Technical Report

Determination of Average Grain Sizes and Water Evaporation Rates of Some Nigeria Clays at Oven Drying Temperature

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Abstract: Studies were carried out to determine the average grain sizes and evaporation rates of some Nigeria clay at oven drying temperature. The grain sizes were determined by sedimentation analysis using hydrometer method. The drying process was carried out at a temperature range: 80-110^{0}C. The results of the sedimentation analysis show that the average grain sizes of Olokoro, Otamiri and Ukpor clay are 9.8195, 11.6 and 13.98 µm respectively. This implies mathematically that Olokoro Clay Grain Size < Otamiri Clay Grain Size < Ukpor Clay Grain Size. It was found that Olokoro clay has the highest water evaporation rate compared to Ukpor and Otamiri clay though of the three, it has the smallest grain size. This resulted from higher gangue contents of Olokoro clay which were burnt off during drying thereby enlarging existing inter-particle spacing and invariably enhancing the quantity of water lost by evaporation [Report and Opinion.2010;2(4):21-28]. (ISSN: 1553-9873).

Keywords: Determination, Grain Sizes, Evaporation Rates, Nigeria Clay, Drying.

1. Introduction

Reed (1988) reported that processing systems with particle distribution of particle sizes and shape are produced by proper selection and blending of raw materials with different initial characteristics and by subsequent crushing, grinding, dispersion, classification and granulation.

Mc Geary (1961) studied the packing of coarse (0.37mm) monosize spherical particles experimentally using axial vibration and observed packing mostly in an orthorhombic arrangement and packing density of 62.5%. The report concluded that packing density of nearly monosized spherical particles of silica and alumina of colloidal size packed by filter pressing deflocculated slurry is about 60-65%.

It was discovered (Barsoum, 1979) that the accuracy of particle size data depend somewhat on the sample preparation, the particle shape and technique used for the analysis. Techniques in current use are microscopy, sieving, sedimentation, electrical sensing, laser diffraction and light intensity fluctuation (Barsoum, 1979).

It has been reported (David, 1979) that sedimentation analysis is more precise and sensitive to the size distribution of clay suspension than electrical sensing technique.

Singer and Singer (1963) reported that in electrical sensing techniques, the resistance of an electrolyte current path through a narrow orifice between two electrode increases when ceramic particle pass through the orifice. The resistance pulse for a stream of dispersed particle passing through the orifice are converted into the voltage pulse, amplified, scaled and counted electronically.

In During sedimentation analysis using hydrometer method, spherical particles with a particular density and diameter are released into a viscous fluid to ascertain the velocity and time of settling.

Reed (1988) reported that drying occurs in three stages; increasing rate, constant and decreasing rate. Reed pointed out that during the increasing rate; evaporation rate is higher than evaporating surface hence more water is lost. At constant rate, the evaporation rate and evaporation surface are constant.

Nwoye (2009) derived a model for calculating the quantity of water lost by evaporation during oven drying of clay at 90^{0}C. The model;

$$\gamma = \exp[(\ln t)^{1.0638} - 2.9206] \qquad (1)$$

indicated that the quantity of evaporated water, γ during the drying process is dependent on the drying time t, the evaporating surface being constant. The validity of the model was found to be rooted in the expression $(\text{Log}\beta + \ln\gamma)^N = \ln t$.

Model for predictive analysis of the quantity of water evaporated during the primary-stage processing of a bioceramic material sourced from kaolin has been derived has been derived by Nwoye et al. (2009). The model;

$$\alpha = e^{(\ln t/2.1992)} \qquad (2)$$

shows that the quantity of water α, evaporated at 110^{0}C, during the drying process is also dependent on the drying time t, where the evaporating surface is constant. It was found that the validity of the model is rooted on the expression $(\ln t/\ln\alpha)^N = \text{Log}\beta$ where both sides of the expression are correspondingly approximately equal to 3. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value was found to be less than 22% which is quite within the acceptable deviation range of experimental results.

Model for quantifying the extent and magnitude of water evaporated during time dependent drying of clay has been derived (Nwoye 2009). The model;

$$\gamma = \exp((\ln t/2.9206)^{1.4}) \qquad (3)$$

indicates that the quantity of evaporated water γ during the drying process (at 90^{0}C) is dependent on the drying time, t the evaporating surface being constant. It was found that the validity of the model is rooted in the expression $\text{In}\gamma = (\text{Int}/\text{Log}\beta)^N$ where both sides of the expression are correspondingly almost equal.

