

Oven-Dewatering of Otamiri Clays Designated for Production of Porcelain and Multi-Factorial Analysis of Periodic Water Loss

C. I. Nwoye^{1,*}, E. Obidiegwu², E. M. Ameh³, S. O. Nwakpa¹

¹Department of Metallurgical and Materials Engineering, NnamdiAzikiwe University, Awka, Nigeria

²Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria

³Department of Metallurgical and Materials Engineering, Enugu State University of Science & Technology, Enugu Nigeria

*Corresponding author: nwoyennike@gmail.com

Received October 02, 2013; Revised March 24, 2014; Accepted April 08, 2014

Abstract Oven-dewatering of Otamiri clay designated for production of porcelain was carried out over a time and temperature range: 30-130 mins. and 80-110°C respectively, following a well strategize step-wise preparation of the clay in as-mine condition. Multi-factorial analysis of periodic water loss during the drying process was also carried out using a derived empirical model. Water loss at 100°C by evaporation through a rectangular surface was found to be least compared to other drying temperatures considered irrespective of the drying time. This was basically due to the fall-back of condensed part of the water leaving the drying clay as steam, since steam can re-convert to water without any change in temperature. Evaluations from generated results indicate that the evaporation rates of the Otamiri clay and the standard error incurred in predicting water loss for each value of the drying times considered, as obtained from experiment, derived model and regression model were 0.0770, 0.0733 and 0.0733g min⁻¹ as well as 0.8051, 2.1 x 10⁻⁴ and 3.45 x 10⁻⁵ % respectively. The maximum deviation of the model-predicted water loss (from experimental results) was less than 20%, implying a model confidence level above 80%.

Keywords: Oven-dewatering, water loss analysis, Otamiri clay, porcelain

Cite This Article: C. I. Nwoye, E. Obidiegwu, E. M. Ameh, and S. O. Nwakpa, "Oven-Dewatering of Otamiri Clays Designated for Production of Porcelain and Multi-Factorial Analysis of Periodic Water Loss." *Materials Science and Metallurgy Engineering*, vol. 2, no. 2 (2014): 11-16. doi: 10.12691/msme-2-2-1.

1. Introduction

The wide applicability of porcelain has aroused the need for intensive research and development geared towards structural stability through improvements in its chemical, physical and mechanical properties. Previous research [1] indicated that the physical and chemical changes activated in clay minerals when subjected to high temperature affects their properties.

Past report [2] of studies carried out on the vitrification and fired properties of an electrical porcelain body indicate that at vitrification point which usually occurred around 1100°C, porosity dropped as much as 10%, pore shapes changed and hard structures like mullite began to appear. In a related study [3] on ceramic properties, in relation to mineralogical composition and microstructure, investigation thoroughly the effect of various factors including internal stress, size and size distribution on the strength of hard porcelain. The results of the investigation [3] show that the matrix of such bodies is a poorly conducting glass and with an increase in its concentration, the dielectric strength increases. Research [4] on the evaluation of electrical properties of porcelain shows that the vitrification point rises with the stabilizing of

shrinkage, bulk density, water absorption and increased strength of the porcelain.

Research [5] has been carried out to investigate the effect of drying temperature and loss of water through evaporation on the strength of the clay designated for production of ceramic materials including porcelain up till when vitrification sets in. The research shows that drying of clays through heating is associated with evaporation of water followed by formation of a hard but porous piece. The report revealed that a swollen appearance might occur during the release of some gases, but overall shrinkage must occur when vitrification sets in, leading to a strong dense piece. Similar research [6] revealed that the quantity of water evaporated from the drying clay determines the extent of shrinkage, strength and vitrification occurring in the drying clay.

