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Application of Factorial Analysis for Quicklime Production from Limestone

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Abstract

Production of quicklime from limestone was investigated in this study. Two level Full Factorial Design has been employed to study the effect of different experimental variables on the production of quicklime. Two variables of calcinations temperature (800 °C and 1000 °C), calcinations time (30 mins and 60 mins) and limestone particle size (0.3 mm and 6 mm) were used to identify the significant effects and interactions in the limestone calcination batch studies. An empirical model has been developed using the experimental data. The results show that production of quicklime was strongly affected by the variations in calcinations temperature, calcinations time and limestone particle sizes. The factorial analysis also suggested that there is a significant interaction between calcination temperature and calcination time to produce quicklime of high yield and reactivity. The maximum quicklime quality yield of 94.97% was achieved when the production was carried out at 1000 °C, calcinations time of 30 minutes with limestone particle size of 0.3 mm. The result of Mean Absolute Percentage Error (MAPE) of 3.44% less than minimum of 15% obtained from the validation and confirmatory experiment shows that the regression is suitable for predicting the yield of quicklime from limestone.

Keywords: limestone, quicklime, Full Factorial Design, Yield, Reactivity
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Introduction

Large limestone and dolomite occurrences have been reported by Bell (1963), Ola (1977), Gwosdz (1996) and RMRDC (2010) and they are widespread in the sedimentary basin of Nigeria. Nigeria Ministry of Mines and Steel Development reported that Nigeria has an estimated reserve of about 3 trillion tonnes of limestone which are scattered in different states of the country. Those states include Abia, Anambra, Benue, Cross River, Ebonyi, Enugu, Ogun, Sokoto, Gombe, Nassarawa, Edo, Borno, Yobe, Adamawa and Kebbi (RMRDC, 2010). Despite the huge deposit of the limestone which is the basic ingredient for quicklime production in the country, process industries in Nigeria still relied on the imported quicklime for the production of their products. Quicklime is a solid material that is produced from thermal decomposition of limestone from which carbon dioxide gas is evolved and upon hydration, forms white powder and releases large amount of heat to form hydrated lime. Hydrated lime is an important industrial mineral because of its physical, chemical and mineralogical properties, as well as its commercial importance and ease of production. Foramfera (2012) reported that Nigeria has high demand for quicklime based on its wide range of uses. The industries that use quicklime include building, agriculture, water treatment; sugar refining, tannery, paper and glass. The bulk demand for quicklime in Nigeria is for water treatment, soft drink bottling, tannery, breweries and food processing (Foramfera, 2012).

Quicklime is produced in a chemical reactor often referred to as kiln. Kilns are of various designs and it includes shaft kilns, rotary kilns, multiple hearth furnaces, and fluidized bed reactors (Boynton, 1980). Oates (1998) reported that the minimum amount of energy in the form of process heat that is required to thermally decompose limestone near temperature of 1173K (900 °C) is about 3029 kJ/kg (723 kcal/kg) of CaO, while the heat of decomposition of calcite relative to 298 K (25 °C) is 3184 kJ/kg (760 kcal/kg) of CaO. He further reported that total heat usage of modern limestone kilns ranges from 3600 kJ/kg (860 kcal/kg) of CaO for vertical double shaft kilns to 7500 kJ/kg (1800 kcal/kg) of CaO for non-preheated long rotary kilns (Soares et al., 2008). Hence care must be taken to select favourable conditions for production of quicklime from limestone. Design of experiment is a method that can be used to select favourable conditions for production of quicklime from limestone. Design of experiments is a series of tests in which purposeful changes are made to the input variables of a process and the effects on response variables are measured. Montgomery (2005) stated that fundamental approach to process and product design and development using design of experiment consists of three phases: characterization, control and optimization. Characterization is the process of determining the specific process variables that are responsible for the variability in the process output responses. Thus identifying the most important factors early is critical to successful development of the process. Soares *et al.* (2008) reported that calcinations process variables (temperature, time and particle size) have effect on the process output responses (quicklime yield and reactivity). This observation has been established by the following authors (Khraisha and Dugwell (1989); Rao *et al.* (1989); Khinast *et al.* (1996); Dogu and Irfan (2001); Demir *et al.* (2004); Muaazu *et al.* (2011); Okonkwo and Adefila (2012) and Rashidi *et al.* (2012)) but none was focused on determining the degree of the effect of limestone particle sizes, calcinations temperature and calcination time and their interaction for production of quicklime using factorial experimental design approach. In this study, preliminary experiment was carried out to observe effect of calcination parameters (limestone particle sizes, calcinations temperature and calcination time) on the production of quicklime from limestone.