The present work is to determine the average grain size and water evaporation rates of some Nigeria clays at oven drying temperature.

2. Materials and Method

2.1 Sedimentation Experiment

All clays (Olokoro, Ukpor and Otamiri) used were collected in lumps from deposits in South-eastern Nigeria. These clays were allowed to dry in air for 96 hours. Following pretreatment of the clays using a dispersing agent (sodium hexametaphosphate), sedimentation analysis was carried out using the conventional procedure (BS1377:1975). During the experiment, general corrections were done to facilitate accuracy of results. These corrections are meniscus correction cm, temperature correction Mt and dispersing agent correction X, and water density correction cw. The difference between the two scale readings multiplied by 1000 gives the meniscus correction;

$$Cm = (B-A) \times 1000 \qquad (4)$$

Where

Cm = Meniscus correction

B = Scale reading at the upper rim of the Meniscus

A = Reading at the surface of the liquid

True hydrometer reading Rh is calculated by

$$Rh = Rh^1 + Cm \qquad (5)$$

Where

Rh^1 = the first hydrometer reading

The correction X applied to Rh is given by

$$X = 2m_d \qquad (6)$$

Where

X = Dispersant correction

m_d = Mass of dispersing agent remaining after evaporation

The X correction is subtracted from Rh value. Water density correction used :1.8 was added to the true density Rh. The fully corrected hydrometer reading R is given by;

$$R = Rh^1 + Cm + Mt - X + 1.8 \qquad (7)$$

The equivalent particle diameter at a known and after a certain time interval from the start of sediment The equivalent particle diameter, at a known and after a certain time interval from the start of the sedimentation process can be calculated from the equation:

$$D = 0.005531\sqrt{(2H/(G_0 - 1)t)} \qquad (8)$$

Where

D = Equivalent particle diameter (mm)

η= Viscosity of water at test temperature (Mpas)

H = Effective depth (mm)

G_o = Specific gravity of particles (determined using conventional procedure (BS1377:1975))

t = Elapsed time (mins.)

The percentage by mass of particles smaller than the equivalent diameter D, is denoted by K. This percentage is equivalent to the 'percentage passing' in sieve analysis. It is given by the equation;

$$K = \frac{G_o \times R \times 100\%}{m(G_o - 1)} \qquad (9)$$

Where

m = mass of dry particles after pretreatment

R = Fully corrected hydrometer reading

Also the effective depth H_R was calculated using the equation;

$$H_R = 219 - 4.1Rh \qquad (10)$$

The average grain size of the clay samples analyzed was calculated using the equation;

$$Dm = \frac{\sum [\Delta K \times D]}{\sum [\Delta K]} \qquad (11)$$

Where

Dm = Average grain size (µm)

ΔK = Actual percentage finer D

2.2 Evaporation Experiment

Fresh samples of each of these clay types were crushed and sized to a fine particle size of 125µm using assembly of sieves and sieve shaker. Each sample was manually homogenized separately in a mixing drum using 2% starch as binder. Samples were mixed with water (6% of the total weight of dry materials). The clays were prepared, moulded and dried at temperatures 80, 90, 100 and 110^{0}C. Each clay-type was dried for 30, 50, 70, 90, 110 and

130 minutes at each of the temperatures stated. A wooden mould of surface area 833mm^2 was used to make a rectangular shape of the clay. The moulded clays were then dried in an electric oven to enhance loss of water through evaporation. At the end of the drying process, average value of the masses of water evaporated from each clay-type were taken and recorded.

3. Results and Discussion

3.1 Sedimentation analysis

Samples collected within the surroundings of each clay deposits were homogenized prior to chemical analysis. The chemical composition of the homogenized clay samples used is given in Table 3.

Experimental corrections were made to ensure precision in the results obtained. These corrections were evaluated from the equation already stated. Corrections done includes the meniscus correction Cm = +0.5, temperature correction Mt = +2.3, dispersant correction X = 3 and water correction Cw = 1.8 for Olokoro clay. Cm, Mt, X, and Cw were + 0.5, +2.3, + 3.5 and 1.8 respectively for both Ukpor and Otamiri clay.