A model was derived [7] for periodic assessment and prediction of the quantity of water evaporated during oven drying of Otamiri clay designated for development of refractories. The model; $E = e^{(\ln t / 1.7579)}$ shows that the quantity of water lost through evaporation during the drying process is dependent on the drying time, the evaporating surface being constant. The validity of the model is rooted in the expression $(\ln t / \ln E)^N = \text{Log } \beta$, since both sides of the expression are correspondingly approximately equal to 3. The maximum deviation of the

model-predicted quantity of evaporated water from the corresponding experimental value is less than 14%. Evaporation rates evaluated from experimental and model-predicted results are 0.0713gmin^{-1} and 0.0836gmin^{-1} respectively, indicating proximate agreement. The grain size of clay particles used was $425\mu\text{m}$, weight of clay and binder (bentonite) used (for each rectangular product) were 100g and 10g respectively, while quantity of water used for mixing was 6% (of total weight). The wet clays were subjected to a range of drying times: 50-130 mins. at a temperature of 110°C .

The present work aims at oven dewatering of Otamiri clays designated for production of porcelain and multi-factorial analysis of periodic water loss during the drying process.

2. Materials and Method

The materials employed for this research work comprised Otamiri Clay mined at Owerri, Imo and Bentonite obtained from Bridge Head Market, Onitsha, Anambra state, Nigeria. The chemical composition of the clay used is shown in [Table 1](#).

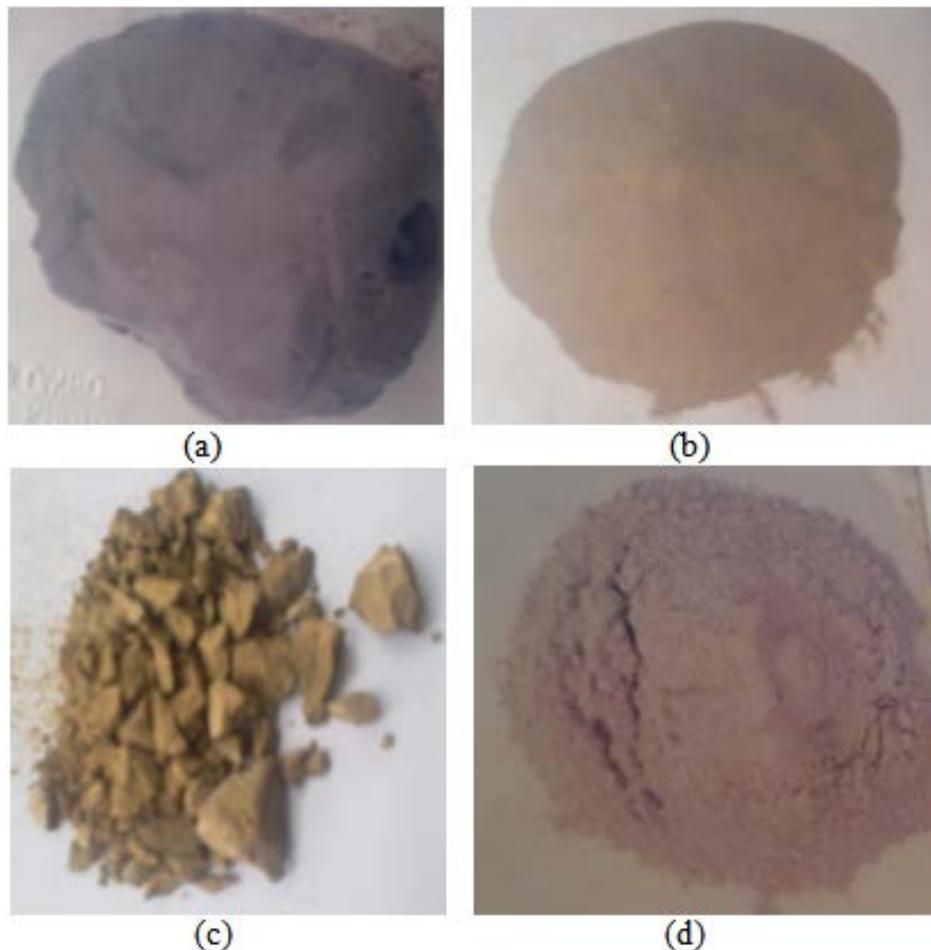


Figure 1. (a) Otamiri clay (as mined) (b) Dried and crushed Otamiri clay (c) Dried Otamiri clay mixed with Bentonite (d) Bentonite powder

