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Determination of Thermal Properties of Bombax Costatum

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ABSTRACT
Thermal properties of liquid food products are very important and frequently critical parameters in food processing, handling and storage. Therefore reliable and useful thermal property data should be established for food engineers in order to effectively design and develop processes and equipment needed in the drying, storage and thermal processing of agricultural materials. Thermal properties of Bombax costatum such as specific heat capacity, thermal diffusivity, thermal conductivity, bulk density and activation energy were determined at 10%, 28% and 82% of moisture contents respectively. The result showed that the specific heat capacity and bulk density of Bombax costatum increase with moisture content while thermal diffusivity and thermal conductivity did not produce a particular trend. The activation energy for all samples of Bombax costatum decreases with moisture content and viscosity. It was also established that the viscosity of Bombax costatum decreases with increase in temperature. The ANOVA and regression analyses were performed using the CRD and SPSS 16 respectively.

Key words: Thermal, Conductivity, Diffusivity, Specific heat capacity, Temperature, Activation energy, Viscosity and Moisture content

I. INTRODUCTION

Bombax costatum is a deciduous, open savannah woodland tree. It is 3 – 15m high and up to 1m in girth (Keay, 1989). It produces flowers from November to February and then fruits from February to June. During Hamattan season (from November to March) when most crops are harvested, the flowers become loosened from the stalk and fall freely with little blow of wind (Tingir, 2003). The petals are detached from the calyx which is then dried and ground into powder and stored for reconstitution into soup. Because of the ability of the powder to form a gel when mixed with water, it can be classified as a food gum. Food gums are high molecular weight polymeric compounds, mostly carbohydrates which are characterized by their ability to give highly viscous solution at low concentration (Ihekoronye and Ngoddy, 1985). Glicksman (1982) described food gums as long chain polymers that dissolve or dispense in water to give a thickening or viscosity producing effect. In many parts of West Africa especially middle belt states of Nigeria, there are many traditional foods that are swallowed without mastication. Such foods include the famous pounded yam and other types of foods prepared and moulded from cereals like maize, sorghum and millet (Kent, 1983). Traditionally such foods are eaten along with soups and stews that are prepared to facilitate the movement of food along the digestive track. In Nigeria, there are many of these types of soup which are generally referred to as "slimming soup" due to their viscous gelatinous nature when they are cooked. Most common amongst these are Okra, ewedu, ogbono, okoho and ager. One additional of such very popular soups in Tiv land is Genger which is produced from the flowers of the plant Bombax costatum both in fresh and dry form, which is the focus of this study. Due to wide acceptability and popularity of the soup, the need to produce data that will aid its handling, processing and storage is gaining prominence. Thermal parameters such as specific heat, thermal conductivity, thermal diffusivity, density and and activatiom energy are important. This study is therefore aimed at investigating the thermal properties of Bombax costatum for the purpose of combining equipment and raw materials during processing to achieve quality of finished product (Toledo, 1980; Sherman, 1974). Thermal properties of foods include thermal conductivity, thermal diffusivity, density and specific heat. Knowledge of these thermal properties of food substances is essential to researchers and designers for the optimum design of heat transfer, dehydration and drying process (Odigboh, 1978).

Specific objectives

i. To investigate the effect of temperature on the viscosity of Bombax costatum.

ii. To determine the specific heat capacity, thermal diffusivity and thermal conductivity of Bombax costatum

Many edible biological materials such as Okoho, Bombax costatum etc in Nigeria are usually available for a short period of the year. The desire to maintain high quality standards of such products is usually of paramount importance (Anaka, 1990). However lack of information on some of the quality control parameters of such materials tends to restrain the attainment of such noble objectives. Thermal parameters, are some of the prerequisites necessary for quality control and process formation during processing and storage. Thermal properties of Bombax costatum are also essential for quality cooking, commercial production, equipment and process design.