The percentage pretreatment loss was calculated for the three clay types using the equation ;

$$PTL = \frac{IDM - DMP}{IDM} \times 100 \qquad (12)$$

Where

PTL = Pretreatment loss (%)
IDM = Initial dry mass (g)
DMP= Dry mass after pretreatment (g)
LM = Loss of mass due to pretreatment (g)

Table 1 indicates that the pretreatment loss percent evaluated for Olokoro, Ukpor and Otamiri clays are 2.3%, 1.8% and 1.18% respectively. The pretreatment loss is suspected to have resulted from the removal of gangue materials from the clays. The pretreatment loss percent recorded (Table 1) is indicative of the fact that Olokoro clay contains greater quantity of gangue materials than Ukpor and Otamiri clays.

Table 1 Result of Pretreament process carried out

Clay Source	IDM	DMP	LM	PTL
Olokoro	50	48.85	1.15	2.3
Ukpor	50	49.10	0.9	1.8
Otamiri	50	49.41	0.59	1.18

The specific gravities of Olokoro, Ukpor and Otamiri clays were determined as 2.52, 2.62 and 2.48 respectively.

The results of the sedimentation analysis (Tables 4 – 6) indicate that the average grain sizes of Olokoro, Otamiri and Ukpor clay are 9.8195, 11.6 and 13.98 µm respectively. Mathematically, this implies that Olokoro Clay Grain Size < Otamiri Clay Grain Size < Ukpor Clay Grain Size. This shows that Olokoro clay is the finest of the three clay types studied.

3.2 Evaporation rates

The water evaporation rate resulting from drying of Olokoro, Ukpor and Otamirir clays at temperatures: 80, 90, 100 and 110^{0}C within the drying times: 30, 50, 70, 90, 110 and 130 minutes were determined.

Evaporation rate, Er (gmin^{-1}) is calculated from the equation;

$$Er = E/t \qquad (13)$$

Therefore, a plot of mass of water evaporated E (from Olokoro, Ukpor and Otamiri clay) against drying time, t at a drying temperature of 80^{0}C (as in Figures 1 - 3) gives a slope, S at points (30,1.6) & (110, 6.2), (30,1.6) & (110, 6.2) and (30,1.6) & (110, 6.2) for Olokoro, Ukpor and Otamiri clay respectively, following their substitution into the mathematical expression;

$$S = \Delta E/\Delta t \qquad (14)$$

Eqn. (14) is detailed as

$$S = E_2 - E_1 / t_2 - t_1 \qquad (15)$$

Where

ΔE = Change in the quantities of water evaporated E_2, E_1 at two drying time values t_2, t_1.

3.2.1 Water evaporation rate at 80^{0}C

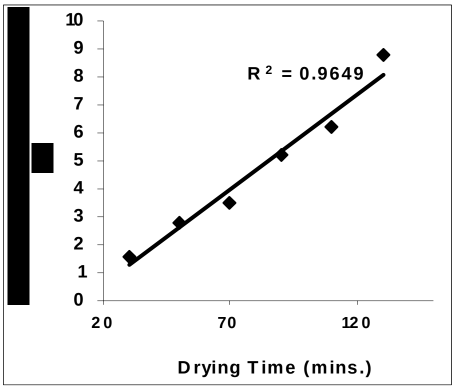

Figure 1: Variation of quantity of water evaporated (from Olokoro clay) with drying time

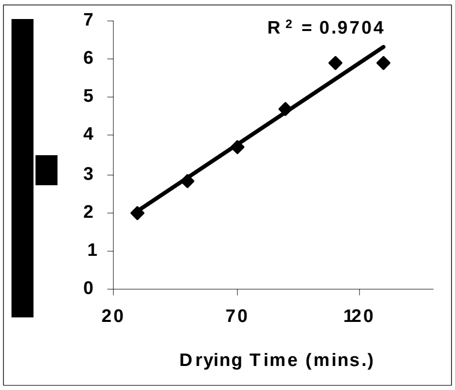

Figure 2: Variation of quantity of water evaporated (from Ukpor clay) with drying time

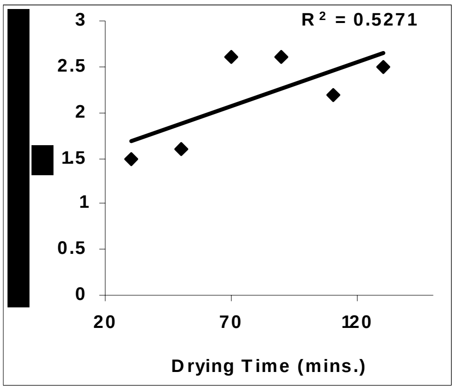

Figure 3: Variation of quantity of water evaporated (from Otamiri clay) with drying time .