2.1. Clay Sizing and Moulding

The dried clay was homogenized and sieved using an assembly of sieves running from 0.075 to 2 mm. The sieve assembly was placed on a mechanical sieve shaker and power supply switched on. The set-up was allowed to function for 5 minutes. The sieving process was repeated severally until the quantity of clay required for the moulding process was available. Hundred grams (100g) of the 0.425mm sieved sized clay sample and 10g of bentonite powder were weighed out and thoroughly mixed. The bentonite powder was used to increase plasticity and strength during firing. Six percent (6%) of total weight (clay and Bentonite) of water was added and it was then mixed until complete homogeneity was achieved. The mixed samples were poured into the rectangular metal mould of internal dimension 50 x 18 x 10 mm. Just before air drying, the clay samples were weighed.

2.2. Air Drying

The moulded specimens were carefully placed in a plastic tray and kept outside the laboratory to loose some water and become strengthened. The reason for air drying includes (1) to prevent the samples from being defective as a result of evaporation during oven drying and firing (2) to give the specimens adequate strength during oven drying and firing. The weights of the specimens were measured prior to oven drying.

2.3. Oven Drying

An electrically heated oven of internal dimension 500 x 500mm was used in the drying operation. The oven was sourced from Erosion Research Center of the Federal University of Technology, Owerri (FUTO). Each set of specimens was dried at a temperature of 80°C for 30, 50,

70, 90, 110 and 130 mins., after which their respective weights were measured. The oven drying process was repeated for other sets of specimens at temperatures 90, 100 and 110°C, also each set at drying times 50, 70, 90, 110 and 130 mins., and their corresponding weights measured and recorded accordingly.

3. Results and Discussion

The result of chemical analysis of Otamiri clay is shown in Table 1. The table shows that the clay is most constituted by SiO₂ while Na₂O is the poorest constituent.

Table 1. Chemical composition of Otamiri clays

Constituents	(%)
Al ₂ O ₃	15.60
SiO ₂	69.45
TiO ₂	1.09
Na ₂ O	0.01
K ₂ O	0.21
CaO	0.29
Fe ₂ O ₃	0.05
LOI	13.10

Table 2. Result of sieve analysis of Otamiri clays

S.S	M. R	M. P	% P
2.0	0.0	15.7	100
1.8	0.7	15.0	95.5
0.850	1.8	13.2	84.1
0.600	2.2	11.0	70.1
0.425	3.0	8.0	51.0
0.300	3.2	4.8	30.6
0.150	3.8	1.0	6.37
0.075	0.8	0.2	1.27
Pan			

Where

S. S = Sieve sizes (mm)

M.R = Mass retained (g)

M.P = Mass passing (g)

%P = Percent passing (%)

Results of the sieve analysis indicate that the weights of clay before and after washing and drying are 50 and 15.7g respectively. This implies that the weight of fines is 34.3g, while the process residue is 15.7g. Table 2 shows that M.R and M.P varied with sieve sizes. This resulted in 100% passing of the clay. Between 0.600 and 0.150 mm sieve sizes, the M.P dropped resulting in the decrease of the %P.

