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# COMPARATIVE STUDY OF THERMAL INSULATION BOARDS FROM LEAF AND BARK FIBRES OF CAMEL'S FOOT (*PILIOSTIGMA THONNINGII* L.)

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## ABSTRACT

***Plants and agricultural wastes with high degrees of fibrous content in form of lignocellulose compounds have been identified as main ingredient in composites, making them suitable for manufacturing of insulation boards and panels. Thus, several researches have succeeded in using these plants and agro waste fibres in developing renewable and environmentally friendly thermal insulation products. The aim of this study was to compare the performance of insulation boards made from leave and bark fibres of Piliostigma thonningii L.in terms of density, water absorption, apparent thermal conductivity, specific heat and thermal diffusivity. The leave and the bark fibres were prepared in form of squared boards of 200 mm x 200 mm and thickness of 20 mm using natural rubber latex as a binder. The fibre to binder ratio was varied with a composition of 1:1, 1:2, 1:3 and 1:4. The LFB recorded densities between 528.6 kg/m$^3$ and 538.4 kg/m$^3$ while in the BFB the densities are between 558.3 kg/m$^3$ and 711.8 kg/m$^3$at various compositions. The Percentage water absorption for the LFB is between 36.51% and 12.03% while the BFB is between 25.02% and 13.23%. Similarly, the apparent thermal conductivity values for LFB are between 0.032096 W/mK and 0.040855 W/mK while that of the BFB are between 0.039439 W/mK and 0.043406 W/mK. The specific heat values of the LFB are between 2901.88 J/kg.K and 3656.48 J/kg.K and that of the BFB are between 2044.46 J/kg.K and 2512.61 J/kg.K while the thermal diffusivity is between 2.05E-8 m$^2$/s and 8.07E-9 m$^2$/s for the LFB and 1.57E-8 m$^2$/s to 2.68E-8 m$^2$/s for BFB. The boards recorded thermal properties that are comparable to those of the commercially available products with LFB performing consistently better than the BFB.***

***Key words:*** *Thermal Insulation, Leave fibres, Bark fibres, apparent thermal conductivity, Lignocellulose compounds, Fibrous content.*

## 1. INTRODUCTION

It has become prevalent to use thermal insulation materials to sustain confortable temperatures in living environment and to reduce the cost of heating and cooling as a result of heat loss or gain in industrial processes [1, 2]. Due to the rising energy demand and consumption, fluctuating prices of fossil fuels (crude oil) and its resultant effect of global warming, energy conservation through the use of thermal insulation is regarded as an effective and efficient method [3, 4]. Thus thermal insulation materials play an important role in achieving high energy efficiency resulting in decrease in the cost of cooling and heating as well as decrease in environmental pollution. However, the commonly used materials for low temperature application such as polyurethane, polyisocynurate and polyestyrene have some negative effects on human health and body and cause environmental pollution due to non-decomposition after their useful life [4]. According to Berge and Johansson [5], thermal insulation materials such as polyurethane (PUR) foam contains ozone depleting chlorofluorocarbons (CFC-11) which are of great environmental concern. For these reasons, there is an urgent need for a more environmentally friendly biodegradable low temperature thermal insulation material to replace the commercially available ones.

Several authors have proposed different plants and agricultural wastes for making products such as particles boards, hard boards and fibre boards focusing majorly on their thermal insulation [6]. These studies revealed the potentials of the natural biodegradable

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fibrous materials for production of thermal insulation with numerous benefits to the health and environment. Panyakaew and Fotios [7] opined that the use of renewable fibrous materials especially from agricultural by-products for thermal insulation will in addition generate economic development for farming and rural populace. Some of the materials studied in this context include; rice husk [8], oil-palm fibres [9], papyrus fibres [4], pineapple leaves [2], coconut husk [8, 10, 11], straw [12], corn cob [6] to mention but few. The plant studied in this work is the Camel's foot (*Piliostigma thonningii* L.) which has been used traditionally in form of mats and loose-fill insulation and as thatch by Fulani herders in the northern part of Nigeria purposely to insulate their huts from hot and cold weathers. These facts inspired us to study the fibres in form of particle boards to ascertain or otherwise the insulation ability of the fibres. In preparation of the boards, natural rubber latex was chosen as a binder which is of great interest from environmental perspective since most of the conventional binders such as formaldehyde and urea formaldehyde are harmful to human health due to emission of toxic substances and causes environmental pollution [2].

