



The Effect of Cassava Starch Solution on the Thermal Conductivities of Selected Biomass

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ABSTRACT

The effect of cassava starch solution (CSS) on the thermal conductivities of selected biomass has been studied. This was done in search of local substitutes for imported insulation materials used in low temperature (45 - 160°C) ovens. The biomass selected for this work were palm-kernel fiber and coconut fiber. Fresh (wet-weights) of these biomass were collected and their moisture contents were reduced to zero (bone-dry) in an isotemp oven. The effect of cassava starch solution on the thermal conductivities of the biomass were then studied using a conductivity Testing apparatus developed locally. The study showed that the conductivities of the specimens generally decreased with increase in the CSS concentrations in them but increased with increase in temperatures.

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Introduction

Since the Industrial Revolution, there has been an exponential growth of population and increase of material wealth. This growth has been associated with the ever increasing use of energy in machines. Energy is the capacity to do work. Energy can exist in the following forms: mechanical, thermal, chemical, electrical, radiant and atomic. Easily exploited reserves of fossil fuel are limited, and many will approach exhaustion in the lifetime of present students. There are two obvious consequences: first, ways have to be found of using our energy resources more efficiently; and secondly, in the long term, other 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 [1-3].

Energy cost account for over 40% of the total cost of production. Efforts are generally directed towards reducing energy cost by exploring alternative sources or minimizing losses. For commercial and industrial energy users, as well as public bodies, the cost of energy often has a significant impact on their present activities and their plans for the future. They have found that by proper management, these costs can be controlled. Expenditure on energy conservation reduces this requirement and provides recurring savings for end users, usually at a far better rate of return [4, 5].

Human need, is insatiable with energy inclusive in the list of human needs. There is a clear need for conservation of heat energy. In an attempt to minimize the wastage of heat energy, the idea of lagging of hot materials becomes very important. Lagging

materials are known as thermal insulators. Materials resist the flow of heat energy through them to various extents [6-9]. This phenomenon is referred to as the insulation characteristics of materials. The efficient use of this property of materials to conserve heat energy depends on the type of material employed, which in turn brings in the cost factor. Hence, it is necessary to source for substitutes for the imported insulation materials, which are quite expensive. Materials that are locally available might serve as substitutes for these foreign materials. Insulation cost might be considerably reduced and this will help to reduce the cost of systems that use them e.g. domestic ovens and furnace [10-14].

In the business of searching for appropriate local materials, the effect of chemical activities on the insulation characteristics of selected biomass is an important consideration. Biomass which are biological materials can be used for insulation purposes [15-18]. These are materials which are biodegradable. These materials are produced in large quantities in Nigeria, mostly in the Middle-Belt (North Central) and most times considered as Waste or used in making fire. Starch which is a complex carbohydrate is a good thermal insulator [19, 20]. They are produced in large quantity in Nigeria. Therefore, the effect of starch on the insulation characteristics of selected biomass is very useful.

The study aims to determine the effect of starch solution on the thermal conductivity of the selected biomass as a step towards sourcing for alternative local insulation materials, for application in low temperature ovens and furnace development. The

temperature range is from 45°C -120°C used mainly for baking domestically. This will contribute towards the enhancement of local development of ovens and furnaces using the insulation materials, thereby reducing the costs. The study could also provide the basis for the development of a suitable technology for the mass production of the insulation materials. It will explore environmentally benign uses for the selected biomass while encouraging mass production of starch. It is also in line with the global agitation of converting waste to wealth [4, 20, 21]. It is limited to testing the effect of starch solution and temperature on the thermal conductivity of the selected biomass.

Materials and Methods

In order to ensure stability of the biomass, the moisture content was reduced by drying the materials and addition of some additives. Minimum error was ensured by the provision of suitable controls at various levels of the experiment.

The equipment used were a conductivity testing box a Variable voltage regulator an Electric heating elements, 500W, 220V, a 100 ml beaker, A 40 x 13 x 5 cm mould, a weighing machine, a compression machine, a Fisher Isotemp Oven, a Thermometer, a Stabilizer, a Meter rule, a multimeter and a Thermostat. The materials used for this work are Coconut fiber, Palm-kernel fiber and Cassava starch. These materials may provide good substitutes for imported insulation materials. These biomass are given by nature and are rapidly available in our different local communities. Preliminary study shows that they are available in large quantity for exportation.

