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Thermal characteristics of oil palm fibre treated with cassava starch solution for possible use as insulation material

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Abstract

The search for local substitutes for imported insulation materials used in local ovens of temperature range (450 °C – 1600°C) and other heat transfer system has motivated this work. At the same time, human agricultural activities have highly generated a lot of biomass materials that constitute environmental hazard. These biomass materials can be processed into useful alternative materials such as those used in thermal insulation. Oil palm fibre and cassava starch are common examples. The thermal characteristics of oil palm fibre treated with 0.20 w/w cassava starch solution (CSS) were investigated. The Maximum Use Temperature of the oil palm fibre treated with CSS was determined using the ASTM C411 recommendation. The mean values of the specific heat capacity, density, thermal conductivity, thermal diffusivity and maximum use temperature were determined as 27.09523 kJ/kg°C (67 °C), 275.69 kg/m^3, 0.159 W/m K, 2.129 x 10^{-8} m^2/s (at 67 °C), and 320 °C respectively. The determined characteristics show that the oil palm fibre board is suitable for use as an insulation material in low temperature oven application and thermal solar processes.

Keywords: Insulation materials, local ovens, palm fibre, cassava starch solution, thermal conductivity and thermal diffusivity

1. Introduction

In recent times, man has witnessed rapid exponential growth in population and material wealth. This growth is a direct consequence of the industrial revolution that has brought about ever increasing use of energy in the manning of machines in all sphere of life. In energy issues, fossil fuels i.e. fuels derived from the remains of dead organic matter, are of paramount importance as they supply ample and easily exploitable sources of energy. However, their reserves are limited and approaching exhaustion. This has dire consequences that can adversely affect the world economy especially for developing nations.

There are two major ways of checking this. First of all, ways of using our energy resources more efficiently must be found and secondly, in long term, alternative sources of power must be developed. Energy conservation measures and new inventions will enable society's needs to be met with a smaller expenditure of scarce resources (Jindal and Murakami, 1984; Morley and Miles, 1997; Cansee *et al*., 2008; Wang and Hayakawa, 1993) [5, 10, 2, 15]. There is a clear need for conservation of heat energy. This is done to minimize the wastage of heat energy, through the process of lagging of hot materials. Materials that are used for lagging are called thermal insulators (heat retarders).

Materials resist the flow of heat energy through them to varying extent. This phenomenon describes the insulation characteristics of materials. Thermal insulators are materials that resist the flow of heat to high extent. The efficient use of this property of materials to conserve heat energy depends on the material type which in turn, brings in the cost factor. Hence, the need for materials with the most economic advantage is there. Most insulation materials are imported and expensive, thus it is necessary to source for substitutes. Materials that are locally available may serve as direct substitutes or after certain treatment, serve as a replacement for the foreign ones. This will help to reduce the cost of systems that use them e.g. furnaces and domestic ovens.

In the task of searching for an appropriate local material, the thermal characteristics of oil palm fibre treated with cassava starch solution (CSS) is an important consideration. Oil palm fibre is a biological material (biomass); it is biodegradable and can be used for insulation purposes (Zulkifli *et al*., 2009; Panyakaew and Fotios, 2008) [16, 11]. Oil palm fibre is abundant in nature and it is considered as a waste and used for making fire in rural areas. Starch which is a complex carbohydrate is a good thermal insulator (Wang and Hayakawa, 1993; Bam *et al*., 2015; Zulkifli *et al*., 2009; Panyakaew and Fotios, 2008) [15, 1, 16, 11]. They are produced locally in large quantities during the process of 'garri' making from cassava.

This work aims to determine thermal characteristics of oil palm fibre treated with cassava starch solution (CSS). These materials may provide good substitutes for imported insulation materials. Oil palm fibre is abundant in nature in different local communities. None of the naturally occurring materials are suitable for use as an insulating material directly and must be treated and subsequent manufacturing or forming process is demanded (Panyakaew and Fotios, 2008) [11]. Among the significances of the study is the sourcing for local alternative insulation materials for application in low temperature furnace and oven development. This will enhance local development of oven and furnace using the insulation material thereby reducing the cost of ovens and furnaces. Furthermore, the results of this work will provide the basis for the development of a suitable technology for the mass production of the insulation materials.

