

Model for Quantifying the Extent and Magnitude of Water Evaporated during Time Dependent Drying of Clay

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Abstract

Model for quantifying the extent and magnitude of water evaporated during time-dependent drying of clay has been derived. The model; $\gamma = \exp((\text{Int}/2.9206)^{1.4})$ shows that the quantity of evaporated water during the drying process is dependent on the drying time, the evaporating surface being constant. It was found that the validity of the model is rooted in equation (1) where both sides of the equation are correspondingly almost equal. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 19% which is quite within the acceptable deviation range of experimental results, hence depicting the usefulness of the model. [New York Science Journal. 2009;2(3):55-58]. (ISSN: 1554-0200).

Keywords: Model, Water, Evaporation, Drying, Clay

1. Introduction

According to Barsoum (1997a), 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 are clays which are intermediate product of disintegration of mica into kaolin. The structure of sinters and pellets may be divided into two parts viz, the mineral and the pores. It is widely accepted that the properties of pellets and sinters are closely related to the mineral constituents (Unal, 1986).

Voids volume in packed dispersed powder according to Furnass (1928), depends on the ratio of smallest size (Ss) to largest size (Ls) particle as well as the percentage of constituent monosized particles. He maintained that the smaller the (Ss/Ls) ratio, the more continuous the distribution and the lower the void volume of the system. It has been discovered (Singer and Singer, 1963), 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.

Chemical composition of the pellet, pelletisation parameters and firing conditions has been found to affect the shrinkage of clay pellets (Nwoye, 2003a). He 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. He also stated that the 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.

Recent analysis (Viewey and Larrly, 1978a) shows that fine particles shrink more, are denser and exhibit excellent mechanical properties. These ceramists also came out with some startling findings following investigations carried out on the relationship between particle size and size distribution with linear drying shrinkage, firing shrinkage and apparent porosity. They concluded that no visible relationship exists between particle size and linear drying shrinkage. Finer particles tend to shrink more. They also stated that the finer the particle size, the lesser the apparent porosity and greater the bulk density.

Arisa, (1997) stressed that the behaviour of ceramic product are very dependent on their composition, grain size, grain distribution, structure of grain and pores. Nwoye (2003b) 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).

Pores are usually 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 (Barsoum, 1997b). Viewey

and Larrly, (1978b) in an intensive study of the relationship between particle size and linear drying shrinkage revealed that there is no visible relationship existing between them. They also stated that the finer the particle size, the lesser the apparent porosity and the greater the bulk density.

Reed, (1988a) 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 (Singer and Singer, (1963); Reed, (1988); Keey, (1978); Barsoum, (1997)) have been done on shrinkage of clay but none of them investigated the effect of porosity on the swelling and shrinkage behaviour of clay. Porosity is known to influence the swelling and shrinkage behaviour of clay sinters and pellets.

Drying according to Reed (1988b) occurs in three stages; increasing rate, constant and decreasing rate. He 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. He posited that shrinkage occurs at this stage. Keey (1978) 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.

The present work is to derive a model for quantifying the extent and magnitude of water evaporated during time-dependent drying of Nsu (Nigeria) clay.

2. Model formulation

Experimental data obtained from research work (Nwoye,2007) carried out at SynchroWell Research Laboratory, Enugu were used for this work. Results of the experiment used for the model formulation are as shown in Table 1.

Computational analysis of the experimental data (Nwoye,2007) shown in Table 1, gave rise to Table 2 which indicate that;

$$\ln\gamma = (\ln t / \ln \beta)^N \quad (\text{approximately}) \quad (1)$$

$$\gamma = \exp((\ln t / \ln \beta)^N) \quad (2)$$

Introducing the values of β and N into equation (2)

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

Where

(γ) = Weight of water lost by evaporation during the drying process (g)

(β) = Area of evaporating surface (mm²)

$N = 1.4$; (Collapsibility coefficient of binder-clay particle boundary at the drying temperature of 90⁰C) determined in the experiment (Nwoye, 2007).

t = Drying time (mins.).

Table 1: Variation of quantity of evaporated water with drying time (Nwoye,2007)

(t)	(β)	(γ)
30	833	2.90
50	833	3.90
70	833	5.90
90	833	6.60
110	833	7.60
130	833	8.01

Table 2: Variation of $\ln\gamma$ with $(\ln t/\ln \beta)^N$

Int	Log β	$\ln\gamma$	$(\ln t/\ln \beta)^N$
3.4012	2.9206	1.0647	1.2378
3.9120	2.9206	1.3610	1.5056
4.2485	2.9206	1.7750	1.6900
4.4998	2.9206	1.8871	1.8315
4.7005	2.9206	2.0281	1.9468
4.8675	2.9206	2.0807	2.0446

3. Boundary and Initial Conditions

Consider a rectangular shaped clay product of length 49mm, width 17mm, and breadth 9mm exposed to drying in the furnace while it was in 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 425 μ m, weight of clay and binder (bentonite) used (for each rectangular product); 100g and 10g respectively, quantity of water used for mixing; 2% (of total weight), drying temperature used; 90 $^{\circ}$ C, area of evaporating surface; 833mm 2 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 and the rectangular shaped clay products are taken to be symmetries.