For assessing the insulation materials selected, the following parameters were investigated:

- (a) Thermal conductivity (K) of the selected biomass.
- (b) The effect of chemical additive (starch solution) on the thermal conductivity of the selected biomass.
- (c) The effect of temperature on the thermal conductivity of the selected biomass.

None of the naturally occurring materials are suitable for use as insulating materials directly and therefore must undergo certain treatments and subsequent manufacturing or forming processes if demanded. The harvested coconut fiber was shredded so as to increase its surface area for drying. The shredded fiber was properly washed using water and non-reactive detergent to remove any form of impurities. The fiber was initially sundried to reduce its moisture content. Further drying was carried out by the use of an isotemp oven until constant weight of the fiber was obtained.

The extracted palm-kernel fiber from oil-palm Was Washed using water and a non-reactive detergent to completely remove the oil content of the fiber. The fiber was initially sundried to reduce its moisture content. Further drying was carried out by the use of an isotemp oven until constant weight of the fiber was

obtained. The dried fiber was properly shredded so as to increase its surface area to enable proper mixture with the chemical.

The extraction of starch from fresh cassava roots can be presented in the flow diagram shown in figure 1. The screened starch was sundried to completely remove its moisture content. The dried starch was grounded so as to increase its surface area. Further screening was carried out using a 425 µm diameter screen. The cassava starch solution (CSS) was prepared by mixing 100 mL of distilled water at 100°C with cassava starch powder at different masses of 50, 100, 150, 200, 250g for each of the fibers. 100g of each of the fiber was soaked in the CSS at different concentrations until there was a proper mixture. The soaked fibers were poured into a mould of dimension 40 x 13 x 5 cm and compressed to a thickness of 2.5 cm. The compressed sample was dried in an oven until a constant weight was obtained. The test specimens so produced are as shown in figure 2.

The testing box is of mild steel sheet construction and rectangular in shape. Air inlet and outlet passages are created at the rear end of the box. A metal door of the same material is created in the box to allow for insertion of the refractory bricks, the test specimen and the suction fan connected to the variable voltage regulator. An electric heating element is placed on the refractory bricks held together in space by spacers. The electric heater is connected to a power source via a thermostat and a stabilizer for regulating current and voltage respectively. The walls of the box are doubled, except for the side wall which is being cooled constantly by air sucked in through the passages. Fiber glass of about 25mm thick is placed in between the walls to avoid heat loss through the walls. Drilled holes are made on the top of the box to allow for the passage of two thermometers: one taking the temperature of the hot aluminum sheet and the other taking the temperature of the cool mild steel sheet. Figures 6 and 7 shows the conductivity test box. The components of the testing box included an Electric heating element a Refractory bricks a Suction fan, a Variable voltage regulator a Thermometer to measure T1 another Thermometer to measure T2; a Hot aluminum sheet, Cool mild steel, a Thermostat and a Stabilizer.

The test specimens of 40 x 13 x 2.5 cm were inserted in the box and held in place by spacers as shown in fig 8. The test specimens were placed in between the aluminum sheet (hot plate) and the mild steel sheet (cold plate). Air was sucked into the air jacket through an inlet with the aid of the suction fan and expelled out through the air exit, thereby cooling the mild steel sheet which then serves as cold surface. Air flow is at constant rate (optimum value), as set by the regulator.

Two thermometers were passed in through the holes in the top of the thermometers gives the temperature reading of the hot surface (aluminum sheet) and the other gives the temperature reading of the cold surface (mild steel sheet). The heating element takes supply from a stabilizer via a thermostat connected across

the mains. The current supplied to the heating element was read from a multimeter connected across the terminals of the element. The thermostat ensures a steady state condition.