2. Materials and Methods

The main equipment used include a 40x13x2.5 cm mould made of aluminum, a Mettler Toledo digital weighing machine, 200N compression machine, a Gallenkamp hotbox oven with fan, a beaker, a copper calorimeter with stirrer, a kerosene stove with wire gauze, a meter rule, a stop watch, ORL hot plate electric stove (230V, 500W-1000W), thermocouple reader and thermocouple sensor (K-type).

The materials used for this work are oil palm fibre and cassava starch solution. The oil palm was treated to ensure its stability during usage. This treatment involves reduction of the moisture content of the biomass by drying and addition of additives. Controls are provided at different levels of the experiment to reduce error to the barest minimum (Cansee *et al*., 2008) [2].

The extracted fibre from the oil palm was washed using a non-reactive detergent (*Klin*) to completely remove the oil content from it and then rinsed with water four times to remove any traces of the detergent. The fibre was sun-dried to remove its moisture content. The dried fibre was shredded to increase its surface area to enable an even mixing with the cassava starch solution (CSS). The extraction of starch from cassava roots can be carried out as presented in the flow chart in fig. 1 below.

The cassava starch solution (CSS) was prepared by mixing 1000 ml distilled water at 100 °C with cassava starch powder of 200 g to a mass of 200 g of oil palm fibre. The mass of the oil palm fibre was soaked in the cassava starch solution until there was a proper mix. The mixed fibre was poured into a mould that has an extractor of dimension 40 x 13 x 2.5 cm. The mixture of the oil fibre and cassava starch solution was poured into a mould and compressed with a force of 200 N to ensure a thickness of 2.5 cm (which is the thickness of the mould). The sample was dried in a Gallenkamp hotbox oven with fan at 50 °C until a constant weight was obtained.

To test the thermal properties of oil palm fibre treated with cassava starch solution, the parameters that were determined were thermal diffusivity, thermal conductivity, maximum use temperature, specific heat capacity and density of the oil palm fibre board (Cansee *et al*, 2008; Frydrych *et al*., 2002; Kouchakzadeh and Tavakoli, 2010; Soom *et al*., 2008; Suradi *et al*., 2010) [2, 3, 6, 12, 13].

In determining the specific heat capacity of the oil palm fibre board with 0.20w/w of CSS, the transfer method was used. The mass, m_c, of the empty calorimeter and stirrer was measured and also the mass of the solid, m_c, was measured. The mass of water in the calorimeter, m_w, was then obtained. The initial temperature, T_1 of water and temperature, T_2 of the oil palm fibre board were measured. The oil palm fibre board was placed sealed in a polythene bag. A nickel wire was tied to the mouth of the polythene bag and put in boiling water for 20 minutes. After boiling for 20 minutes, the oil palm fibre board was removed and polythene bag was torn open to remove the test sample. The test sample was quickly transferred to the calorimeter and stirred until a steady temperature; T_3 was attained. The final temperature of the solid, T_f was measured. Then, by energy conservation and neglecting heat losses, the specific heat capacity can be found from equation 1.

$$c_s = \frac{m_w c_w (T_3 - T_1) + m_c c_c (T_3 - T_1)}{m_s (T_f - T_2)} \qquad (1)$$

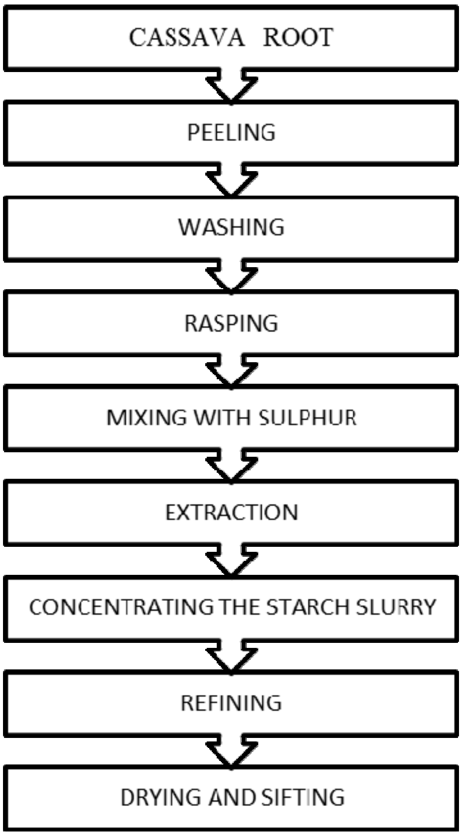


Fig. 1: Flow Chart of the extraction of starch from cassava roots

To determine the density, the mass of the oil palm fibre board was measured using a Mettler Toledo digital weighing machine that has an accuracy of 0.001 g. The volume of the oil palm fibre board (V) was measured directly from the geometry of the material. The density of the material was then calculated from equation 2.

$$\rho = \frac{m}{V} \qquad (2)$$

Where ρ is the density (kg/m^3) of the material, m = mass (kg) of the material, and V is the volume (m^3).