Materials and Methods

The raw materials used in the production of quicklime were limestone obtained from Mfamosing quarry in southern part of Nigeria. The limestone was selected from preliminary study which shows Mfamosing is most suitable for quicklime production from limestone (Akande, 2015).

Methodology

Calcination Experiment

To investigate the effect of calcination temperature on quicklime yield, the procedure is as follows: 30g (C) of the 0.3 mm Mfamosing limestone sample (Run 1 of Table 3) was placed in an empty crucible and weighed on an electronic weighing balance. The mass of the empty crucible was noted and the mass of the crucible with the sample was also recorded (A). The crucible containing the limestone sample was charged into a carbolite furnace and the temperature was set to 1000 °C (Run 1 of Table 3) for a period of 30 mins (Run 1 of Table 3) and the sample was withdrawn and placed in a glass desiccator containing silica gel as the desiccant to cool. The crucible containing the cold calcined limestone sample (B) was then reweighed and recorded. The whole procedure was repeated for other experimental runs of factorial experimental design shown in Table 3.

Quicklime Yield Determination Experiment

The yield of quicklime produced was determined by measuring the residual loss on ignition. For each calcined limestone sample obtained in calcination experiment, the Loss on Ignition (LOI) which is the actual material lost during the calcination of the limestone in the furnace is mathematically given as:

$$LOI = \frac{A-B}{C}\ \% \qquad (1)$$

The yield of quicklime which is a measure to which the limestone was calcined to produce quicklime was calculated from ASTM C25 method using Equation 2 below:

$$Yield = \frac{LOI}{0.4392} \qquad (2)$$

Quicklime Reactivity Determination Experiment

The hydration reaction of quicklime is an exothermic reaction and can be expressed by:

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)} + 64.5\ kJmol^{-1}_{CaO} \qquad (3)$$

The reactivity of calcined limestone (quicklime) produced in calcination experiment was determined according to ASTM C25. Quicklime reactivity is typically measured using the water extinction test following the ASTM C25. A mass of 30 g of quicklime was introduced into 120 g of water in an adiabatic receiver (Dewar), shaken by a magnetic stirrer. A thermometer placed in the suspension measures the temperature of water, which increased due to the heat released during hydration of CaO and then stabilizes to a final value. The maximum temperature recorded during the slaking experiment (ΔT_m) and the time taken to reach it (Δt) were recorded. The reactivity, R, was calculated using Equation 4.

$$R = \frac{\Delta T_m}{\Delta t} \qquad (4)$$

Where; R is defined as reactivity (°C/s), ΔT_m = maximum temperature recorded during the reactivity experiment (°C) and Δt = time at which the maximum temperature was acquired (s).

Design of Experiments

When process factors (independent variables) satisfy an important assumption that they are measurable, continuous, and controllable by experiments, with negligible errors, the factorial analysis procedure was carried out as follows:

- A series of experiments were performed for adequate and reliable measurement of the response of interest.
- A mathematical model of the second-order response surface with the best fit was developed.
- The magnitude of the process parameters (factors) were estimated using ANOVA.
- The direct and interactive effects of the process parameters (factors) were represented through factorial plots.