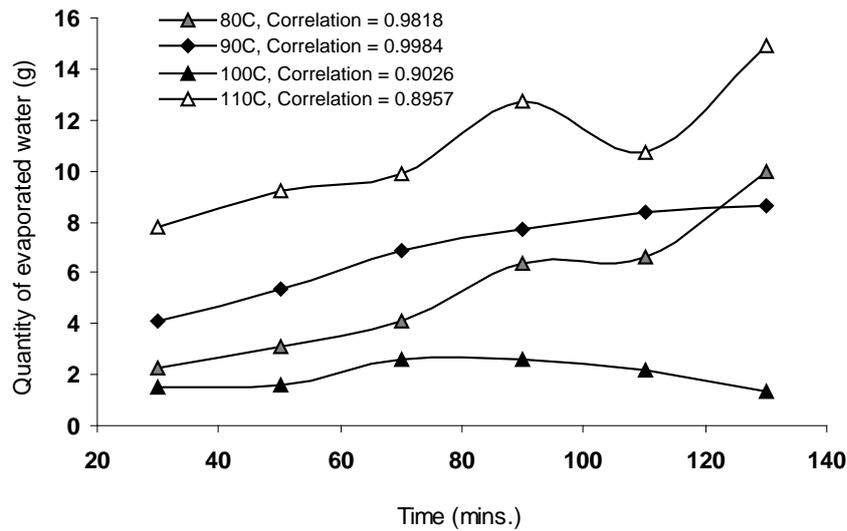


Figure 2. Comparison of quantities of water evaporated from a rectangular surface at different temperature

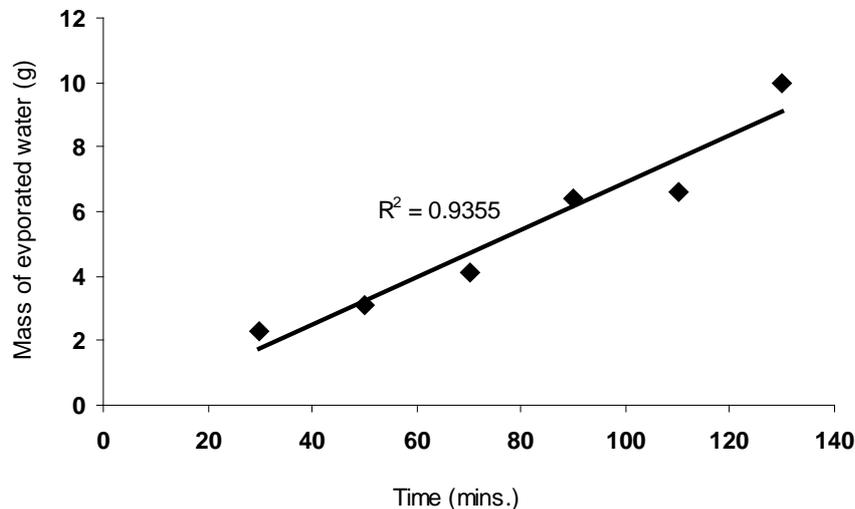


Figure 3. Coefficient of determination between quantity of water evaporated and drying time as obtained from experiment

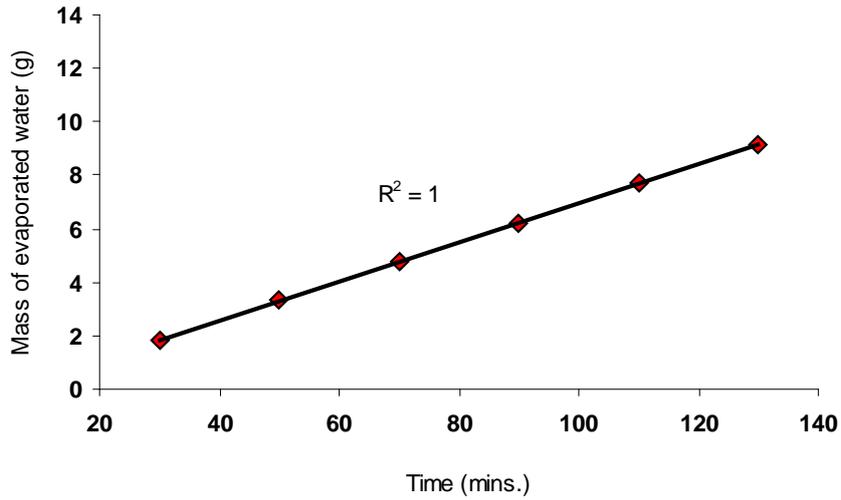


Figure 4. Coefficient of determination between quantity of water evaporated and drying time as obtained from derived model