II. MATERIALS AND METHODS

Sample Preparation

This study was conducted on three samples of Bombax costatum obtained from Yandev Community of Gboko Local Government Area of Benue State, Nigeria. Flowers were collected from a chosen tree as they droped without the influence of any human activity. Petals were manually detached using hands while the calyx were reserved for the study as can be seen in Plate 1.These samples were studied at the moisture contents of 82%wb, 28%wb and 10%wb respectively. These materials were pounded and sieved to achieve uniform particle size. Equal volume of distilled water was used along with equal mass of sample to form slurries for the three samples. The experiments for the determination of thermal properties of the samples were carried out in the chemistry of food laboratory, food science and technology department of the University of Agriculture Makurdi from December 3rd to December 22nd 2010.Temperatures at all experiments were measured using either the mercury in glass thermometer graduated in degree celcius (˚C) or the thermocouple graduated in milivoltmeter. Samples were always stirred for even distribution of heat during measurements.The moisture content (percent wet basis) was measured by air-oven method. Wet basis which is expressed in a lot of literature is mostly used by farmers. Apparatus such as electronic weighing balance, crucibles, oven (gallencarp) and thermometer were used to carry out the experiments, while Equation (1) was used for the calculation of moisture content.

$$\text{Moisture content} = \frac{\text{weight of sample } (w_s) - \text{constant weight } (w_c)}{\text{weight of sample } (w_s)} * 100\% \quad .....(1)$$

Bulk densities of the test samples at 82%wb,28%wb and 10%wb were determined using the tapping method. Apparatus such as electronic weighing balance (FA2004 Max 200g), measuring cylinder and spoon were used for the experiments. Five replicated measurements of samples were taken in a measuring cylinder, using an electronic weighting balance to obtain the masses at room temperature. Measured masses obtained were substituted with the measured volume in to Equation (2) to obtain their densities

$$\text{Density} = \frac{\text{mass (g)}}{\text{volume (cm}^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The viscosity of Bombax costatum was determined with the aid of the following apparatus: A Brookfield viscometer, electric hotplate, beaker, thermometer, distilled water, ice par and. Brookfield viscometer . The experiment was based on the power law equation.

$$\tau = K\gamma^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

τ= Shear stress

K= Flow consistency index

γ = Shear rate

n = Flow behaviour index

The experiment was conducted at four temperature levels (30˚C, 40˚C, 50˚C and 60˚C) using spindle 4 and four selectable speeds 6, 12, 30 and 60 rpm. Slurries were reconstituted for the three samples using same volume of distilled water and mass of sample across the three samples and treated one after the other. Each sample was heated above the required temperature level in a calorimeter cup on a hot plate and cooled to the desired temperature, while being monitored with a thermometer. The slurry just enough to cover the immersion groove of the spindle shaft was immediately transferred into the viscometer cup already maintained at the corresponding temperature level in a water bath. The apparatus was energized with the viscometer guard leg on and viscosity readings were taken. With the aid of flash or indicators the correct spindle size and speed for the experiment was achieved with ease.

Readings were replicated three times at interval of two minutes, using the same spindle and speed, but different portions of the Bombax costatum sample. A plot of log of apparent viscosity against log of shear rate was done for the three samples. Using the power law Equation, the regression equations for all temperature levels were determined from which the flow behaviour index (n) and the consistency index (K) were determined respectively.

To determine the Specific Heat Capacity of Bombax costatum, the following apparatus were used;T-type thermocouple made of copper and constantine wires, electronic weighing balance, hot plate, stop watch. The specific heat capacity of samples was calculated using equation (4), while Figure 4 presents a schematic drawing of the Comparison calorimeter set up for the determination of specific heat.

$$C_S = \frac{C_a W_a + C_w W_w)\Delta Y_b - C_b W_b \Delta Y_a}{W_s \Delta Y_b}$$

……………………………. (4)

Gonap(2000)

where:

ΔY_a = Time for cup A and content to drop to Δt (sec)

ΔY_b = Time for cup B and content to drop to Δt (sec)