Thus, the aim of the research was to develop thermal insulation boards from the leaves and bark fibres of Camel's foot (*Piliostigma Thonningii* L.), investigate the physical properties viz; density and water absorption and thermal properties viz; thermal conductivity, specific heat and thermal diffusivity. The performance of the boards from the two different materials was then compared. In addition, micro structure analysis of the boards was carried out using scanning electron microscope (SEM).

## 2. MATERIALS AND METHOD

### 2.1 Materials

The major raw materials for this work are the bark fibres and the leave fibres of Camel's foot (*Piliostigma thonningii* L.) which were collected from Girei Local Government Area of Adamawa State, Nigeria. Other materials include sodium hydroxide (NaOH), distilled water and Pre-treated natural rubber latex all of analytical grade obtained from Northern Scientific Chemicals shop in Yola, Nigeria.

### 2.2 Materials Preparation and Moulding

The major raw materials, which are the bark fibre and the leave fibres of Camel's foot (*Piliostigma thonningii* L.), were mercerized using 5%w/v sodium hydroxide (NaOH) solution at room temperature of $34^0C$ for 24 hours to soften the fibres. The fibres were thoroughly rinsed in a fresh tap water and air dried. The dried samples were ground into small sizes using a commercial grinder and then used for the preparation of the particles board. Two different sets of samples, one from the bark fibres and the other from the leaves were prepared separately as described above and stored in nylon. A rectangular wooden mould of size 200 mm by 200 mm was constructed with a thickness 20 mm. A required quantity of the fibre and the binder was charged into a mixer rotating at 120rpm and continuously mixed for 10 minutes until the particles were thoroughly impregnated with the resin and the mixture was then poured into the mould. A force of 0.25 kN was applied to ensure even settling of the product and was allowed to cure under the sun for five (5) days. Four (4) types of boards were produced from each sample with particles to binder ratios of 1:1, 1:2, 1:3 and 1:4. After forming, the boards were then cut into various test samples.

### 2.3 Tests

To determine the suitability of the particle boards for insulation, the thermal properties are of prime importance. But other physical and thermo physical properties are also significant. Hence, the following tests were conducted on the fibre boards.

#### *2.3.1 Microscopic Analysis*

A specimen of about 3 cm diameter was cut from each of the boards for surface preparation. The surface of interest on the cut samples were ground with abrasive paper starting with coarse grit and finishing with a fine grit. The surface was then thoroughly cleaned and polished to reveal the surface contrast. The microstructure analysis of the prepared board's samples was performed on the polished surfaces by Scanning Electron Microscopy (SEM).

#### *2.3.2 Density*

The densities of the boards were determined in accordance with the American Society for Testing and Materials (ASTM) C303-02 (Standard test method for dimensions and density of preformed block and board type thermal insulation) [13]. From each of the produced boards, four (4) specimens of 60 mm x 60 mm were cut. The thickness, length and the width were measured in three (3) different locations, with the thickness measured generally near the four corners of each specimen and the average of each was determined and recorded. The volume of each specimen was then calculated.

Each specimen was weighed using a digital weighing balance and the mass recorded. The density of each specimen was then calculated using equation (1):

$$Density = \frac{\text{mass, kg}}{Volume,\ m^3} \quad \left[{}^{kg}/{}_{m^3}\right] \qquad (1)$$

### *2.3.3 Water Absorption*

The water absorption test was conducted according to ASTM D1037 (water absorption test method A) [13]. The specimens used in the determination of the density were used since their masses and volumes were recorded. The water absorption was expressed as the percentage increase in volume based on the volume before submersion. The specific gravity of the water was assumed to be 1.0 for this purpose.

### *2.3.4 Apparent Thermal Conductivity*

The apparent thermal conductivity of the boards was determined in accordance with ASTM C518-02 (Standard Test Method for Steady –State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus) [13]. The equipment used for the test was Armfield HT10XC Heat Transfer Service Unit and HT11C Computer Compatible Linear Heat Conduction Accessory. From each of the boards, four (4) specimens were cut in form of a disc with a diameter (d) of 25±1 mm and the thickness (Δx) was measured and recorded. A specimen was clamped tightly in between two faces of heated and cooled brass sections, the heater voltage (V) was set to 10 volts and the heater current (I) was read from the console and recorded. After HT11C was stabilised, the temperatures $T_1$, $T_2$, $T_3$, $T_6$, $T_7$ and $T_8$ were also read and recorded from the console display. Where $T_1$, $T_2$ and $T_3$ are the thermocouples connected to the heating section of the instrument and $T_6$, $T_7$ and $T_8$ are those connected to the cold section of the instrument.