Considering the points (30, 1.6) & (110, 6.2), (30, 1.6) & (110, 6.2) and (30, 1.6) & (110, 6.2) (for Olokoro, Ukpor and Otamiri clay respectively) for (E_1, t_1) and (E_2, t_2) respectively, and substituting them into eqn. (15), gives the slope as 0.0575, 0.0488, and 0.0538gmin^{-1} respectively.

3.2.2 Water evaporation rate at 90^{0}C

Plots associated with drying temperature: 90^{0}C (as in Figures 4 - 6) give slopes at points (30, 2.5) & (110, 7.7), (30, 2.6) & (110, 6.1) and (30, 4.1) & (110, 8.4) (for Olokoro, Ukpor and Otamiri clay respectively) as 0.065, 0.0438, 0.0538 gmin^{-1} respectively.

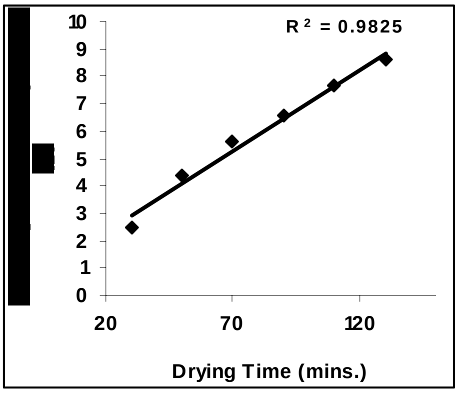

Figure 4: Variation of quantity of water evaporated (from Olokoro clay) with drying time

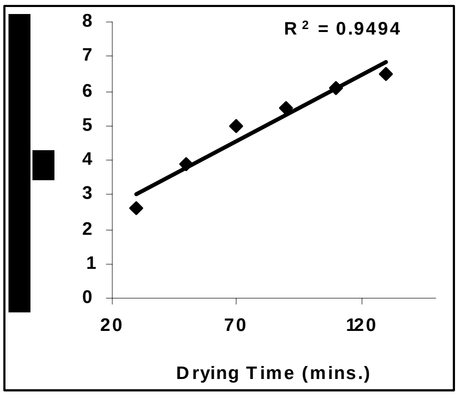

Figure 5: Variation of quantity of water evaporated (from Ukpor clay) with drying time

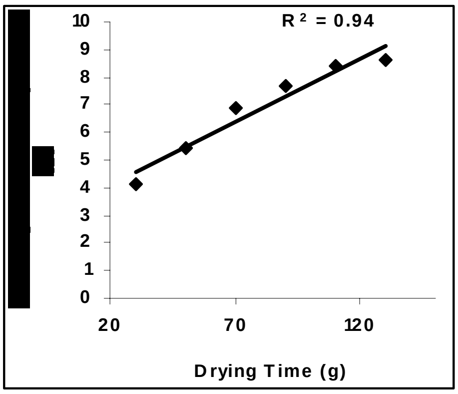

Figure 6: Variation of quantity of water evaporated (from Otamiri clay) with drying time

3.2.3 Water evaporation rate at 100^{0}C

Similarly, plots associated with drying temperature: 100^{0}C (as in Figures 7 - 9) give slopes at points (30, 0.7) & (110, 4.1), (30, 1.3) & (110, 2.9) and (30, 1.5) & (110, 2.2) (for Olokoro, Ukpor and Otamiri clay respectively) as 0.0425, 0.02, 0.0088 gmin^{-1} respectively.

