

## Effect of Water-Steam Transition Temperature on the Evaporation of Water and Shrinkage of Clay during Oven Drying of Clays

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**Abstract:** The effect of water-steam transition temperature on the evaporation of water and shrinkage of clay during oven drying of clays has been studied. The investigation was carried out over a range of drying temperature and time; 80-110<sup>0</sup>C and 30-130 minutes respectively. The results of the investigation indicate that evaporation of water and shrinkage of clays are lowest at the water-steam transition temperature (100<sup>0</sup>C) compared to drying temperatures: 80, 90 and 110<sup>0</sup>C due to repeated reversible transition of state between water and steam at this temperature (100<sup>0</sup>C) within the clay-surrounding interface, resulting to absorption of the condensed water by the clay matrix. This is in agreement with the boiling characteristics of water at 100<sup>0</sup>C. The condensation process at this temperature increases and decreases the masses of water in the clay and that lost through evaporation respectively. [New York Science Journal. 2010;3(4):33-38]. (ISSN: 1554-0200).

**Keywords:** Effect, Water-Steam Transition Temperature, Evaporation, Shrinkage, Drying, Clay.

### 1. Introduction

Past reported (Barsoum, 1997) that the contents of the basic clay materials are divided into three groups. The first group involves clays containing mainly the mineral kaolinite. The second groups are clays containing mineral montmorillonite, while the third group is clays which are intermediate product of disintegration of mica into kaolin. Unal (1986) reported that the structure of sinters and pellets may be divided into two parts viz, the mineral and the pores. It was stated that the properties of pellets and sinters are closely related to the mineral constituents.

It has been discovered (Furnass, 1928) that voids volume in packed dispersed powder depend on the ratio of smallest size (Ss) to largest size (Ls) particle as well as the percentage of constituent monosized particles. It was concluded that the smaller the (Ss/Ls) ratio, the more continuous the distribution and the lower the void volume of the system. Singer and Singer (1963) found that on heating dried clays, water is given off. With time, a hard but porous piece forms. A swollen appearance might occur during the release of some gases, but overall shrinkage must occur when verifications set in leading to a strong dense piece.

It has been report (Nwoye, 2003) that chemical composition of the pellet, pelletisation parameters and firing conditions affect the shrinkage of clay pellets. The researcher posited that the rate of chemical reaction is very much dependent on the gas-solid contact area, which is mostly governed by the porosity of the pellet. It was stated that shrinkage of clay is probably due to volume change resulting from evacuation of water from the voids, reduction of the size of the pores as well as decrease in the interparticle separation.

It has been reported (Viewey and Larrly,1978) that fine particles shrink more, are denser and exhibit excellent mechanical properties. Further studies (Viewey and Larrly,1978) carried out to investigate the relationship between particle size and size distribution with linear drying shrinkage, firing shrinkage and apparent porosity shows that no visible relationship exists between particle size and linear drying shrinkage. Based on the discovered fact that finer particles shrink more, Viewey and Larrly (1978) concluded that the finer the particle size, the lesser the apparent porosity and greater the bulk density.

The behaviour of ceramic products has been found to be very dependent on their composition, grain size, grain distribution, structure of grain and pores (Arisa, 1997). Nwoye (2003) also posited that the grain size and grain distribution of the clays have significant effect on their physical and technological properties (binding ability, shrinkage and plasticity). It has been reported (Barsoum, 1997) that pores are deleterious to the strength of ceramics not only because they reduce cross-sectioned area over which the load is applied but more importantly act as stress concentrators.

Pore deformation mechanism in shrinking Nigeria clays, was studied over a range of heating temperature from 1000 to 1300<sup>0</sup>C (Nwoye). The results of the study indicate that pores pre-existing before sintering deformed by the collapsing of the wall surrounding the pores. It was discovered (Nwoye) that the wall surrounding the pre-existing pores collapsed as a result of the weakening of the clay-binder contact surface and loosening of the macro structure of the formed clays, occasioned by the response of the clay and binder to temperature increase. Nwoye also found that binder burn-out which releases gases, elimination of gaseous product

of decomposition and oxidation of some clay constituents as well as evaporation of free water between clay and binder particles, all played very vital roles in decreasing the pre-existing interparticle separation hence deforming the pores.