C_S = Specific heat capacity of sample

C_a = Specific heat capacity of cup A

C_b = Specific heat capacity of cup B

C_w = Specific heat capacity of water

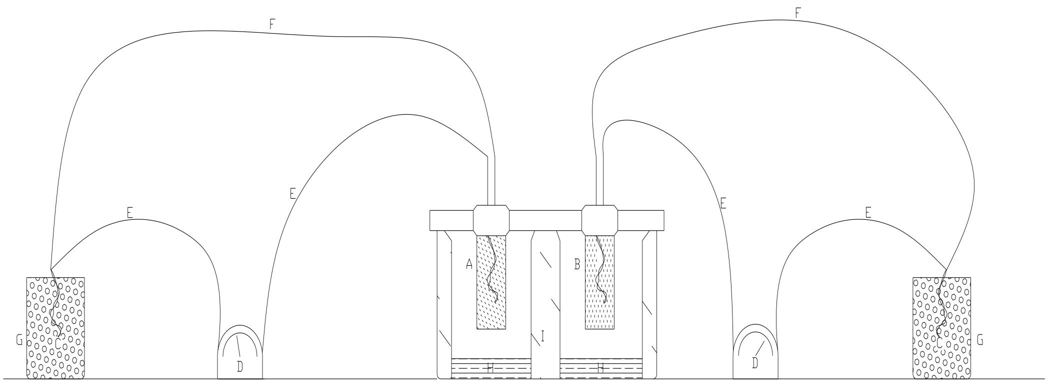
W_s = Weight of genger sample

W_w = Weight of water

W_a = Weight of cup A

W_b = Weight of cup B

Equal volume of distilled water and mass of sample were used to reconstitute slurries for the three samples. A known volume of distilled water and slurry were poured into the calorimeter cups and both heated to the same temperature of 90^0C on a hot plate, which were monitored by the Thermocouples immersed into the centres of the calorimeter cups. The calorimeters were continuously stirred while the heating was in progress. The contents once heated to the required temperature level respectively were immediately transferred into bath filled with water and placed inside the cupboard, while ensuring no heat transfer by convection took place. Temperature readings were taken at two-minutes interval until no further cooling occurs This was replicated three times for each sample. Readings



Gonap(2000)

Fig.1: Comparison calorimeter set up for the determination of specific heat of Bombax costatum.

Legend:
A and B = Calorimeter A and Calorimeter B containing water and sample respectively
C = Cold junction
D = Milivoltmeter
E = Copper wire
F = Constantine wire
G = Ice flask

H = Wooden cork
I = Water
J = Hot junction

obtained were average and cooling curves plotted to determine the specific heat of the Bombax costatum samples at the temperature level.

3.7 Determination of Thermal Diffusivity of Bombax costatum

The thermal diffusivities of the Bombax costatum samples were determined using the Dickerson apparatus. The Dickerson apparatus consists of a water bath, electric heater, aluminum cylinder with two wooden caps wrapped tightly with polyethene to prevent water absorption, stirrer and two thermocouples as can be seen in Figure 2.

The thermal diffusivity of the samples was determined using Equation (5).

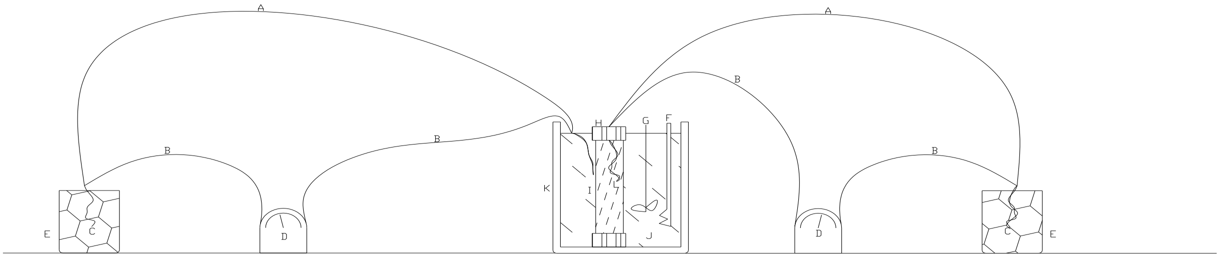
$$\alpha = \frac{0.25AR^2}{t_s - t_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Akinremi(1999)

Where:

α = Thermal diffusivity
A = Heating rate (deduced from slope of heating curve of sample)
R = Radius of cylinder (m)
t_s = Surface optimum temperature reading (°C)
t_c = Centre optimum temperature reading (°C)

The slurry (genger sample) was poured inside aluminum cylinder to the brim and the cylinder has both top and bottom placed inside the bath filled with water. The two thermocouples were to monitor the temperature rise inside and outside the cylinder respectively as the heater gets energized. Temperature readings were taken at intervals of 5 minutes simultaneously until the water in the bath started boiling and no further increase in the outside temperature reading. The time temperature data obtained was plotted and heating rate of the Sample which is the slope of the graph was used in Equation (5) to obtain the values of thermal diffusivities of all the samples.