In determining the thermal conductivity of the treated insulation material, the absolute steady-state measurement method was used since baking in ovens is normally done under such conditions. The parameters of the test materials noted were the thickness and cross-sectional area. Fig. 2 shows a schematic diagram of the specimen of the board. The insulation material was placed in between the double wall of a conductivity testing device (oven) made mild steel. The inner wall surface was heated up using a steady electric power source. The heat from the inner wall was conducted through the insulation material to the outer wall of the device. The temperature of the inner and outer wall surface T_1 and T_2 respectively were monitored using a thermocouple. As heat transfer becomes steady in which state T_1 and T_2 remain constant, the quantity of heat transfer (Q) through the metal sheet and the insulation material is same. The quantity of heat transfer was calculated using equation 3.

$$Q_p = \frac{k_p A(\Delta T)}{x_p} \qquad (3)$$

Q_p is the quantity of heat transferred, k_p = thermal conductivity of the mild steel, A = surface area of the metal sheet, ΔT = temperature difference between the inner and outer surfaces and x_p = thickness of the metal sheet. The thermal conductivity of the insulation material was then calculated using equation 4.

$$k_S = \frac{Q_S x_S}{A(\acute{T}_1 - \acute{T}_2)} \tag{4}$$

$Q_S = Q_p$ = quantity of heat transferred, x_S = thickness of the insulation material, A = surface area of the insulation board, $\acute{T}_1$ = temperature of the inner surface of the insulation board, $\acute{T}_2$ = temperature of the outer surface and k_S = thermal conductivity of the insulation material. This is an acceptable method so long as the steady state conditions are reasonably approximated (Cansee *et al*, 2008) [2].

The thermal diffusivity (α) was calculated using measured and computed values of the thermal conductivity, specific heat and density of the specimen using equation 5.

$$\alpha = \frac{k}{\rho c_p} \tag{5}$$

ρ is the density of the treated oil palm fibre (kg/m^3), c_p is the specific heat capacity (kJ/kg^{0}C) and k is the thermal conductivity (W/m K) (Cansee *et al*., 2008) [2].

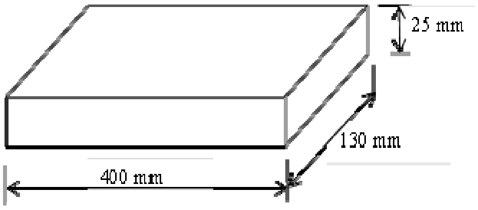
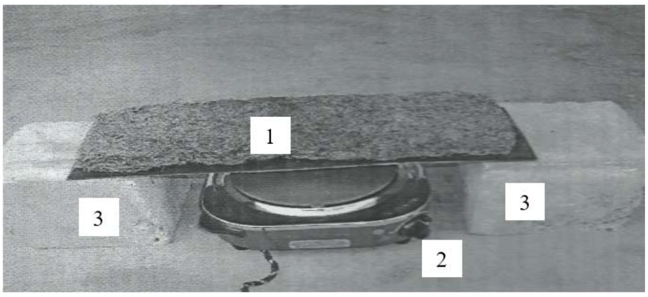


Fig 2: Schematic diagram of the specimen

In determining the maximum use temperature of the oil palm fibre board treated with CSS (0.20 w/w), an approximation of the ASTM C411 recommendation was used (Ibrahim *et al*., 2014; Tangjuank, 2011) [4, 14]. An ORL hot plate electric stove with a voltage of 230 V and power ratings of 500 W - 1000 W corresponding to the minimum and maximum output power respectively was used. The top of the plate is cleaned thoroughly to avoid any premature smoking. Two concrete blocks were then arranged on either side of the hot plate electric stove to avoid direct contact with the hot plate electric stove. The hot plate electric stove is plugged to AC power supply and turned on, with the power adjustment knob set at the maximum power output of 1000 W. The sample was placed on a flat plate that is placed on the two blocks. The flat plate serves as a conducting medium between the hot plate electric stove and oil palm fibre board. The initial temperature of the flat surface was noted using a K- type, TK-102 thermocouple reader with its sensor bent at 90^0. The oil palm fibre was left on the flat surface with the thermocouple thermometer (thermocouple reader) sensor held on it until the oil palm fibre board began to smoke. The temperature was noted and recorded as the maximum use temperature of the oil palm fibre board. Fig. 3 shows the set-up for the maximum use temperature determination of oil palm fibre board.