Nwoye (2008a) studied the effect of porosity on the shrinkage behavior of clay pellets and briquettes of different porosities. The result of the investigation indicates that shrinkage which is a major cause of rupture in fired clay increased with decrease in porosity. It was also discovered (Nwoye, 2008a) that the porosity of pellet/briquette plays important role in controlling and determining the shrinkage index of the pellet.

Reed (1988) described firing as having three stages through which it proceeds; preliminary reactions which include binder burnout, elimination of gaseous product of decomposition and oxidation, sintering as well as cooling which may include thermal and chemical annealing.

Several works (Barsoum, 1997; Viewey and Larrly, 1978; Reed, 1988; Keey, 1978) have been carried out on shrinkage of clay during drying. In all these works, porosity has been shown to influence the swelling and shrinkage behaviour of clay products of different geometry. It has been reported (Reed 1988) that drying occurs in three stages; increasing rate, constant and decreasing rate. The researcher 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. The scientist (Reed, 1988) posited that shrinkage occurs at this stage. Keey (1978) also in a similar study suggested that at this stage, free water is removed between the particles and the interparticle separation decreases, resulting in shrinkage. During the decreasing rate, particles make contacts as water is removed, which causes shrinkage to cease.

Model for calculating the volume shrinkage resulting from the initial air-drying of wet clay has been derived (Nwoye, 2008b). The model;

$$\theta = \gamma^3 - 3\gamma^2 + 3\gamma \quad (1)$$

calculates the volume shrinkage when the value of dried shrinkage  $\gamma$ , experienced during air-drying of wet clays is known. The model was found to be third-order polynomial in nature. Olokoro clay was found to have the highest shrinkage during the air drying condition, followed by Ukpok clay while Otamiri clay has the lowest shrinkage. Volume shrinkage was discovered to increase with increase in dried shrinkage until maximum volume shrinkage was reached, hence a direct relationship.

Nwoye et al. (2008c) derived a model for the evaluation of overall volume shrinkage in molded clay products (from initial air-drying stage to completion of firing at a temperature of 1200°C). It

was observed that the overall volume shrinkage values predicted by the model were in agreement with those calculated using conventional equations. The model;

$$S_T = \alpha^3 + \gamma^3 - 3(\alpha^2 + \gamma^2) + 3(\alpha + \gamma) \quad (2)$$

depends on direct values of the dried  $\gamma$  and fired shrinkage  $\alpha$  for its precision. Overall volume shrinkage was found to increase with increase in dried and fired shrinkages until overall volume shrinkage reaches maximum.

Nwoye et al., (2009a) derived a model for calculating the quantity of water lost by evaporation during oven drying of clay at 90°C. The model;

$$\gamma = \exp[(\text{Int})^{1.0638} - 2.9206] \quad (3)$$

indicated that the quantity of evaporated water,  $\gamma$  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  $(\text{Log}\beta + \text{Ln}\gamma)^N = \text{Int}$ .

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. (2009b). The model;

$$\alpha = e^{(\text{Int}/2.1992)} \quad (4)$$

shows that the quantity of water  $\alpha$ , evaporated at 110°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  $(\text{Int}/\text{Ln}\alpha)^N = \text{Log}\beta$  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, 2009c). The model;

$$\gamma = \exp((\text{Int}/2.9206)^{1.4}) \quad (5)$$

indicates that the quantity of evaporated water  $\gamma$  during the drying process (at 90°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  $\text{Ln}\gamma = (\text{Int}/\text{Log}\beta)^N$  where both sides of the expression are correspondingly almost equal.

The present work is to study the effect of water-steam transition temperature on the evaporation of water and shrinkage of clay during oven drying of clays.