The first requirement of the factorial analysis, as mentioned above, involves the design of experiments to achieve adequate and reliable measurements of the response of interest. A two-level full factorial, which is a very efficient design tool for fitting second-order models (Montgomerry, 2005), was selected for use in this study. The number of tests required for a two-level full factorial design is shown in Equation 5.

No of Experimental Run = :. ;4 (5)

where N is the number of variables, L is the number of level and R is the number of replicate. Replicates of the test are very important as they provide an independent estimate of the experimental error. A two-level full factorial for 3 factors (calcination temperature, calcination time and limestone composition), with 2 replicates resulting in total $(2^3)2=16$ runs, is illustrated in Figure 1.

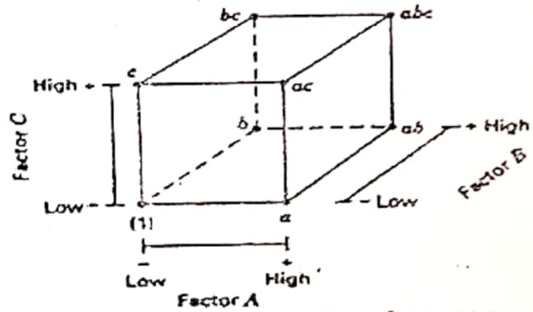

Figure 1: Geometric design of three factors at two level settings

In order to define the experimental domain explored, preliminary experiments were carried out to determine narrower, more effective ranges of calcination temperature, calcination time and limestone composition prior to designing the experimental runs. It was found from the preliminary calcination tests that calcination temperature was most effective in the range from 800 to 1000°C, calcination time in the range from 30 to 60 mins and limestone particle size in the range from 0.3 to 1.18 mm as shown in Table 1. A two-level full factorial and 2 experiments as replicates of the experimental point are given in Table 2.

Table 1: Preliminary Calcination Parameters Ranges

Parameters	Ranges	
Calcination Temperature (°C)	800	1000
Calcination Time (mins)	30	60
Limestone Particle Size (mm)	0.3	1.18

Table 2: Coded Levels of the Independent Variables for the Low and High Level Settings

Process Variables	Low level settings	High level settings
	-	+
X_1: Calcination Temperature (°C)	800	1000
X_2: Calcination Time (mins)	30	60
X_3: Limestone Particle Size (mm)	0.3	1.18

In order to determine if a relationship existed between the factors and the responses investigated, the collected data was analysed statistically using regression analyses. A regression design is employed to model a response as a mathematical function (either known or empirical) of a few continuous factors and 'good' model parameter estimates are desired (Montgomerry, 2005). Each response of Y can be represented by a mathematical equation that correlates the response surface. The responses can be expressed as a second-order polynomial equations, according to Equation (6):

$$Y = f(x) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 \quad (6)$$

where Y is the predicted response (quicklime yield and reactivity) used as a dependent variable; k the number of independent variables (factors), x_i (i = 1, 2) the input predictors or controlling variables (factors); β_0 the constant coefficient, and β_i, β_{ii} and β_{ij}, the coefficients of linear, interaction and quadratic term, respectively. The coefficient parameters were estimated using a multiple linear regression analysis employing the software Minitab (version 17.0). Minitab 17 was also used to find the factorial plots of the response models.

Results and Discussion

This study focused on the factorial analysis of quicklime production from limestone sourced from Mfamosing, Nigeria. Influences of the calcination temperature, calcination time and particle size were investigated using factorial design approach. Results obtained as presented in Table 3 reveals that best yield of 94.97% of quicklime was obtained at calcination temperature of 800°C, calcination time of 30 minutes and particle size of 0.3mm with quicklime reactivity of 0.21°C/s. Calcination temperature is considered as the most important parameter in the production of quicklime from limestone (Hassibi, 2009). Results as presented in Table 3 indicate that while keeping other parameters constant and varied the temperature from 800°C to 1000°C, the yield of the limestone obtained reduces while the reactivity increases. On the influence of particle size on the yield of quicklime from limestone, results as presented indicate that the yield from large particle size is higher than that of lower particle size. Results as presented in Table 3 also shown that the higher the calcination time, the lower will be the yield of quicklime from limestone. Considering the unpattern nature of the influence of individual parameters on the yield and reactivity of quicklime from limestone, there is the need to optimize the process for the purpose of selecting the best conditions for the yield of quicklime from limestone, which is the focus of this study.