1. Insulation board; 2. Hot plate; 3. Supports

Fig 3: Set-up for the Maximum use Temperature determination

3. Results and Discussion

The mean values of the respective thermal data obtained from the various experiments carried out in the course of this work are presented in Table 1.

Table 1: Mean values of the thermal data for the Palm Fibre Board, untreated Palm Fibre and Cassava Starch Solution

Parameter	Magnitude		
	Palm Fibre Board	***Untreated Palm fibre**	****Cassava Starch Solution**
Density (kg/m^3)	275.69	797	1044
Thermal conductivity (W/m K)	0.159	0.09824	0.307
Specific heat capacity (kJ/kg$^\circ$C)	27.09523	-	3.354
Thermal Diffusivity (m^2/s)	2.129 x 10^{-8}	-	8.767 x 10^{-8}
Maximum use temperature ($^\circ$C)	320	-	-

*Obtained from Manohar (2012a) [7]

**Obtained from Cansee *et al* (2008) [2]

Manohar (2012a) [7] investigated the feasibility oil palm fibre as insulation in building. The study reported for all the densities considered the tendency of thermal conductivity of the oil palm fibre to generally increase with temperature while decreasing with density. This also agrees with the findings of Ibrahim *et al.* (2014) [4] though their test involved impregnation of the oil fibre with paper pulp. A mean value of about 0.09824 W/m K for a mean temperature of 30 °C as reported by Manohar (2012a) [7] and 0.115 W/m K by Ibrahim *et al.* (2014) [4] for 10 % paper pulp at the same temperature indicate that the mean value of thermal conductivity obtained for the insulation board in the present study is lower than that of oil palm fibre. This claim is valid because the mean value for this study of 0.159 W/m K was obtained at 122 °C. This trend of increasing thermal conductivity with temperature has also been observed in several an unpublished studies leading to this work. However, the chemical stability of the untreated fibres at the higher temperatures is poor compared to that of the insulation board. Also, the value of thermal conductivity obtained was lower than that obtained by Cansee *et al.* (2008) [2] when they studied the effects of temperature and concentration on the thermal properties of cassava starch solutions (CSS). The value reported by them for a 0.2 w/w concentration of CSS was 0.307 W/m K.

Generally, it has been established that low thermal diffusivity and high specific heat values favor good insulation characteristics or results from low thermal conductivity of the material (Tangjuank, 2011; Mohapatra *et al*., 2014; Manohar, 2012b) [14, 9, 8]. This is obvious from equation 3. The value of the thermal diffusivity could have been lowered because of the combined effect of oil palm fibre treated with cassava starch solution (CSS). This is in agreement with findings from various studies and has informed the impregnation of biomass materials such as oil palm fibre in order to improve their thermal behaviour (Tangjuank, 2011; Mohapatra *et al*., 2014) [14, 9]. The material tested thus has the potentials of being a good heat insulator. The performance can still further be improved by adding other materials. This is an area for further work in the nearest future.

The maximum temperature of use of 320 °C for this material is only compatible for low temperature applications however. Further inoculation with other additives can improve this temperature (Mohapatra *et al*., 2014; Manohar, 2012a) [9, 7]. Meanwhile it is very suitable for low temperature solar thermal processes such as drying and water desalination. Most of the recent efforts in this area of research in Makurdi have used rice husk and saw dust as insulation material as well as waste fibre glass. This material has the potential of competing favorably as options for use in these processes. The oil palm fibre board can serve also as a substitute for imported insulation materials which can be used in the production of low temperature ovens and furnaces within the range of temperatures (45 °C – 160 °C) used mainly for domestic baking.

4. Conclusion

The thermal characteristics insulation boards made from oil palm fibre treated with cassava starch solutions (CSS) have been studied. It was observed that the material has a high specific heat capacity and very low thermal diffusivity values respectively. It is therefore suitable as insulation material for low temperature applications. All the materials used are available locally in significant quantities and can be harnessed to support the industry. This in turn will create job opportunities, increase the nation's foreign earnings and also bring about scientific development. Further work will investigate the mechanical properties.

5. References

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