In the determination of the thermal conductivity (k) of the treated insulation material, the absolute steady-state measurement method was used. Baking in the ovens are normally done under such conditions. The parameters of the test materials noted were thickness t (m) and cross-sectional area A (m²). The test material was placed between a hot and cold surface. The hot surface was heated up by an electrical power source which was kept constant. The cold surface is a mild steel sheet body in which air was sucked through continuously to cool the surface at constant rate by the suction fan during the time of heating. The temperature of the hot and cold surfaces T_1 and T_2 respectively were measured by means of thermometers. As heat transfer becomes steady, in which state T_2 and T_1 remain invariable with time, thermal flux q , was found by measuring (determining) the electric power of the heater. This was done by measuring the current across the heating element and using the voltage value read from the stabilizer meter. The power of the heater for the different current supplied by the thermostat was also determined using the relationship in Eq. 1.

$$\text{Power, } P = V \times C \quad (1)$$

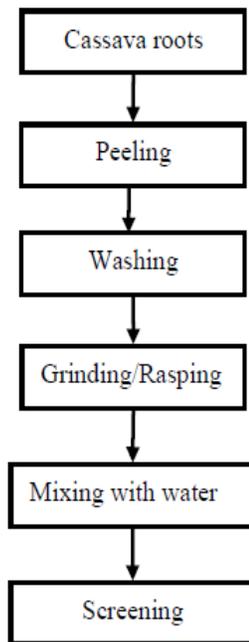


Figure 1. Flow chart for the extraction of Cassava Starch [7]

The thermal conductivity was calculated using Eq. 2.

$$k = \frac{Pt}{A(T_1 - T_2)} \quad (2)$$

where, P = thermal power flux (W), t = thickness (m), A = surface area (m²) and ΔT = temperature gradient (K).

Results and Discussion

The data obtained from the various experiments carried out in the course of this work are presented in the tables in this chapter. Some of the results are presented in the tables below and the corresponding graphs plotted 1 and 2 show the moisture content of the biomass after drying at temperature of 50°C to constant mass (dry bone mass). The initial and final moisture content of the biomass was calculated using Eq. 3 [22].

$$M_C = \frac{M_i - M_d}{M_d \times 100} \quad (3)$$

where, M_C = moisture content (%), M_i = initial mass (g) and M_d = dried mass (g).

Table 2. Moisture Content of Coconut Fiber

Material	Mass (g)	Heating Time (min)	Moisture content (%)
Wet Mass	850.60		39.31
	810.30	3.00	32.71
	79	6.00	26.17
	770.40	9.00	19.59
	730.20	12.00	13.05
	690.30	15.00	6.47
	650.10	18.00	0.00
Dried Mass	610.60	21.00	0.00

Table 3. Moisture content of palm-kernel fiber

Material	Mass (g)	Heating Time (min)	Moisture content (%)
Wet mass	900.40		45.13
	860.30	3.00	38.67
	820.10	6.00	32.19
	780.40	9.00	25.79
	740.20	12.00	19.31
	700.30	15.00	12.88
	660.40	18.00	6.45
	620.40	21.00	0.00
Dried mass	620.40	24.00	0.00

The treated biomass with cassava starch solution (CSS) was dried at a temperature of 50°C to constant mass. The table below shows the moisture content of the specimen when dried to constant mass (bone dry). The initial and final moisture content of the test specimen were also calculated using Eq. 3. The moisture content of treated coconut and palm-kernel fibers at different concentrations are given in Tables 3 and 4.

The conductivity of the test specimens were determined at the different concentrations and power variations. The tables below show the conductivities of the test specimen. The graph for corresponding conductivity is also shown below. The conductivity of each specimen was calculated from the base data for steady state condition using Eq. 2. The mean surface area of

specimen used was 0.052 m² with a thickness of 0.025 m. The plot of conductivity against concentration for treated coconut fiber at a hot plate temperature of 122°C is shown in figure 2 while the corresponding one at 50°C is shown in figure 3. The corresponding plots for treated palm kernel fiber are shown in figures 4 and 5.