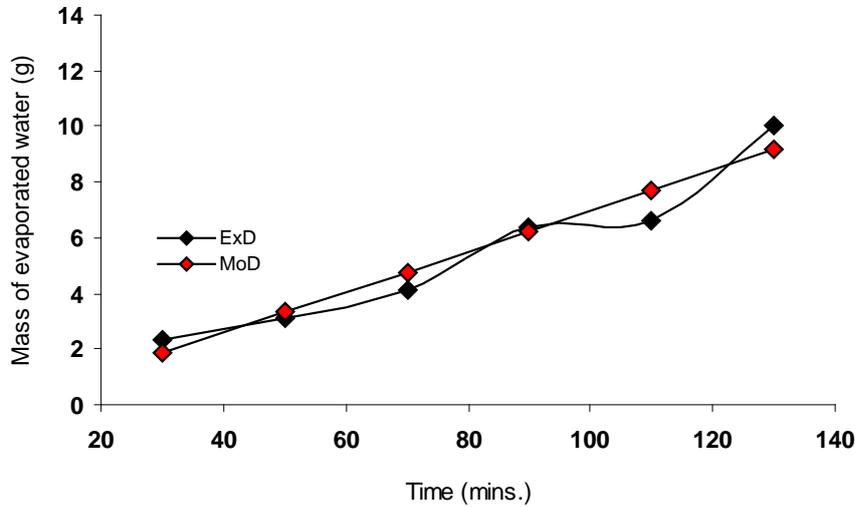


Figure 5. Comparison of quantities of water evaporated as obtained from experiment and derived model

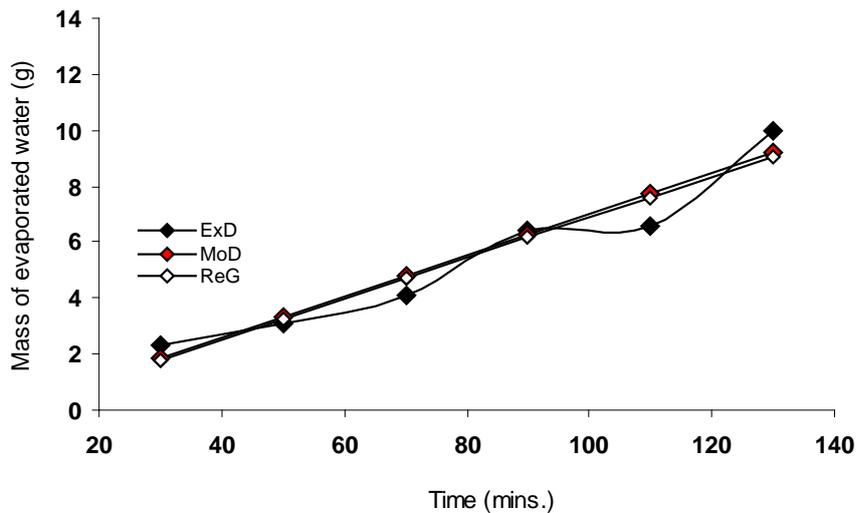


Figure 6. Comparison of quantities of water evaporated as obtained from experiment, derived model and regression model

Analysis of Figure 2 shows that the weight of evaporated water increases with increase in the drying time of the clay materials until maximum shrinkage occurs, providing the materials are of the same shape. At this stage (maximum shrinkage), the inter-particle voids containing water are displaced, permitting close contact of

the clay particles. This is because shrinkage begins with the inception of water evaporation.

The quantity of water evaporated was least on oven drying the clay material at 100°C irrespective of the drying time employed, providing the evaporating surface is flat. At 100°C, water in the clay evaporates as steam

and part of the steam condenses to water without any temperature change and falls back to the evaporating surface. This results to an overall low level of water evaporation at the end of the drying process. This is inline with previous research [8]. The flat evaporating surface ensures uniform evaporation of water per second during the drying process.

3.1. Analysis of water loss

Analysis of water loss during oven drying of the clay was carried out using a derived model. Experimental results generated from oven drying rectangular shaped clay materials at 80°C (as shown Figure 2 and Table 3) was used for the model formulation. These results were randomly considered amongst results obtained from drying temperatures 90, 100 and 110°C.

