad (9)$$

This is the predicting equation for a known distance for Melina.
For Tick (Wall nut) the prediction equation is

$$T = 84.6 + 0.154X \quad (10)$$

The predicting equations can be used for any distance on the wood sample. That is to say that the behaviour of the heat (heat flux) for the entire wood sample can be determined using the equation. At any measured distance 'x' you get the corresponding temperature T, and further get the gradient that gives the 'K'.

RESULTS/FINDINGS

Investigation of Thermal Conductivity of Woods by Linear Regression Approach

From the tables 1 and 2 we have gotten the data to plot temperature against distance so that we can get our thermal conductivity for each of the two samples.

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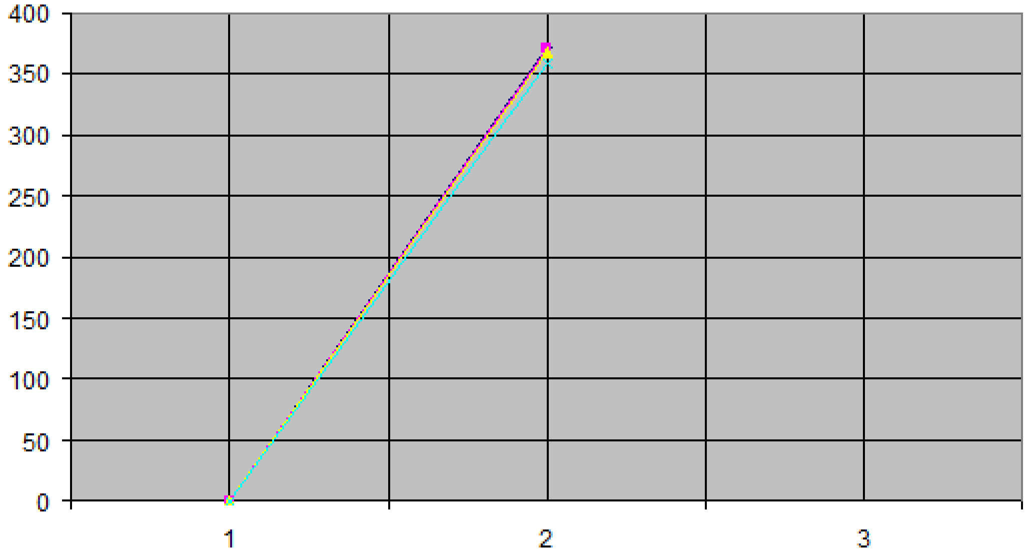