For each set of readings, the derived results were tabulated under the following headings: heat flow Q = IV; cross sectional area $A = \pi d^2/4$; temperature of hot face ($T_{hot}$) and cold face ($T_{cold}$) which were determined using equations 2 and 3.

$$\text{Where } T_{hot} = T_3 - \frac{(T_2 - T_3)}{2} \qquad (2)$$

$$T_{cold} = T_6 + \frac{(T_6 - T_7)}{2} \qquad (3)$$

The temperature difference across the specimen was determined from equation 4

$$\Delta T = T_{hot} - T_{cold} \qquad (4)$$

The thermal conductivity (k) of the specimen was calculated using Fourier rate equation given by equation 5.

$$k = \frac{Q\Delta x}{A\Delta T} \qquad (W/mK) \qquad (5)$$

### *2.3.5 Specific Heat*

The specific heat test was conducted according to ASTM C351-92b (Standard test method for mean specific heat of thermal insulation) (ASTM, 2004).

### *2.3.6 Thermal Diffusivity*

The thermal diffusivity of the material was calculated using equation (6) [14] as shown:

$$\alpha = \frac{k}{\rho Cp} \qquad (m^2/s) \qquad (6)$$

Where; k, ρ and $Cp$ are the apparent thermal conductivity, density and the specific heat of the material respectively as obtained from the experiments on thermal conductivity, density and specific heat.

## 3. RESULTS AND DISCUSSION

### 3.1 SEM Images

Plates 1 (a) – (d) show boards from the leave fibres with particles to binder ratio of 1:1, 1:2, 1:3 and 1:4, respectively.