Table 3. Variation of evaporated water from Otamiri clay with drying time

Drying time (mins.)	Water loss (g)
30	2.30
50	3.10
70	4.10
90	6.40
110	6.60
130	10.00

Computational analysis of results in Figure 3 for a drying temperature of 80°C, represented in Table 3 indicate that;

$$\mathcal{J} = K\vartheta + S\beta^2 - N\theta - Ne \quad (1)$$

Introducing the values of K, S, N and Ne into equation (1) reduces it to;

$$\mathcal{J} = 0.0733\vartheta + 1.02 \times 10^{-6} \beta^2 - 7.7 \times 10^{-3}\theta - 0.4462 \quad (2)$$

Where

\mathcal{J} = Model-predicted evaporated water (g)

(ϑ) = Drying time (mins.)

(β) = Evaporating surface area (mm²)

(θ) = Drying temperature (°C)

K = 0.0733, S = 1.02 x 10⁻⁶, N = 7.7x10⁻³ and

Ne = 0.4462; where K, S, N and Ne are empirical constants determined using C-NIKBRAN [9].

3.2. Boundary and Initial Conditions

Consider a rectangular shaped clay product of length 49mm, width 17mm, and breadth 9mm exposed to drying in the oven while it was in slight wet condition. Initially, atmospheric levels of oxygen are assumed. Atmospheric pressure was assumed to be acting on the clay samples during the drying process (since the furnace is not air-tight). The grain size of clay particles used is 425µm, weight of clay and binder (bentonite) used (for each rectangular product); 100g and 10g respectively, quantity of water used for mixing; 6% (of total weight), drying temperature used; 80°C, area of evaporating surface; 833mm² and range of drying time used; (30-130 mins.).

The boundary conditions are: atmospheric levels of oxygen at the top and bottom of the clay samples since they are dried under the atmospheric condition. No external force due to compression or tension was applied to the drying clays. The sides of the particles are taken to be symmetries.

Figure 3-Figure 5 indicates that a plot of experimental results generated from the application of a drying temperature of 80°C (represented as Table 3) and those predicted from the derived model indicate close alignment of curves (Figure 5). Figure 3 and Figure 4 show that model-predicted results (Figure 4) proffered a higher correlation compared to results obtained from the experiment (Figure 3).

3.3. Comparison of Derived Model with Standard Model

The validity of the derived model was further verified through application of the regression model (Least Square Method (ReG)) in predicting the trend of the experimental results. Comparative analysis of Figure 6 show very close alignment of curves and significantly similar trend of data point's distribution for experimental (ExD), derived model-predicted (MoD) and regression model predicted (ReG) results of evaporated water. These values are in proximate agreement.

The standard error incurred in predicting water loss for each value of the drying times as obtained from experiment, derived model and regression model were 0.8051, 2.1 x 10⁻⁴ and 3.45 x 10⁻⁵ % respectively.

3.4. Deviation of Model-Predicted Results

Table 4 shows that the maximum deviation of model-predicted quantity of evaporated water (from that of the experiment) is less than 20%.

Table 4. Variation of experimental results of water loss with resultant correction factors and deviations of model-predicted results

(ϑ)	Dv (%)	Cf (%)
30	-19.8	19.8
50	6.79	-6.79
70	16.5	-16.5
90	-2.46	2.46
110	16.8	-16.8
130	-8.25	8.25

Correction factor, Cf to the model-predicted results is given by

$$Cf = -\left(\frac{Ps - Es}{Es}\right) \times 100 \quad (3)$$

Where deviation is given by

$$Dv = \left(\frac{Ps - Es}{Es}\right) \times 100 \quad (4)$$

while Es and Ps are water losses evaluated from experiment and derived model respectively.

Equations (3) and (4) indicate that correction factor is the negative of the deviation.

The correction factor took care of the negligence of the reaction-based contributions of surface properties of the clay and the physiochemical interactions between the clay and binder, which actually played vital role during the evaporation process. The model predicted results deviated from those of the experiment because these contributions were not considered during the model formulation.