Dickerson (1965)

Fig.2: A schematic drawing of Dickerson apparatus used for the determination of thermal diffusivity of Bombax costatum.

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Legend:
A = Constantine wire
B = Copper wire
C = Ice flask
D = Milivoltmeter
E = Cold junction
F = Electric heater
G = Stirrer
H =Wooden cork
I = Aluminium cylinder
J = Water
K =Water bath

The thermal conductivity of the samples was calculated theoretically using values obtained for specific heat, thermal diffusivity and bulk densities of the Bombax costatum samples obtained in this work. Thermal conductivity was determined using Equation (6).

$$K = \alpha C_s \rho \quad (6)$$

Gonap(2000)
Where:

K = Thermal conductivity
α = Thermal diffusivity
ρ = Bulk density
C_s = Specific heat capacity

3.9 Experimental Design and Statistical Analysis:

To investigate the effect of temperature on viscosity of Bombax costatum samples, Analysis was done for 3 - sample level, 4-shear rates and 4-temperature levels as one experimental design (i.e. 3 x 4 x 4) in CRD (SPSS version 15, Ogbaji, 2003, Bajpai, 1978). Linear regression analyses was also carried out for the thermal properties and all other linearly related properties.

III. RESULTS

TABLE 1: THE EFFECT OF MOISTURE CONTENT AND SHEAR RATE OF THE SAMPLES ON VISCOSITY AT VARYING TEMPERATURES.

Sample	ShearRate (RPM)	Temperature (^{0}C) and corresponding viscosity			
		30	40	50	60
82%wb	6	25.807	25.730	25.990	26.060
	12	17.441	17.562	17.948	16.964
	30	8.600	8.355	8.331	7.903
	60	5.293	5.060	5.180	5.347
28%wb	6	34.483	32.183	32.33	31.953
	12	20.442	19.625	19.726	18.783
	30	12.648	12.474	12.054	10.265
	60	6.643	6.610	6.160	5.993
10%wb	6	37.217	32.697	31.187	31.943
	12	24.726	22.474	21.383	20.93
	30	13.432	11.912	11.976	11.95
	60	7.543	6.480	6.563	5.950

The above results are obtained from the average of three replications per cell.

TABLE 2: THE EFFECT OF MOISTURE CONTENT AND TEMPERATURE OF THE SAMPLES ON VISCOSITY AT VARYING SHEAR RATES

Samples(MC%wb)	Temp. (°C)	Shear Rate			
		6	12	30	60

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82	30	62.154	6.520	100.731	124.014
	40	58.596	71.147	91.955	111.652
	50	58.293	71.272	92.965	113.663
	60	58.293	71.212	92.965	113.663
28	30	83.406	103.400	137.366	170.294
	40	86.008	108.865	148.658	188.165
	50	76.465	94.139	123.923	152.567
	60	72.089	87.532	113.131	137.362
10	30	87.345	108.282	143.853	178.336
	40	81.925	100.861	132.773	163.462
	50	80.687	101.425	137.235	172.507
	60	75.821	92.061	118.987	144.474

TABLE 3 RESULTS OBTAINED FROM PLOT OF VISCOSITY VERSUS TEMPERATURE FOR SAMPLES OF BOMBAX COSTATUM

Sample (MC%wb)	Temp	Regression equation	R^2
82	30	$y = -0.010x + 25.43$	0.729
	40	$y = -0.026x + 18.46$	0.833
	50	$y = -0.021x + 9.249$	0.889
	60	$y = -0.002x + 5.093$	0.810
28	30	$y = -0.073x + 36.05$	0.670
	40	$y = -0.048x + 21.83$	0.858
	50	$y = -0.075x + 15.26$	0.800
	60	$y = -0.024x + 7.431$	0.908
10	30	$y = -0.173x + 41.05$	0.681
	40	$y = -0.129x + 28.33$	0.946
	50	$y = -0.051x + 14.57$	0.700
	60	$y = -0.047x + 8.747$	0.833