Table 3: Response Factors (Quicklime Reactivity) for Factorial Analysis of Limestone Calcination Experimental Design

Experimental Run	Calcination Temperature (°C)	Calcination Time (minutes)	Limestone Particle Size (mm)	Mfamosing Quicklime Reactivity [R(°C/s)]	Mfamosing Quicklime Yield [R(°C/s)]
1	1000	30	0.3	0.62987013	82.6594
2	1000	30	1.18	0.553459119	94.7322
3	1000	60	0.3	0.320987654	14.2721
4	800	60	0.3	0.251533742	4.7081
5	800	30	0.3	0.206060606	90.0164
6	1000	60	1.18	0.299363057	14.419
7	800	60	0.3	0.251533742	11.6854
8	800	60	1.18	0.203592814	82.1029
9	1000	30	1.18	0.540372671	90.5893
10	1000	60	1.18	0.295597484	4.6265
11	800	30	1.18	0.189349112	5.4742
12	800	30	0.3	0.206060606	94.9663
13	1000	60	0.3	0.327160494	89.1594
14	1000	30	0.3	0.614379085	11.9094
15	800	60	1.18	0.212121212	3.1009
16	800	30	1.18	0.195266272	82.6594

Presented in Table 4 are the estimated effects and coefficients for quicklime reactivity. The result of the estimated effects suggests that the model contains three main effects, which can be evaluated in the absence of significant interactions and three two-way interaction effects. The p-values for all three main effects are less than 0.05 (Temperature = 0.000, Time = 0.000 and Limestone particle size = 0.000). Therefore, there is evidence of a significant effect. This assertion is in agreement with literature as kinetic studies of limestone decomposition by many researchers (Dogu (2001); Demir *et* *al.* (2003); Beruto *et al.* (2004); Muaazu et al. (2011); Okonkwo and Adefila (2012); Rashidi *et al.* (2012)). The p-value result from Table 4 also indicates that there is significant interaction between temperature and time (0.000) and between temperature and particle size as their terms have p-values less than 0.05 ($\alpha = 0.05$). The work of Escardinao *et al.* (2008) has shown that there is a correlation between thermal decomposition of calcite and the calcination process variables (temperature and time) using the Homogeneous Reaction Model (HRM) and the Grainy Pellet Model (GMP).

Table 4 also shows that calcination temperature has the greatest effect (0.23321) on quicklime reactivity. In addition, the table shows that setting the calcination temperature low produced higher quicklime reactivity than setting the calcination temperature high. The interaction between calcination temperature and calcination time has the second greatest effect (-0.15213) on quicklime reactivity. The negative sign shows the settings of the two process variables have antagonistic effect (need to be at opposite setting).

Table 4: Estimated Effects and Coefficients for Quicklime Reactivity

Term	Effect	Coef	SE Coef	T	P
Constant		0.33104	0.00149	221.61	0.000
Temperature	0.23321	0.1166	0.00149	78.06	0.000
Time	-0.12162	-0.06081	0.00149	-40.71	0.000
Particle Size	-0.03981	-0.0199	0.00149	-13.32	0.000
Temperature*Time	-0.15213	-0.07606	0.00149	-50.92	0.000
Temperature*Particle Size	-0.01109	-0.00555	0.00149	-3.71	0.006
Time*Particle Size	0.00467	0.00234	0.00149	1.56	0.156
Temperature*Time*Particle Size	0.01963	0.00982	0.00149	6.57	0.000

Pareto chart of the standardized effect for quicklime reactivity response in Figure 2 shows that calcination temperature (A), calcination time (B) and limestone particle size (C) are significant (□ = 0.05). In addition, it is observed that Pareto plot shows that the largest effect is calcination temperature (A) because it extends the farthest. The effect for the interaction between the calcination temperature and limestone particle size (AC) is the smallest because it extends the least. The limestone particle size by calcination temperature interaction is not significant at □ = 0.05 level in the estimated effects and coefficients in Table 4.