Table 3. Moisture Content of Treated Coconut Fiber at various Concentrations of CSS

Material	Mean Mass (g)	Heating Time (mins)	Moisture content				
			0.05w/w	0.10w/w	0.15w/w	0.20w/w	0.25w/w
Wet	1240	-	666.67	500.00	400.00	285.71	285.71
	1042.08	15.00	533.40	400.10	320.04	266.70	228.60
	842.25	30.00	400.20	300.20	240.08	200.10	171.46
	642.29	45.00	266.80	200.25	160.04	133.37	114.37
	442.20	60.00	133.33	100.00	80.12	66.73	57.20
	242.00	75.00	0.00	0.00	0.00	0.00	0.00
Dry	242.00	90.00	0.00	0.00	0.00	0.00	0.00

Table 4. Moisture Content of Treated palm-kernel Fiber at various Concentrations of CSS

Material	Mean Mass (g)	Heating Time (mins)	Moisture content				
			0.05w/w	0.10w/w	0.15w/w	0.20w/w	0.25w/w
Wet	1250.00	-	666.67	500.00	400.00	333.33	285.71
	1060.28	15.00	533.47	400.15	320.00	267.00	228.80
	860.34	30.00	400.20	300.05	240.28	200.20	171.56
	660.46	45.00	266.93	200.10	160.20	133.37	114.54
	460.30	60.00	133.40	100.20	80.04	66.77	57.34
	260.00	75.00	0.00	0.00	0.00	0.00	0.00
Dry	260.00	90.00	0.00	0.00	0.00	0.00	0.00

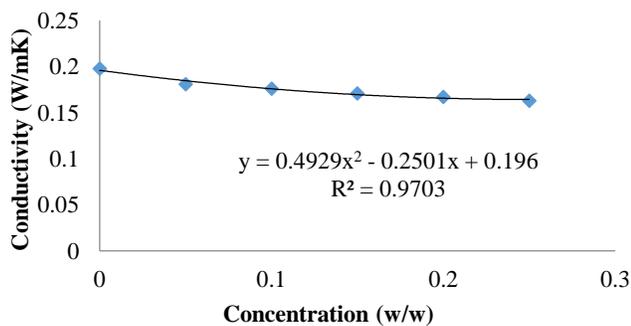


Figure 2. Variation of Conductivity with Concentration of Treated Coconut Fiber at Hot Plate Temperature of 122°C

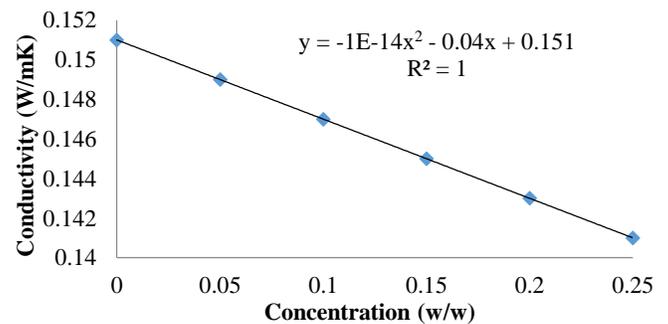


Figure 3. Variation of Conductivity with Concentration of Treated Coconut Fiber at Hot Plate Temperature of 50°C.

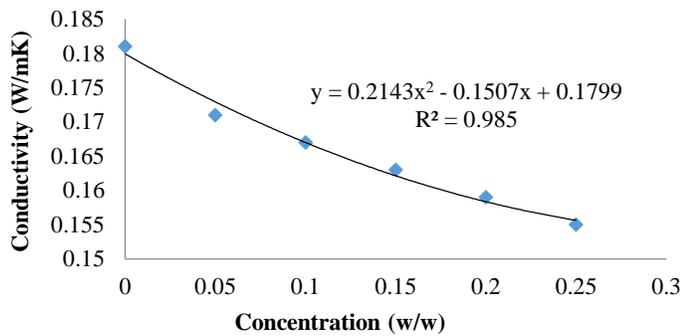


Figure 4. Variation of Conductivity with Concentration of Treated Palm Kernel Fiber at Hot Plate Temperature of 122°C