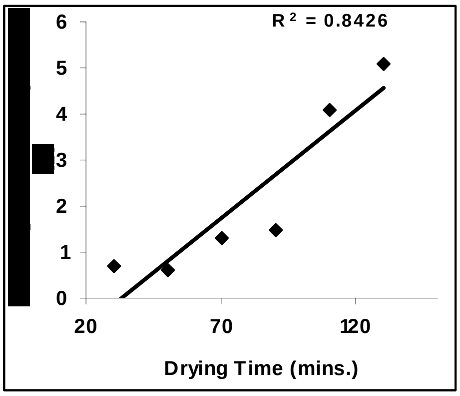

Figure 7: Variation of quantity of water evaporated (from Olokoro clay) with drying time

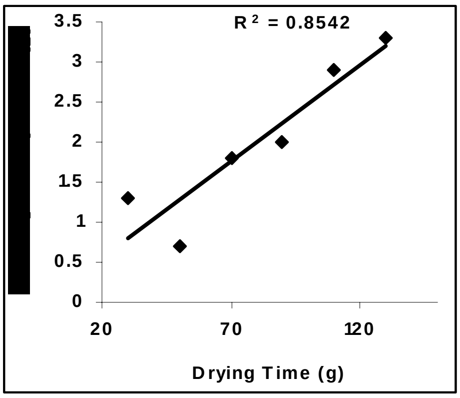

Figure 8: Variation of quantity of water evaporated (from Ukpor clay) with drying time

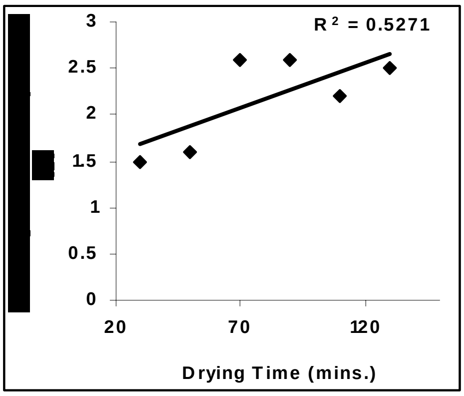

Figure 9: Variation of quantity of water evaporated (from Otamiri clay) with drying time

3.2.4 Water evaporation rate at 110^{0}C

Also, plots associated with drying temperature: 110^{0}C (as in Figures 10 - 12) give slopes at points (30, 7.7) & (110, 8.3), (30, 6) & (110, 7.4) and (30, 7.8) & (110, 10.7) (for Olokoro, Ukpor and Otamiri clay respectively) as 0.0075, 0.0175, 0.0363 gmin^{-1} respectively.

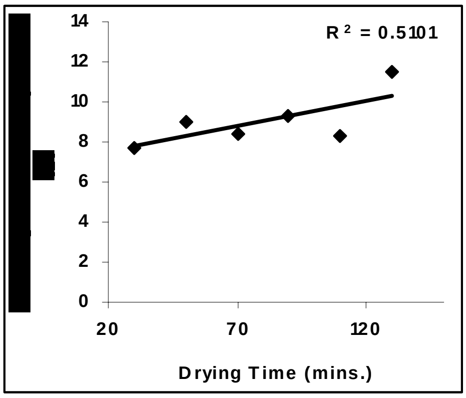

Figure 10: Variation of quantity of water evaporated (from Olokoro clay) with drying time

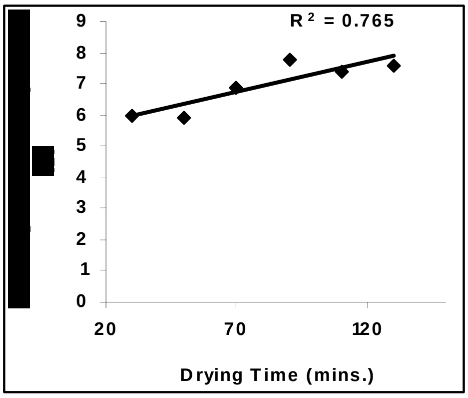

Figure 11: Variation of quantity of water evaporated (from Ukpor clay) with drying time

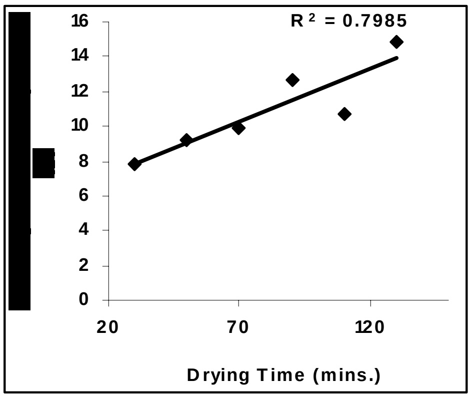

Figure 12: Variation of quantity of water evaporated (from Otamiri clay) with drying time

Figures 1–12 show that for all the drying temperatures used, increase in the drying time results to increase in the quantity of water evaporated. Evaluated water evaporation rates of Olokoro, Ukpor and Otamiri clay as in Table 2 shows that Olokoro clay generally has the highest evaporation rate compared with the other clay types studied though it has the smallest average grain size.