## 2. Methods Material Studied and Description

All clays (Olokoro, Ukpor, Otamiri and Nsu) used were collected in lumps from deposits in South-eastern Nigeria. These clays were allowed to dry in air for 96 hours. Each of these clay samples 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°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<sup>2</sup> 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. Also dried shrinkage sustained by the clays were calculated using the conventional formula, based on the recorded initial and final length of the sample.

**Before drying**

Mass of sample (clay + binder) before drying = β (g) (6)

Mass of sample + water before drying = γ (g) (7)

Mass of water in sample before drying = γ - β (g) (8)

**After drying**

Mass of sample + water after drying = α (g) (9)

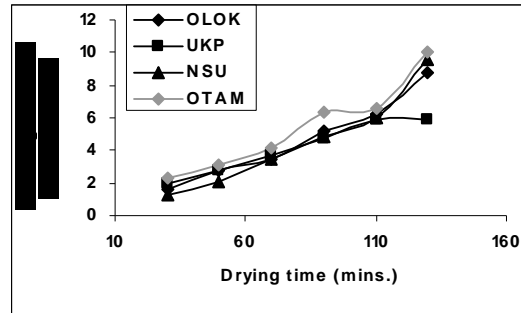
Mass of water lost after drying due to evaporation = γ - α (g) (10)

**3. Results**

The results of the chemical analysis carried out on the clays used are shown in Table 1. The Table shows variation in the chemical constituents of the clay (Olokoro, Ukpor, Nsu and Otamiri clay) which is believed to have played a role in varying their respective responses to evaporation of water.

**Effect of drying time on the quantity of water evaporated from clays**

Figures 1-4 show that evaporation is lowest at the drying temperature of 100°C for all the clay-types used, (Olokoro, Ukpor, Nsu and Otamiri clay designated as OLOK, UKP, NSU and OTAM respectively) compared to the other drying temperatures used. This is strongly believed to have occurred because 100°C is the water-steam transition temperature whereby water at 100°C goes into steam at 100°C and this steam in turn condenses to water on losing heat without any change in temperature. This is in accordance with the boiling characteristics of water at 100°C (Okeke, 1987).



1-Effect of drying time on the quantity of water evaporated from clays at 80°C

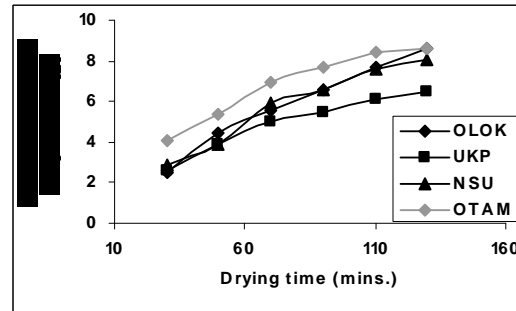


Figure.2-Effect of drying time on the quantity of water evaporated from clays at 90°C

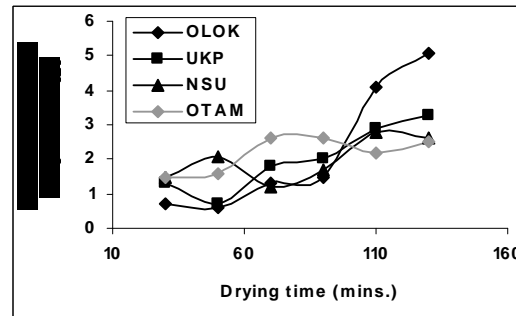


Figure.3-Effect of drying time on the quantity of water evaporated from clays at 100°C

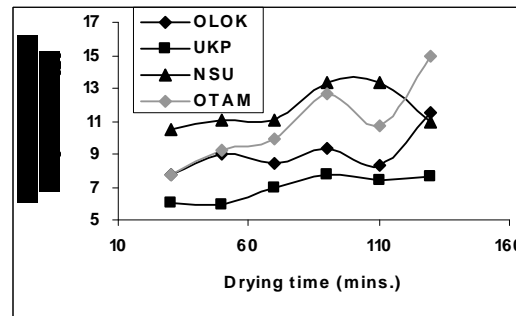


Figure.4-Effect of drying time on the quantity of water evaporated from clays at 110°C