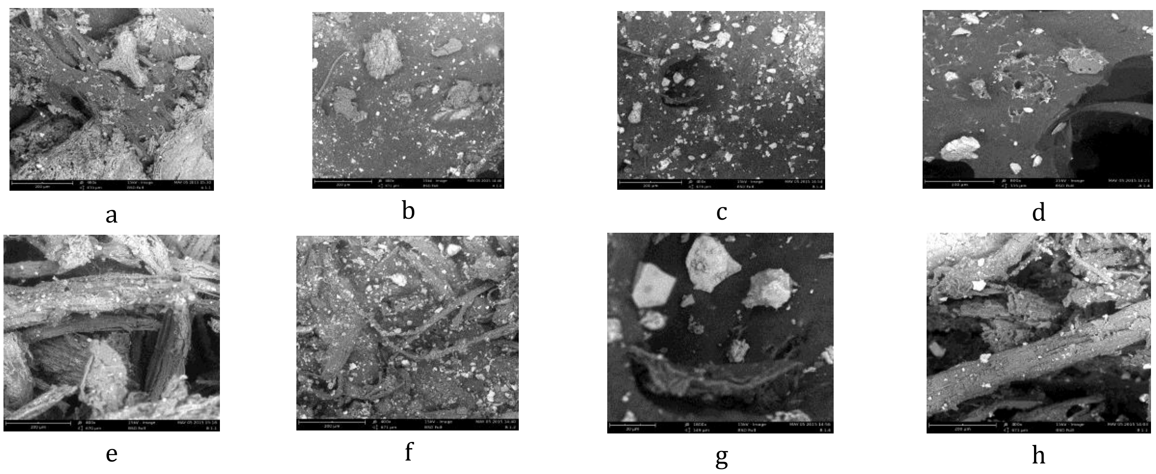


*Plate 1: SEM Micrograph of the Piliostigma thonningii L. fibre boards (400X)*

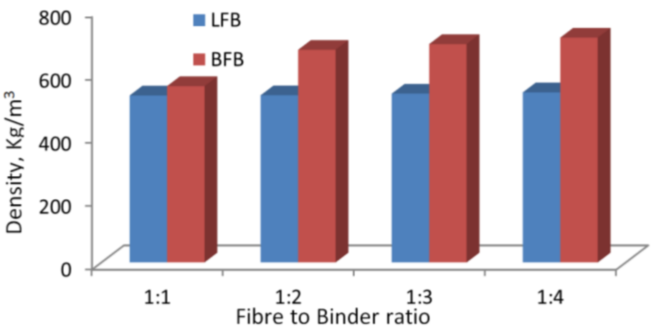


*Figure 1: Comparison of Densities of LFB and BFB at different compositions*

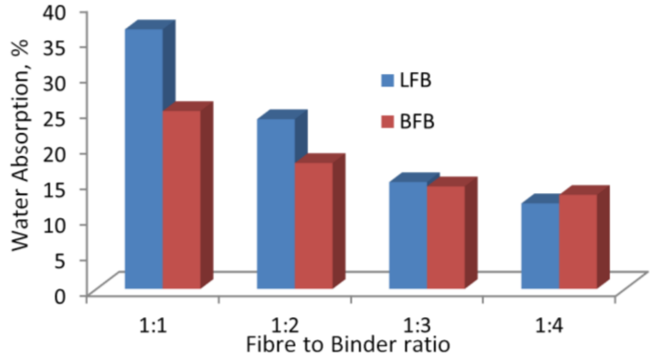


*Figure 2: Percentage water absorption of LFB and BFB at different compositions*

While (e) – (h) are boards from the bark fibres with the fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4, respectively. The SEM micrograph revealed that the boards consist of particles which are bonded strongly with each other and with the binder

### 3.3 Water Absorption

The results of average water absorption properties of the boards from leave fibre (LFB) and bark fibre (BFB) at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4 are presented in Figure 2. The results indicate that for BFB the percentage water absorption at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4 are 25.02%, 17.72%, 14.43%, and 13.23% respectively. On the other hand, the results show that the LFB at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4 have average water absorption of 36.51%, 23.88%, 15.03%, and 12.03% respectively.

From the figure, it can be seen that the percentage water absorption decreases as the fibre to binder ratio varies from 1:1 to 1:4. Thus, it can be deduced from figures 1 and 2 that the percentage water absorption is inversely proportional to the density. This is because the lower density boards have higher voids and pores as a result absorbed higher moisture. In addition, natural fibres derived from lignocellulose are hydrophilic in nature which contain strongly polarized group, thus, increasing the quantity of the fibre in a composition increases the percentage of water absorption [15]. The result of T-test comparing the mean percentage water absorption from the leave fibre (LBF) and the bark fibre boards (BFB) shows that the boards differ significantly from each other with the bark fibre boards recording lower percentage water absorption compared to the boards from the leave fibre boards.

It can be observed that as the binder part in the ratio increases the particles concentration decreases. From the SEM fibre histogram, it was observed that the diameters of the fibres for the leave fibre boards range between 1.0 to 18.96 μm, while that of the bark fibre boards range between 1.27 and 20.22 μm. The pore size histogram of the SEM also reveals the presence of air spaces and their distribution within the surfaces of the boards with the pore sizes ranging between 0.64 and 2710 $\mu m^2$ in the leave fibre boards while the pore sizes in the bark fibre boards range between 0.64 and 2318 $\mu m^2$.

### 3.2 Density

Figure 1 presents the average densities of the boards from the leaves fibres (LFB) and bark fibres (BFB). For the leave fibre boards, the figure reveals that the densities of the boards at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4 are 528.6 kg/m$^3$, 529.3 kg/m$^3$, 534.4 kg/m$^3$ and 538.4kg/m$^3$ respectively. For the bark fibre boards at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4 are 558.3 kg/m$^3$, 673.3 kg/m$^3$, 691.4 kg/m$^3$ and 711.8 kg/m$^3$ respectively. The result of t-test comparing the mean densities of the boards from LFB and BFB shows that there is significant difference in the average densities of the boards at 5% significant level. From the results, it can be seen that the leaves fibre boards (LBF) recorded correspondingly lower densities compared to the boards from the bark fibres (BFB). The figure shows that for both samples, the board's densities increase as the part of the binder in the composition increases. This may be as a result of more binder available to flow into the air pores between the fibres on the surfaces of the board, in addition to the fact that lignocellulose fibres have lower densities compared to polymeric materials; therefore, increasing the binder in the composition will reflect increase in density which is in agreement with the studies of Tangjuank and Kumfu [4].