Table 2: Water evaporation rates of some Nigeria clays

Temp. (^{0}C)	Olokoro clay	Ukpor clay	Otamiri clay
80	0.0575	0.0488	0.0538
90	0.0650	0.0438	0.0538
100	0.0425	0.0200	0.0088
110	0.0075	0.0175	0.0363

This is attributed to its higher PTL (Table1) compared to the other clay types used. This resulted from the presence of greater quantity of removable gangue materials in Olokoro clay compared to Ukpor and Otamiri clays during. The gangue materials interwoven with the clay particles are burnt off during drying in the furnace and its removal implies enlarging the existing inter-particle spacing hence enhancing the quantity of water lost by evaporation. The water evaporation rate of Otamiri clay is lower than that of Olokoro clay but higher than that of Ukpor clay, though it has smaller grain size than Ukpor clay. This is attributed to the chemical nature of Otamiri clay.

Table 3: Chemical composition of clays used

Clay Source	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	SiO_2	Na_2O	K_2O	Loss of Ignition
Olokoro	29.10	7.95	-	0.75	1.26	45.31	0.05	0.09	11.90
Ukpor	31.34	0.63	2.43	0.14	0.06	51.43	0.04	0.10	12.04
Otamiri	15.56	0.05	1.09	-	0.29	69.45	0.01	0.21	13.10

Table 4 Result of Hydrometer analysis (Olokoro clay)

TEST TEMPERATURE = 30^0C
VISCOSITY OF WATER η = 0.8909 mpas
HYDROMETER TYPE: CASAGRANDA 20^0C

(1) Serial No	(2) Elapsed time t (mins.)	(3) Rh^1	(4) Rh	(5) H_R	(6) R	(7) Diameter $4.234\sqrt{(H_R/t)}$	(8) Percentage finer than D 3.394R%	(9) Actual % finer ΔK	(10) ΔK.D	**Calculations**
	27/11/2003 0									
1	0.5	20.41	20.91	128.27	22.01	67.82	74.70	0.71	48.15	
2	1	20.20	20.70	129.09	21.80	48.11	73.99	0.68	32.71	
3	2	20.00	20.50	129.95	21.60	34.13	73.31	14.25	486.35	$Dm = \frac{\sum \Delta K.D}{\sum \Delta K}$
4	4	15.80	16.30	147.17	17.40	25.68	59.06	0.55	14.12	
5	8	15.64	16.14	147.83	17.24	18.20	58.51	0.51	9.28	
6	15	15.49	15.99	148.44	17.09	13.32	58.00	0.47	6.26	$\frac{733.52}{74.7}$
7	30	15.35	15.85	149.02	16.95	9.44	57.53	0.44	4.15	
8	60	15.22	15.72	149.55	16.82	6.68	57.09	0.34	2.27	
9	120	15.12	15.62	149.96	16.72	4.73	56.75	14.32	67.73	= 9.8195 µm
10	240	10.90	11.40	167.26	12.50	3.53	42.43	0.38	1.34	
11	360	10.75	11.29	167.71	12.39	2.89	42.05	0.13	0.38	
12	28/11/2003 1440	10.75	11.25	167.88	12.35	1.45	41.92	$\frac{41.92}{74.7}$	$\frac{60.78}{733.72}$	

Table 5 Result of Hydrometer analysis (Ukpor clay)