In the course of this transition state, it is suspected that some steam condensed (on losing heat) into water at the clay-surrounding interface and trickled back into the clay matrix thereby increasing and decreasing the mass of water in the clay and that lost through evaporation respectively at the same temperature of 100°C. Figures 1-4 also show that

water evaporation increases with increase in the drying time irrespective of the drying temperature. **Effect of Drying Temperature on the Quantity of Water Evaporated from Clays**

Figures 5-10 show that water evaporation is persistently the lowest at this temperature (100°C) compared to the other temperatures above 80°C, irrespective of the drying time used. Figures 5-10 also show that water evaporation increases with increase in the drying temperature irrespective of the drying time used.

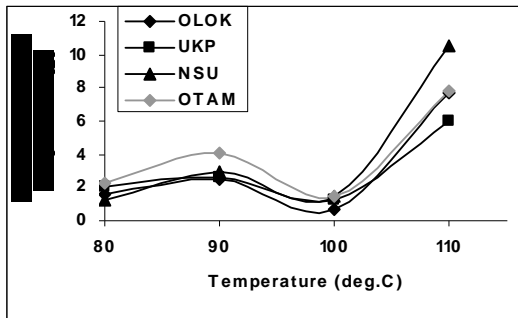


Figure.5-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 30minutes.

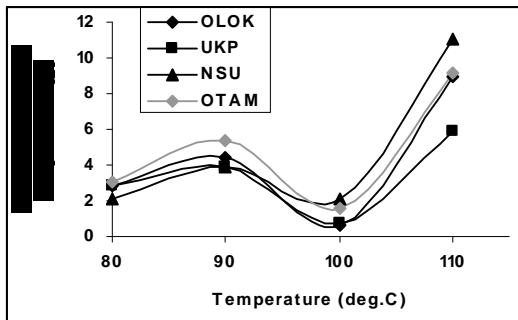


Figure.6-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 50minutes.

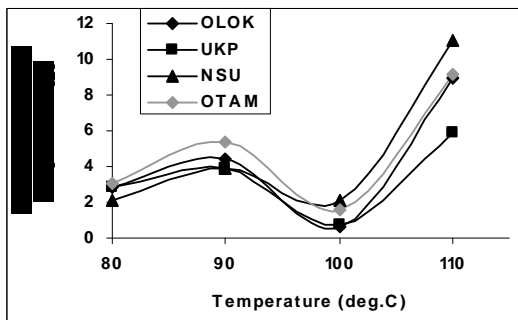


Figure.7-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 70minutes.

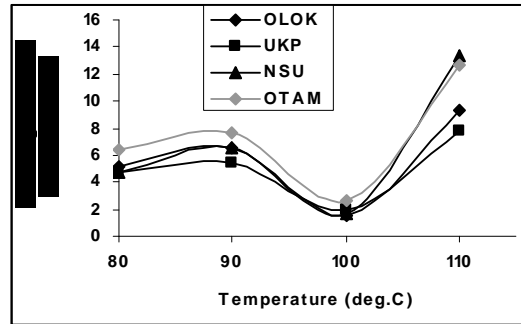


Figure.8-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 90minutes.

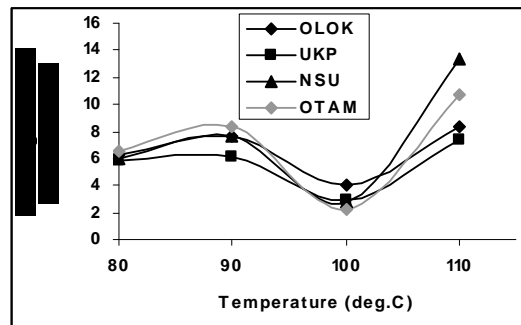


Figure.9-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 110minutes.