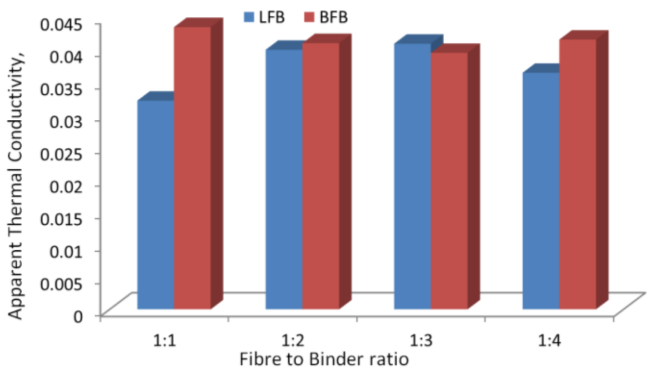


*Figure 3: Comparison of Thermal Conductivity of LFB and BFB at different composition*

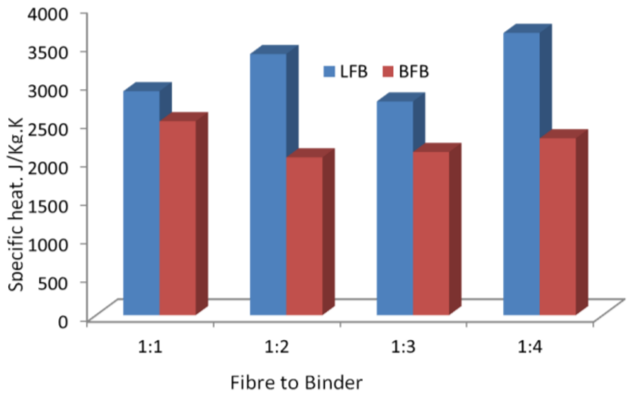


*Figure 4: Specific heat values for LFB and BFB at different compositions*

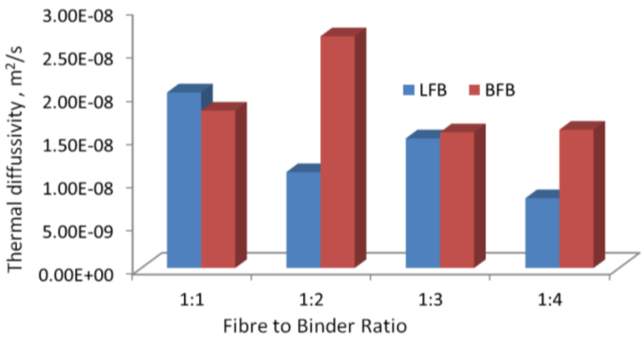


*Figure 5: Thermal diffusivity values for LFB and BFB at different composition*

### 3.4 Apparent Thermal Conductivity

Figure 3 compares the apparent thermal conductivities of the leave fibre boards (LFB) and that of the bark fibre boards (BFB) at different compositions. For the LFB, the apparent thermal conductivity values at 1:1, 1:2, 1:3 and 1:4 are 0.032096W/mK, 0.039928W/mK, 0.040855W/mK and 0.036385W/mK respectively. For the BFB, the apparent thermal conductivities at 1:1, 1:2, 1:3 and 1:4 are 0.043406W/mK, 0.040951W/mK, 0.039439W/mK and 0.041488W/mK respectively.
The result of t-test comparing the mean apparent thermal conductivities of the boards from LFB and BFB shows that there is significant difference in the mean thermal conductivity values of the boards. The result followed the characteristics hooked-shape graph associated with loose-fill fibrous thermal insulation. That is, as the density increases from minimum possible value, the apparent thermal conductivity decreases to a minimum and then increases as reported by some researchers [16, 9, 5, and 17]. For the LFB the lowest apparent thermal conductivity recorded at density of 528 kg/m$^3$ (1:1) while the highest apparent thermal conductivity value occurs at density of 534 kg/m$^3$ corresponding to 1:3 compositions. Similarly, the BFB recorded the lowest apparent thermal conductivity value at density of 691 kg/m$^3$ (1:3) and highest value at 558 kg/m$^3$ density corresponding to 1:1 composition.