4. Model Validation

The formulated model was validated by direct analysis and comparison of the model-predicted γ values and those from the experiment for equality or near equality.

Analysis and comparison between these γ values reveal deviations of model-predicted γ from those of the experimental values. This is believed to be due to the fact that the surface properties of the clay and the physiochemical interactions between the clay and binder, which were found to have played vital role during the evaporation process (Nwoye, 2007) were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted γ value to that of the corresponding experimental value (Table 3).

Deviation (D_v) (%) of model-predicted γ values from the experimental γ values is given by

$$D_v = \frac{DP - DE}{DE} \times 100 \quad (4)$$

Where DP = γ values predicted by model

DE = γ values obtained from experiment

Correction factor (Cf) is the negative of the deviation i.e

$$C_f = -D_v \quad (5)$$

Therefore

$$C_f = -100 \left(\frac{DP - DE}{DE} \right) \quad (6)$$

Introduction of the value of Cf from equation (6) into the model gives exactly the corresponding experimental value of γ (Nwoye, 2007).

5. Results and Discussion

The derived model is equation (3). A comparison of the values of γ obtained from the experiment and those from the model shows little deviations hence depicting the reliability and validity of the model (Table 3). The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 19% which is quite within the acceptable deviation range of experimental results, hence depicting the usefulness of the model. It was found that the validity of the model is rooted in equation (1) where both sides of the equation are correspondingly almost equal. Table 2 also agrees with

equation (1) following the values of $\ln\gamma$ and $(\ln/\text{Log}\beta)^N$ evaluated from Table 1 as a result of corresponding computational analysis.

Table 3: Comparison between quantities of evaporated water as predicted by model and as obtained from experiment. (Nwoye, 2007)

γ_{exp}	γ_M	Dv (%)	Cf (%)
2.90	3.4480	+18.90	-18.90
3.90	4.5069	+15.56	-15.56
5.90	5.4195	-8.14	+8.14
6.60	6.2432	-5.41	+5.41
7.60	7.0062	-7.81	+7.81
8.01	7.7261	-3.54	+3.54

where $\gamma_{\text{exp}} = \gamma$ values obtained from experiment (Nwoye, 2007)
 $\gamma_M = \gamma$ values predicted by model.

6. Conclusion

The model evaluates the quantity of water lost by evaporation during drying of Nsu (Nigeria) clay at 90°C. It was found that the validity of the model is rooted in equation (1) where both sides of the equation are correspondingly almost equal. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 19% which is quite within the acceptable deviation range of experimental results, hence depicting the usefulness of the model.

Further works should incorporate more process parameters into the model with the aim of reducing the deviations of the model-predicted γ values from those of the experimental.

Acknowledgement

The authors thank Dr. Ekeme Udoh, a modelling expert at Linkwell Modelling Centre Calabar for his technical inputs. The management of SynchroWell Nig. Ltd. Enugu is also appreciated for permitting and providing the experimental data used in this work.

References

- Arisa, U. S., (1997) Effect of Initial Particle Size and Size Distribution on Physical and Mechanical Properties of Some Nigeria Clays Sintered at 1200°C. A Thesis Report, p3,15-18.
- Barsoum, M., (1997a) Fundamentals of Ceramics. McGraw Hill Incorporated, Singapore p410-420.
- Barsoum, M., (1997b) Fundamentals of Ceramics McGraw Hill Incorporated Singapore, p420-430.
- Furnass, C.C., (1928) The Relationship Between Specific Voids and Size of Compression In System of Broken Solid of Mixed Size US Bureau Report Investigation Vol. 2894 p 321-340.
- Keey, R.B., (1978) Introduction to Industrial Drying Operations, Pergamon Press, Elmsford, New York. p132-157.
- Nwoye, C. I. (2003a) Investigating the Influence of Particle Size and Size Distribution on the Physical and Mechanical Properties of Ceramic Materials. A Project Report p5-8, 16-22.
- Nwoye, C. I. (2003b) Investigating the Influence of Particle Size and Size Distribution on the Physical and Mechanical Properties of Ceramic Materials. A Project Report p28.
- Nwoye, C. I., (2007). SynchroWell Research Work Report, DFM Unit, No 2007156, p16-26.
- Reed, J., (1988a) Principles of Ceramic Processing, Wiley Interscience Publication, Canada p470.
- Reed, J., (1988b) Principles of Ceramic Processing, Wiley interscience publication, Canada p270.
- Singer, F. and Singer, S.S., (1963). Industrial Ceramics, University Press Cambridge p44.
- Viewey, F. and Larrly, P., (1978). Ceramic Processing Before Firing, John-Wiley and Sons, New York, p3-8.
- Viewey, F. and Larrly, P., (1978). Ceramic Processing Before Firing, John-Wiley and Sons, New York, p10.
- Unal, A., (1986) Trans Institute of Metallurgy Section C. 95, p179.