TABLE 4: RESULTS OBTAINED FROM PLOT OF LOG OF CONSISTENCY INDEX VERSUS TEMPERATURE INVERSE AND THE CALCULATED ACTIVATION ENERGY FOR SAMPLES OF BOMBAX COSTATUM

Sample(MC%wb)	Linear regression	R^2	Activation energy ($KJmol^{-1}$)	Arrhenius Equation
82	$Y = 2.992x + 3.492$	0.961	24.875	$Y = 3.492e^{\frac{2.99}{T}}$
28	$Y = 5.595x + 3.689$	0.931	46.517	$Y = 3.689e^{\frac{5.59}{T}}$
10	$Y = 6.315x + 3.702$	0.829	52.503	$Y = 3.702e^{\frac{6.32}{T}}$

TABLE 5: STATISTICAL INVESTIGATION (ANOVA) OF THE EFFECT OF VARYING SHEAR RATE ON VISCOSITY OF BOMBAX COSTATUM ACROSS ALL SAMPLES CONSIDERED.

		Sum of sq	df	mean	F	Sig
82%wb	Between groups	1047.091	3	349.030	5292.692	0.00
App. viscosity	Within groups	0.791	12	0.660		
$X10^{-3}NS/m^2$	Total	1047.882	15			

28%wb	Between groups	1571.114	3	523.705	667.314	0.00
App. Viscosity	Within groups	9.418	12	0.785		
X10^{-3}NS/m^2	Total	1580.531	15			
10%wb	Between groups	1654.449	3	551.483	194.111	0.00
App. Viscosity	Within groups	34.093	12	2.841		
X10^{-3}NS/M^2	Total	1688.542	15			

TABLE 6: ANALYSIS OF VARIANCE TO INVESTIGATE THE EFFECT OF TEMPERATURE ON VISCOSITY OF SAMPLES OF BOMBAX COSTATUM AT 5% LEVEL OF SIGNIFICANCE

		Sum of sq	df	Mean sq	F	Sig
Viscosity at thirty degree Celsius	Between group	81.741	2	40.871	.306	.744
	Within group	1202.373	9	133.597		
	Total	1284.114	11			
Viscosity at forty degree Celsius	Between group	42.647	2	16.950	.185	.834
	Within group	1034.998	9	110.858		
	Total	1077.7645	11			
Viscosity at fifty degree Celsius	Between group	33.900	2	16.950	.153	.860
	Within group	997.723	9	110.858		
	Total	1031.623	11			
Viscosity at sixty degree Celsius	Between group	27.507	2	13.754	.118	.890
	Within group	1046.737	9	116.304		
	Total	107.244	11			

TABLE 7: RESULTS OBTAINED FROM PLOTS OF TEMPERATURE AGAINST TIME FOR DETERMINATION OF COOLING RATES AND SPECIFIC HEAT FOR THE THREE SAMPLES OF BOMBAX COSTATUM.

Sample	Linear regr. Equation	R^2	Cooling Rate (^{0}C/min)	Bulk Density (kg/m^3)	Specific heat (JK^{-1}Kg^{-1})	M.C (%)wb
82%wb	$Y = -1.1x + 89$	0.98	-1.1	688	21303.54	82
28%wb	$Y = -0.5x + 90$	0.99	-0.5	586	17147.39	28
10%wb	$Y = -0.95x + 86$	0.91	-0.95	516	15013.30	10

TABLE 8: RESULTS OBTAINED FROM THE PLOT OF TEMPERATURE VERSUS TIME FOR DETERMINATION OF HEATING RATE AND THERMAL DIFFUSIVITY OF SAMPLES OF BOMBAXCOSTATUM GENGER.