### 3.5 Specific Heat

Figure 4 presents the results of specific heat for both leave and bark fibre boards at different fibre to binder ratios. For LFB, the results show that the boards have specific heat values of 2901.88 J/kg.K to 3656.48 J/kg.K as the composition of fibre to binder ratio increases from 1:1 to 1:4. While for the BFB, the results indicate that the specific heat values are between 2044.46 J/kg.K and 2512.61 J/kg.K as the fibre to binder ratio is varied from 1:1 to 1:4. The result of t-test comparing the relationship between the LFB and the BFB shows that there is significant difference in the mean specific heat of the boards. From the figure, it can be observed that the leaves fibre boards recorded higher specific heat values as compared to the bark fibre boards for all compositions of the fibre to binder ratio.

### 3.6 Thermal Diffusivity

Figure 5 shows the thermal diffusivity values for LFB and BFB at fibre to binder ratio of 1:1, 1:2, 1:3 and 1:4. For LFB, the thermal diffusivity values are between 2.03E-8m$^2$/s and 8.07E-9m$^2$/s while for BFB, the thermal diffusivity values are between 1.57 E-8m$^2$/s and 2.68E-8m$^2$/s. The results of t-test comparing the two samples show that there is significant difference in the mean value of the thermal diffusivity. From the figure, it can be observed that the thermal diffusivity decreases as portion of binder in the fibre to binder ratio increases. This signifies that the thermal diffusivity is inversely proportional to the density.

### 3.7 Comparison of Density and Thermal Conductivity of the Developed Boards with Other Insulating Materials

Table 1 compares the measured apparent thermal conductivity and density of the developed boards with that of the standard products and published data on biodegradable thermal insulation.

*Table 1: Comparison of Density and Thermal Conductivity of the Prepared Boards with Other Insulating Material*

| Insulation material | Density (kg/m³) | Thermal conductivity (W/mK) | Source |
|---|---|---|---|
| *Piliostigma thonningii* leaves fibre boards (LFB) | 528-538 | 0.0321-0.0409 | Present study |
| *Piliostigma thonningii* Bark fibre boards(BFB)s | 558-711 | 0.0394-0.0434 | Present study |
| Cork boards | 100-220 | 0.045-0.08 | [18] |
| Mineral wool | 20-200 | 0.035-0.045 | [18] |
| Polyurethane | 30-100 | 0.017-0.024 | [18] |
| wood fibre boards | 30-270 | 0.04-0.09 | [18] |
| Extruded Polystyrene (XPS) | 25-45 | 0.028-0.032 | [18] |
| Expanded Polystyrene (EPS) | 15-30 | 0.035-0.04 | [18] |
| Vacuum Insulation panels (VIP) | 150-300 | 0.002-0.008 | [18] |
| Pineapple leaves | 178-232 | 0.039-0.043 | [2] |
| Oil Palm fibre | 797 | 0.0555 | [10] |
| Coconut husk | 250-350 | 0.046-0.068 | [7] |
| Bagasse | 250- 350 | 0. 049-0.055 | [7] |
| Corn cob | 334 | 0.101 | [6] |
| Straw | 76.6 | 0.040-0.085 | [12] |
| Papyrus fibre | 232-266 | 0.0296-0.0304 | [4] |
| Cotton stalk fibre | 150-450 | 0.0585-0.0815 | [19] |
| Narrowed leave cattail fibre | 200-400 | 0.0438-0.0606 | [20] |

From the table, it can be observed that the developed boards recorded higher densities compared to synthetic product such as polyurethane, extruded and expanded polystyrene, but can be compared favourably with the boards from agro fibres such as oil palm, cotton stalk and narrowed leave cattail fibre boards. Similarly, in terms of thermal conductivity, the developed boards can be compared favourably with most of the commercial products except polyurethane and vacuum insulation panels which have lower thermal conductivities.

## 4. CONCLUSION

The research work revealed that the leave fibre boards LBF of *Piliostigma thonningii* L. has larger voids compared to the bark fibre boards BFB resulting in their lower densities and lower thermal conductivity. It also indicates that the LFB has higher specific heat values and lower thermal diffusivity compared to the BFB. On the other hand, the BFB perform better than the LFB in terms of water absorption properties. Thus, it can be concluded that the boards from the leave fibre have better physical and thermal properties viz; density, thermal conductivity, specific heat and thermal diffusivity when compared with the boards from the bark fibres under the same conditions.

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