It is important to state that the deviation of model predicted results from that of the experiment is just the

magnitude of the value. The associated sign preceding the value signifies that the deviation is a deficit (negative sign) or surplus (positive sign).

3.5. Evaporation Rates

Water evaporation rate resulting from oven drying of the clay within a range of drying time 30-130 mins. was determined following comparison of the evaporation rate obtained by calculations involving experimental results, and model-predicted results obtained directly from the model.

Evaporation rate, E_R (g min^{-1}) was calculated from the equation;

$$E_R = E/t \quad (5)$$

Re-written as

$$E_R = \Delta E / \Delta t \quad (6)$$

Equation (6) is detailed as

$$E_R = E_2 - E_1 / t_2 - t_1 \quad (7)$$

Where

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

Considering the points (30, 2.3) & (130, 10), (30, 1.8446) & (130, 9.1746) and (30, 1.7524) & (130, 9.081) as shown in Figure 6, and also designating them as (E_1 , t_1) and (E_2 , t_2) for experimental, derived model and regression model predicted results respectively, and then substituting them into equation (7), gives the slopes 0.077, 0.0733 and $0.0733 \text{ g min}^{-1}$ respectively as their corresponding evaporation rates.

4. Conclusion

Multi-factorial analysis of periodic water loss, following oven dewatering of Otamiri clay indicates that water loss at 100°C by evaporation through a rectangular surface is least compared to other drying temperatures considered irrespective of the drying time. This was

attributed to the fall-back of condensed part of the water leaving the drying clay as steam, since steam can re-convert to water without any change in temperature. Evaluations from generated results indicate that the evaporation rates of the Otamiri clay and the standard error incurred in predicting water loss for each value of the drying times considered, as obtained from experiment, derived model and regression model were 0.0770, 0.0733 and $0.0733 \text{ g min}^{-1}$ as well as 0.8051, 2.1×10^{-4} and 3.45×10^{-5} % respectively. The maximum deviation of the model-predicted water loss (from experimental results) was less than 20%, implying a model confidence level above 80%.

References

- [1] Amer, M., El-didamony, A. A., and El-sheikh. A. A. H. (2000). Effect of Calcination Temperature on the Clay-Limestone Mixes. *Sil. Ind.*, 65(9-10): 95-100.
- [2] Waye, B. E., and Ashley, M., (1963). Vitrification and Fired Properties of An Electrical Porcelain, *Trans. Brit Ceram. Soc.*, 62-421.
- [3] Chanhudri, S. P., (1982). Ceramic Properties In Relation to Mineralogical Composition and Microstructure; Dielectric Behaviour. Post-Doctoral Research work, Dept. of Applied Chemistry, Calcutta, University, India.
- [4] Okerulu, S. O. (1989). Effects of Pulverised Coal Ash, Palm Kernel Shell Ash, Rice Husk Ash on Transverse Strength and Electrical Resistance of Electrical Porcelain. B. Eng., Project, Anambra State University of Technology, Enugu, Nigeria.
- [5] Singer, F. and Singer, S.S., (1963). *Industrial Ceramics*, University Press Cambridge, 44-50.
- [6] Nwoye, C. I., Studies on Pore Deformation Mechanism in Particles *J. Eng. Appl. Sc.* (in press).
- [7] Nwoye, C. I., Obidiegwu, E. and Mbah, C. N. (2010). Periodic Assessment and Prediction of the Quantity of Water Evaporated during Oven Drying of Otamiri Clay Designated for Development of Refractories. *Journal of Metallurgical and Materials Engineering*. 5(2): 48-54.
- [8] Nwoye, C. I., Mbuka, I. E., and Iheanacho, O. (2010). Determination of Average Grain Sizes and Water Evaporation Rates of Some Nigeria Clays at Oven Drying Temperature. *Report and Opinion*. 2(4): 21-28.
- [9] Nwoye, C. I. (2008). C-NIKBRAN "Data Analytical Memory"-Software.