Sample	Linear regr. Equation	R^2	Heating Rate (^{0}C/min)	Bulk Density (kg/m^3)	Thermal Diffus (m^2/hr)	M.C (%)wb
82%wb	$Y = 1.52x + 36$	0.96	1.5	688	1.3254 x 10^{-4}	82
28%wb	$Y = 1.8x + 28$	0.93	1.8	586	6.36192 x 10^{-4}	28
10%wb	$Y = 1.3x + 56$	0.94	1.3	516	3.24492 x 10^{-4}	10

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TABLE24 : THE THERMAL PROPERTIES OF THE THREE SAMPLES OF BOMBAX COSTATUM CONSIDERED AS DETERMINED IN THIS WORK.

Sample	Specific heat ($JK^{-1}kh^{-1}$)	Thermal diff. (m^2/hr)	Thermal cond. ($wm^{-1}K^{-1}$)	BulkDen. (Kg/m^3)
82%wb	21303	1.3254×10^{-4}	1.9420	688
28%wb	17147.39	6.36192×10^{-4}	6.5145	586
10%wb	15013.30	4.59472×10^{-4}	3.5595	516

IV. DISCUSSION

Table 1 shows the average results of Apparent viscosity against temperature at different share rates and moisture contents. It can be seen that all samples followed the same thermal pattern. Rha (1975) and Kahn et al (1990) reported that chemical composition affects rheological and thermal behaviours of food materials. The similarity in thermal behaviour of all the samples is therefore not surprising, since they all have the same chemical composition, though there were variations in their moisture contents. Table 2 also revealed that apparent viscosity decreased with increasing temperature. Similar trends were observed by Alakali and Ijabo, 2003 for tomato pastes, Alakali et al., (2001) for canarium oil, Satimehin et al., (2003) for palm oil. The observation of increasing temperature resulting to decreasing viscosity can be attributed to increase in molecular kinetic energy brought about by increased temperature, which hasten alignment of molecules in the flow direction. The trend has been reported for many food materials in literature (Robinson, 1990, Sopade and Kasumu, 1992, Satimehin et al 2003).

The temperature dependency of consistency index was investigated using the Arrhennius relationship Satimehin et al (2003). The regression parameters are presented in Table 4 .The activation energy (slope) and frequency factor term of Arrhennius plot were derived by least squares regression equation as $24.88KJmol^{-1}$, $46.52KJmol^{-1}$ and $52.50KJmol^{-1}$ for samples of bombax costatum at moisture contents of 82%wb, 28%wb and 10%wb respectively. The R^2 was between 0.86 to 0.96, which implies that the temperature effect can be explained with Arrhenius relationship. Predictive models were subsequently developed for the prediction of apparent viscosity of Bombax costatum at different temperatures as can be seen in Table 4. The importance of this is known in the bond breaking energy required to initiate a thermal activity and chemical reaction when necessary (Akinremi, 1999).According to the values of activation energies obtained in this work, the sample at moisture content of 10%wb required more activation energy to initiate thermal activity, followed by that at 28%wb and lastly the sample at 82%wb. This difference in values of activation energies can be attributed to the variation in percentage of moisture and flow consistency index of samples. Satimehin et al (2003) also established that activation energy of palm oil is higher at lower temperature range when viscosity is high and low at higher temperature range when viscosity is low.

One – way analysis of variance was performed to investigate the effect of temperature and shear rate on the viscosity of Bombax costatum across samples as can be seen in Table 5 . Comparing at fixed temperatures across wet, fairly dried and fully dried samples, results show that temperature and shear rate have no significant difference on viscosity of Bombax costatum across all samples considered at 5% level of significance. The above results only confirm that the three samples have same thermal and rheological characteristics and composition .comparing viscosity across temperatures, there was significant effect at the same level of significance as can be seen in table 6. This confirms the result in table 1. The result of specific heat determined for the Bombax costatum samples at a final temperature of $90.01^{\circ}C$ is given in table 7 and appendix i. Comparing the specific heat of the three samples, it was observed that the specific heat capacity is highest for samples of Bombax costatum at moisture content of 82%wb, followed by sample at 28%wb and lastly that at 10%wb. Sample at 82%wb gave a specific heat of 21303.54 $Jk^{-1}kg^{-1}$ and bulk density of $688kg/m^3$, 28%wb moisture content gave a specific heat of $17147.39JK^{-1}kg^{-1}$ and bulk density of $586kg/m^3$ while the sample with moisture content of 10%wb presented a specific heat capacity of 15013.30 $JK^{-1}kg^{-1}$ and bulk density of $516kg/m^3$. This trend or observation can be attributed to their percentage moisture content since all the samples have same chemical composition. The temperature–time plot that produced conditions for determination of specific heat of samples gave $R^2 \geq 0.91$, which indicate that the regression or predictive equations in Table 7 can be applied to estimate temperature change with time in a cooling system for Bombax costatum. The result shows that both specific heat and bulk density of Bombax costatum increased with moisture. Irtwange (2003) presented specific heat of African Yam bean as increasing with moisture content. Akinremi (1999) also revealed that specific heat of palm oil increase with moisture content. Obetta (2000) reported that specific heat of palm kernel increases with increase in moisture content.