TEST TEMPERATURE = 30^0C
VISCOSITY OF WATER η = 0.8909 mpas
HYDROMETER TYPE: CASAGRANDA 20^0C

(1) Serial No	(2) Elapsed time t (mins.)	(3) Rh^1	(4) Rh	(5) H_R	(6) R	(7) Diameter $4.234\sqrt{(H_R/t)}$	(8) Percentage finer than D 3.394R%	(9) Actual % finer ΔK	(10) ΔK.D	**Calculations**
	1/12/2003 0									
1	0.5	20.60	20.10	127.49	21.70	65.50	71.48	1.15	75.33	
2	1	20.25	20.75	128.93	21.35	46.58	70.33	14.33	667.49	
3	2	15.90	16.40	146.76	17.00	35.14	56.00	0.92	32.33	$Dm=\frac{\sum \Delta K.D}{\sum \Delta K}$
4	4	15.62	16.12	147.91	16.72	24.94	55.08	0.66	16.45	
5	8	15.42	15.92	148.73	16.52	17.69	54.42	0.56	9.91	
6	15	15.25	15.75	149.43	16.35	12.95	53.86	0.50	6.48	$\frac{999.34}{71.48}$
7	30	15.10	15.60	150.04	16.20	9.17	53.36	13.56	127.10	
8	60	10.18	11.39	167.30	11.99	6.85	39.50	0.80	5.48	
9	120	10.65	11.15	168.29	11.75	4.86	38.70	0.75	3.65	= 13.98 µm
10	240	10.42	10.92	169.23	11.52	3.44	37.95	0.33	1.14	
11	360	10.32	10.82	169.64	11.42	2.82	37.62	0.66	1.86	
12	2/12/2003 1440	10.12	10.62	170.46	11.22	1.41	36.96	$\frac{36.96}{71.48}$	$\frac{52.11}{999.34}$	

Table 6 Result of Hydrometer analysis (Otamiri clay)

TEST TEMPERATURE = 30^0C
VISCOSITY OF WATER η = 0.8909 mpas
HYDROMETER TYPE: CASAGRANDA 20^0C

(1) Serial No	(2) Elapsed time t (mins.)	(3) Rh^1	(4) Rh	(5) H_R	(6) R	(7) Diameter $4.291\sqrt{(H_R/t)}$	(8) Percentage finer than D 3.391R%	(9) Actual % finer ΔK	(10) ΔK.D	**Calculations**
	27/11/2003 0									
1	0.5	10.82	11.32	167.59	11.92	78.56	40.42	0.34	26.71	
2	1	10.72	11.22	168.00	11.82	55.62	40.08	0.68	37.82	
3	2	10.52	11.02	168.82	11.62	39.42	39.40	0.67	26.41	$Dm=\frac{\sum \Delta K.D}{\sum \Delta K}$
4	4	10.32	10.82	169.64	11.42	27.94	38.73	0.92	25.70	
5	8	10.05	10.55	170.75	11.15	19.82	37.81	14.07	278.87	
6	15	5.90	6.40	187.76	7.00	15.18	23.74	0.68	10.32	$\frac{451.09}{40.42}$
7	30	5.70	6.20	188.58	6.80	10.76	23.06	0.17	1.83	
8	60	5.65	6.15	188.79	6.75	7.61	22.89	0.78	5.94	
9	120	5.42	5.92	188.73	6.52	5.40	22.11	0.58	3.13	= 11.16 µm
10	240	5.25	5.75	190.43	6.35	3.82	21.53	0.34	1.30	
11	360	2.15	5.65	190.84	6.25	3.12	21.19	0	0	
12	28/11/2003 1440	5.15	5.50	190.84	6.25	1.56	21.19	$\frac{21.19}{40.42}$	$\frac{33.06}{451.09}$	

Conclusion

Results of sedimentation analysis carried out indicates that the average grain sizes of Olokoro, Otamiri and Ukpor clay are 9.8195, 11.6 and 13.98 µm respectively. This implies mathematically that Olokoro Clay Grain Size < Otamiri Clay Grain Size < Ukpor Clay Grain Size. Olokoro clay has the highest water evaporation rate compared to Ukpor and Otamiri clay. This resulted from higher gangue contents of Olokoro clay which were burnt off during drying thereby enlarging existing inter-particle spacing and invariably enhancing the quantity of water lost by evaporation.

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Appendix for Tables 4-6

$\text{Col } 9_1 = \%\ \Delta K = \text{Col } 8_1 - \text{Col } 8_2$

$\text{Col } 9_2 = \text{Col } 8_2 - \text{Col } 8_3$

$\text{Col } 9_i = \text{Col } 8_i - \text{Col } 8_{i+1}$

$\text{Col}_{10} = \text{Col}_7 \times \text{Col}_9$

2/1/2010