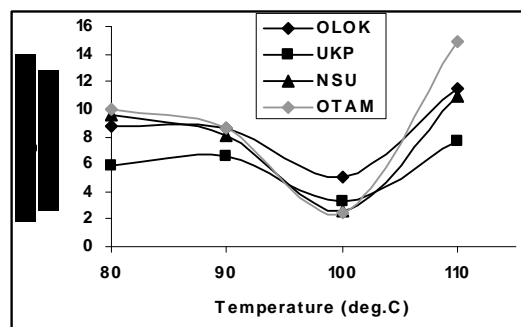


Figure.10-Effect of drying temperature on the quantity of water evaporated from clays after a drying time of 130minutes.

Figures 1, 2 and 4 show that Ukpork and Otamiri clay lost the lowest and highest quantities of water respectively to evaporation at temperatures; 80, 90 and 110°C. Figures 5-10 however, show that above 100°C, Ukpork and Nsu clay lost the lowest and highest quantities of water respectively to evaporation. This variation in the magnitude of water loss by evaporation is attributed to variation in the response of these clay materials to drying temperatures as a result of variation in the chemical composition of the clay materials.

**TABLE 1: CHEMICAL COMPOSITION OF CLAYS USED**

SOURCE	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	MgO	CaO	SiO <sub>2</sub>	N <sub>2</sub> O	K <sub>2</sub> O	Loss of ignition
Nsu	25.61	1.74	1.40	0.78	0.54	59.29	Trace	0.23	9.95
Otamiri	15.56	0.05	1.09	-	0.29	69.45	0.01	0.21	13.10
Olokoro	20.10	7.05	-	0.75	1.26	45.31	0.05	0.09	11.00
Ukpor	31.34	0.63	2.43	0.14	0.06	51.43	0.04	0.10	12.04

#### *Effect of water-steam transition temperature on the shrinkage of clays*

The result of investigation on the effect of water-steam transition temperature on the shrinkage of clays (as shown in Figure 11) shows that shrinkage increases with drying temperature up to 90°C. However, beyond 90°C, shrinkage begins to drop reaching the lowest value at 100°C for all the clays used. Shrinkage also increased after 100°C was reached.

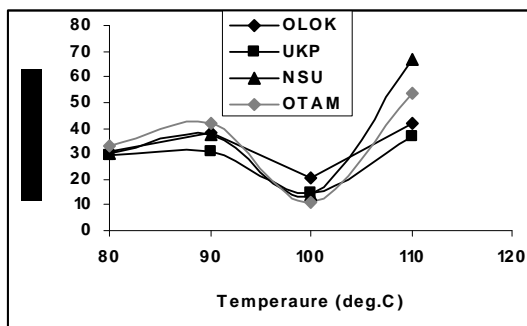


Figure.11-Effect of drying temperature on the shrinkage of clays after a drying time of 110minutes.

Comparison of Figures 9 and 11 shows similarities in the orientation of the two sets of graphs. This indicates similarities in the relationship between evaporation of water and drying temperature as well as between shrinkage and drying temperature. This implies that at a particular drying temperature, increase in evaporation of water results to increase in shrinkage. Figure 9 shows that at 100°C, lesser water was evaporated due to condensation of water vapour (steam) on the surface of the clay. This implies lesser shrinkage due absorption of condensed water into the clay which increased inter-particle separation. This is agreement with past report (Keey, 1978).

#### **Conclusions**

The results of the investigation on the effect of water-steam transition temperature on the evaporation of water and shrinkage of clay during oven drying of clays indicate that evaporation of and shrinkage are lowest at the water-steam transition temperature (100°C) compared to drying temperatures: 80, 90 and 110°C due to repeated reversible transition of state between water and steam at this temperature (100°C) within the clay-surrounding interface resulting to absorption of the condensed water by the clay matrix.

The condensation process at this temperature increases and decreases the masses of water in the clay and that lost through evaporation respectively.

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