Figure 3: Thermal conductivity of Melina

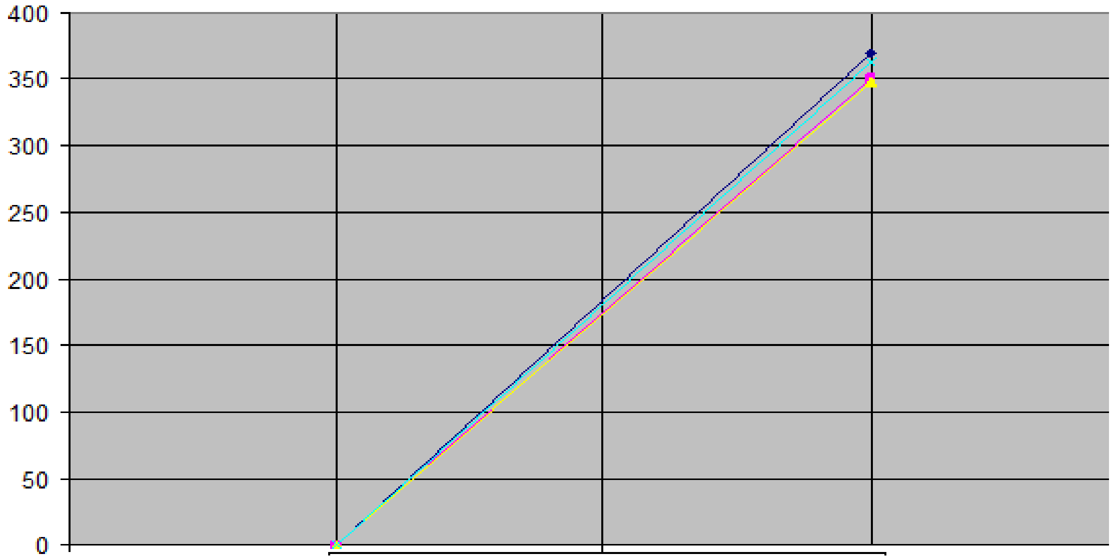

Figure 4: Thermal conductivity of wall nut

DISCUSSION

Form the above plot we had our gradient of dx/dt as the thermal conductivity of Melina taking from each of the linear lines, is between the values below: $K = 0.002w/mk^{-1}$ - $0.007w/mk^{-1}$ Taking our gradient from the highest and the lowest values the best value for Melina is $0.002w/mk^{-1.}$ The K value of wall-nut sample as plotted is between $0.0001w/mk^{-1}$ – $0.041w/mk^{-1,}$ however, the wall-nut values was very low in the range of thermal conductivity values of wood, because the gradient of the highest and lowest values of the points were taking and the $k = 0.0001w/mk^{-1}$

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IMPLICATIONS TO RESEARCH AND PRACTICE

This research has aided the development of an equation for the prediction of thermal conductivity of engineering materials using linear regression approach.
In the use of wood as an engineering materials, designers should consider the direction of the wood grains as this will help determining the right side and way to place the wood to the heat source.

CONCLUSION

From the thermal conductivity investigation of woods by linear regression approach, it is shown that the values of thermal conductivity for Melina woods falls in the range of K 0.002w/mk^{-1} to 0.007w/mk^{-1} which is on the low side and the wall nut between 0.0001w/mk^{-1} to 0.041w/mk^{-1} which is on the high side. It therefore depicts that Melina is a better heat conductor than wall nut since thermal conductivity of (Melina) agrees with the literature.

Further Research

Using regression analysis is one of many engineering analytical methods, hence, more work is advice to be carried out for the same wood samples using many other analytical methods available, this will help us in further validations of our results.

References

Ayers, G. H., Fletcher, L. S. and Madhusudana, C.V. (1997) Thermal contact conductance of composite
cylinders, journal of thermophysics and heat transfers, vol. 11 (1).

Hankalin, V., Tuukka, A. and Risto, R. (2009) Thermal properties of pyrolysing wood particles, Finnish
flame research committee of international flame research foundation vol. 10

Holman, J.P, (1990) Heat transfer Tenth Edition, McGraw-Hill Series in Mechanical Engineering, 2 (27-
60, 3 (77-120)

Hunt, J.F, Gu, H and Lebow, P.K, (2008) Theoretical thermal conductivity equation for uniform density
wood cells, wood and fiber science journal, vol. 40, Nos 2,

MacLean, J.D (1941) Thermal Conductivity of Wood, Heat. /Piping/Air-Conditioning journal, vol.13,
380-91

Tenwolde, A, McNatt, J.D and Krahn, L, (1988) Thermal property of wood and wood panel products for
use in buildings, Oak ridge national laboratory, USA.

Williamson, G.B and Wiemann, M. C, (1989) Radial gradients in the specific gravity of wood in some
tropical and temperate trees, Forest Science, 35, 197 – 210.

Williamson, G.B (1992) Thermal conductivity study of wood, by springer series

Wilkes, K.E (1981) Thermo-Physical Properties Data Base Activities at Owens-Corning Fiberglas,"pp.

Print ISSN: ISSN 2055-6551(Print), Online ISSN: ISSN 2055-656X(Online)

662-77, in Thermal Performance of the Exterior Envelopes of Buildings, ASHRAE SP 28, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta,Ga