Table 8 and Appendix ii present the result of the thermal diffusivity obtained for three samples of Bombax costatum . Thermal diffusivity of samples at the moisture contents of 82%wb , 28%wb and10%wb were found to be 1.3254 x 10^{-4} m^2/hr, 6.36192 x 10^{-4} m^2/hr and 4.59472 x $10^{-4}$$m^2$/hr respectively. Linear regression was performed using the temperature-time plot with $R^2 \geq 0.93$, which indicates that the regression equations for 82%wb, 28%wb and 10%wb can be used under the same condition to predict temperature and time change in a heating system for Bombax costatum. The result shows that thermal diffusivity of the three samples does not follow a particular trend. However, sample with moisture content of 82%wb present the highest value of thermal diffusivity, followed by 10%wb and lastly the 28%wb sample (Table 8). Irtwange (2003) reported that thermal diffusivity of African Yam bean increases with increase in moisture content. Obetta (2000) also presented that thermal diffusivity of palm kernel increases with increase in moisture content. Akinremi (1999) reported a case of no particular trend on thermal diffusivity of palm oil. Sneenarayanan and Chattopadhay (1986) revealed that thermal diffusivity of rice brain decrease with increase in moisture content.

Table 9 shows the result of all the thermal properties determined in this work. Thermal conductivity of Bombax costatum samples was obtained using equation (6) It can be seen that fairly dried sample has very high thermal conductivity, followed by fully dried and lastly the wet sample. The thermal diffusivity of wet, fairly dried and fully dried samples were found to be 1.9420$wm^{-1}k^{-1}$, 6.5143$wm^{-1}k^{-1}$ and 2.6875$wm^{-1}k^{-1}$ respectively. Chang (1986) reported that thermal conductivity of wheat, corn and grain increase with increase in moisture content and bulk density. Obetta (2000) reported that thermal conductivity of palm kernel increases with increase in moisture content. Jansansky (1973) reported that thermal conductivity of soyabean seed increases with moisture content. Akinremi (1999) reported that thermal conductivity of palm oil increases with increase in moisture content.

V. CONCLUSIONS

The following conclusions are made:

(a) Apparent viscosity of Bombax costatum was found to decrease with increasing temperature indicating that it varies with temperature according to Arrhenius relationship.

(b) The specific heat and bulk density of Bombax costatum was found increasing with moisture content while thermal diffusivity and thermal conductivity of Bombax costatum did not give a clear trend across the samples.

Recommendation

The rheological and thermal properties of Bombax costatum are very important characteristics that demand attention. Since there is little literature on this, I wish to recommend that other methods may be considered for the determination of this properties and compared with the results obtained in this work. Thermal conductivity may also be determined for Bombax costatum using an experimental procedure and comparing with that obtained theoretically in this work.

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(a)

(b)

(c)

Plate 1: Samples of Bombax Costatum at varying moisture contents: (a)82%wb, (b) 28%wb and (c) 10%wb

TIME – TEMPERATURE DATA DETERMINED USING THE COMPARISON CALORIMETER METHOD.