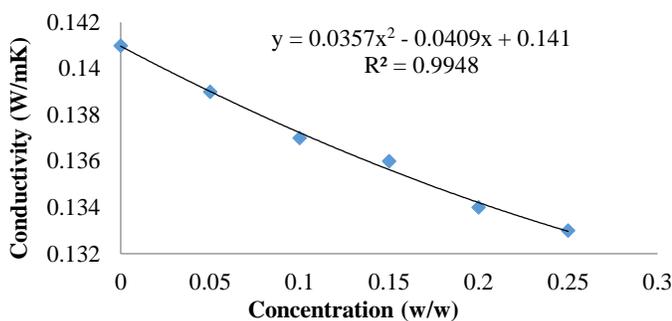


Figure 5. Variation of Conductivity with Concentration of Treated Palm Kernel Fiber at Hot Plate Temperature of 50°C

From the tables and figures above, it can be seen that concentrations and temperatures greatly affect conductivity of the biomass. Though the concentration had more effect compared to temperature. The conductivity of the specimen at hot plate temperature of 122 °C for coconut fiber with 0.00w/w concentration is higher than specimen with 0.05w/w by 9.4% and higher than specimen with 0.25w/w by 21.5% while the conductivity of the specimen at hot temperature of 122 °C for palm-kernel fiber with 0 w/w concentration is higher than specimen with 0.05w/w by 5.8% and higher than specimen with 0.25 w/w by 16.8%. It also shows that palm-kernel fiber has lower conductivity values than coconut fiber. This could be partly as a result of different orientations of their fiber.

The results generally shows or depict that the conductivity of the material decreases with increase in concentration of the materials which agrees with the work done by [23]. The observation above can be explained using the molecular theory of matter. The transfer of heat through the material is a direct combination of conduction through the fibrous, convection through the air trapped in the void and, at sufficiently high temperatures, radiation. For the purpose of this work, conduction is the most prominent mode of heat transfer. This is the transfer of heat through the material by vibration of the molecules of the

materials. On the other hand is the transfer of heat through the air in the material by the actual movement of the molecules of the air. Since the test specimen is a combination of dried biomass and dried cassava starch solution (CSS), therefore the insulation characteristics is a direct combination of the two. The insulation characteristics of biomass were given by [24].

The effect of starch on the biomass can be explained thus: Starch is a hydrocarbon [5, 6, 19]. In hydrocarbons, the outermost electrons of the atoms of the molecules are covalently bonded. Therefore, there are no free valence electrons that can be mobilized, thereby making starch a good thermal and electrical insulator. The effect of concentration on the conductivity of the material can be seen from the density point of view. As the density increases, the fibers and the starch molecules become more closely packed together, thereby retarding the freedom of vibration of its constituents, therefore, and conductivity of the test specimen decreases as concentration increases.

The values of conductivity for the test specimens at different temperatures of 122°C and 50°C are plotted against concentration in figures 3 to 5. It was seen that as temperature increases, conductivity values increases for the test specimen which agrees with the work of [1]. The observation above can also be explained using the molecular theory of matter. From our knowledge of electrical/thermal energy, increase in voltage or current brings about increase in power. For a heating element, as current increases, heat which is a function is of temperature increases. As the temperature of the test specimen increases, the vibration of the molecules of the material increases. This increase in vibration thus brings about increase in conductivity of the material. Therefore as power increases, conductivity increases.

Conclusion

The effect of cassava starch solution (CSS) on the thermal conductivity of the selected biomass has been studied. It has been observed that conductivity of the material decreases with concentration of the CSS. Similarly, it has also been established that conductivity increases with temperature. All the selected materials are adequately available locally to support the industry. This will assist in the creation of jobs, conserve the nation's foreign earnings and bring about scientific and technological development. The material can serve as a substitute for imported insulation materials and therefore can be used in the production of low temperature ovens and furnaces viz ovens with temperature range from 45% (93°F) to 120°C (248°F) use mainly for baking (domestic oven)

The work is recommended for further research to improve on the conductivity values and physical requirement of the materials. If it is to be used at higher temperature, it is recommended that the material is tested for its ability to withstand higher temperatures without deteriorating. For some application, the insulation material may need to have more sufficient structural



strength to be tough enough to resist rough usage and strength to be self-supporting. It may need to vibration. Therefore, further work on its physical characteristics is recommended.

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