		Wet				Fairly dried				Fully dried			
Rep	time(min)	sample(mv)	°C	Water(mv)	°C	sample(mv)	°C	water(mv)	°C	water(mv)	°C	sample(mv	°C
1	0	03.85	90.01	3.85	90.01	3.85	90.01	3.85	90.01	3.85	90.01	3.85	90.01
2	2	3.59	83.93	3.59	83.93	3.76	87.91	3.72	86.98	3.59	83.93	3.42	79.96
3	4	3.55	83.08	3.51	81.70	3.72	86.98	3.64	85.11	3.59	79.96	3.38	79.03

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4	6	5.51	82.07	3.34	78.09	3.65	86.04	3.55	83.00	3.38	79.03	3.3	78.09
5.	8	3.42	79.96	3.25	75.99	3.64	85.11	3.46	80.90	3.25	75.99	3.16	73.88
6	10	3.34	78.09	3.16	68.38	3.59	83.93	3.38	79.03	3.21	75.05	2.99	69.91
7	12	3.25	75.99	3.08	67.40	3.55	83.00	3.29	76.92	3.16	73.88	2.95	68.85
8	14	3.08	72.01	2.91	66.04	3.46	80.90	3.25	75.99	3.12	71.12	2.91	68.04
9	16	2.95	68.85	2.82	65.93	3.42	79.96	3.21	72.05	3.08	67.04	2.87	67.10
10	18	2.91	68.04	2.69	62.89	3.38	78.09	3.12	68.12	2.99	68.41	2.82	65.93

Appendix 11

Thermal diffusivity time-temperature data determined using the Dickerson apparatus set up

Rep	**Time (minutes)**	**Wet sample**				**fairly dried sample**				**fully dried sample**			
		Sample temp.		**water temp.**		**sample temp.**		**water temp.**		**sample temp.**		**water temp.**	
		MV	**°C**	**MV**	**°C**	**MV**	**°C**	**MV**	**°C**	**MV**	**°C**	**MV**	**°C**
1	**0**	**0.98**	**22.91**	**0.98**	**22.91**	**0.98**	**22.91**	**0.98**	**22.91**	**0.98**	**22.91**	**0.98**	**22.91**
2	**5**	**1.71**	**39.98**	**2.74**	**64.06**	**1.11**	**25.95**	**1.88**	**43.96**	**2.69**	**62.89**	**1.80**	**42.09**
3	**10**	**2.31**	**54.01**	**3.34**	**78.09**	**2.05**	**47.93**	**2.91**	**68.04**	**3.34**	**78.09**	**2.05**	**47.93**
4	**15**	**2.74**	**64.08**	**3.59**	**83.93**	**2.39**	**55.88**	**3.34**	**78.09**	**3.51**	**82.07**	**2.65**	**61.96**
5	**20**	**3.25**	**76.99**	**4.02**	**93.99**	**2.99**	**69.90**	**3.76**	**87.91**	**3.72**	**86.98**	**2.82**	**65.93**
6	**25**	**3.51**	**82.04**	**4.12**	**96.33**	**3.59**	**83.93**	**4.15**	**97.03**	**4.19**	**97.97**	**3.46**	**80.89**
7	**30**	**3.65**	**86.54**	**4.19**	**97.97**	**4.02**	**93.99**	**4.15**	**97.03**	**4.19**	**97.97**	**3.68**	**86.04**
8	**35**	**3.76**	**88.91**	**4.19**	**97.97**	**4.12**	**96.33**	**4.15**	**97.03**	**4.19**	**97.97**	**3.85**	**90.02**
9	**40**	**3.93**	**92.19**	**4.19**	**97.97**	**4.12**	**96.33**	**4.15**	**97.03**	**4.19**	**97.97**	**3.85**	**90.02**
10	**45**	**4.02**	**94.99**	**4.19**	**97.97**	**4.12**	**96.33**	**4.15**	**97.03**	**4.19**	**97.97**	**3.85**	**90.02**

Appendix 111

TABLE24 : THE THERMAL PROPERTIES OF THE THREE SAMPLES OF BOMBAX COSTATUM CONSIDERED AS DETERMINED IN THIS WORK.

Sample	Specific heat ($JK^{-1}kh^{-1}$)	Thermal diff. (m^2/hr)	Thermal cond. ($wm^{-1}K^{-1}$)	BulkDen. (Kg/m^3)
82%wb	21303	1.3254×10^{-4}	1.9420	688

28%wb	17147.39	6.36192×10^{-4}	6.5145	586
10%wb	15013.30	4.59472×10^{-4}	3.5595	516