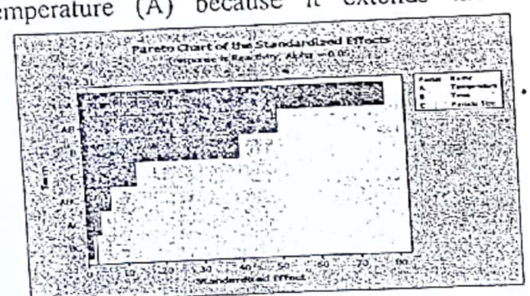

Figure 2: Pareto Chart of the Standardized Effect for Quicklime Reactivity Response

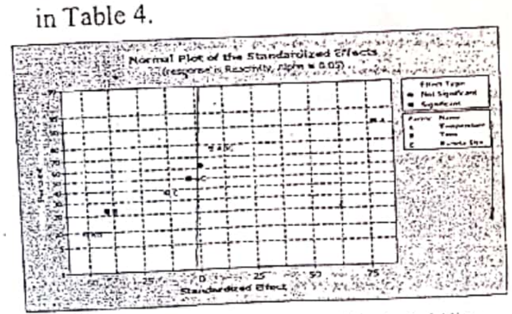

Figure 3: Normal Plot of the Standardized Effect for Quicklime Reactivity Response

Normal plot ~~of the~~ standardized effect for quicklime reactivity response of Figure 3 shows the direction of the effect. Calcination temperature (A), the combined effects of temperature, time and particle size (ABC) all have positive effects because they reside to the right of the line. This means when process variables change from the low level to the high level of the factor, the quicklime reactivity increases. Because calcination time (B), limestone particle size (C), resides to the left of the line, it has a negative effect, meaning when the calcination time and limestone particle size change from the low level to the high level, the quicklime reactivity decreases. The significance of the process factors and their ranking is agreement with the result of estimated effects and coefficients for quicklime reactivity (Table 4).

Main effect plot of the fitted means of Figure 4 indicate that calcination temperature produced higher reactivity at high temperature (1000 °C) than at low temperature (800 °C) as the fitted mean increased from temperature of 0.22 to 0.46 °C/s respectively. This observation is in agreement with Wang and Thomson (2005) inference that higher quicklime reactivity is obtained when the calcination process is carried out at low soaking time and high temperature. Also, calcination time produced higher reactivity at low calcination time (30 min) than at high time (60 min) as the fitted mean decreased from 0.27 to 0.37 °C/s respectively. Rashidi *et al.* (2012) reported that limestone of smaller porosity and surface area are produced when the soaking time is too long, thus limiting the reactivity of the quicklime. smaller limestone particle size (0.3 mm) produced quicklime of higher reactivity than bigger limestone particle size (0.6mm) as the fitted mean decreased from temperature of 0.35 to 0.31 °C/s respectively. Hu and Scaroni (1996) reported that the calcination rate is location-dependent and smaller limestone particles produced quicklime of higher yield and reactivity than bigger limestone particles.

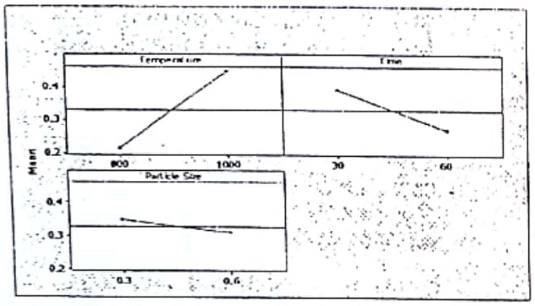

Figure 4: Main Effect Plot for Quicklime Reactivity Response

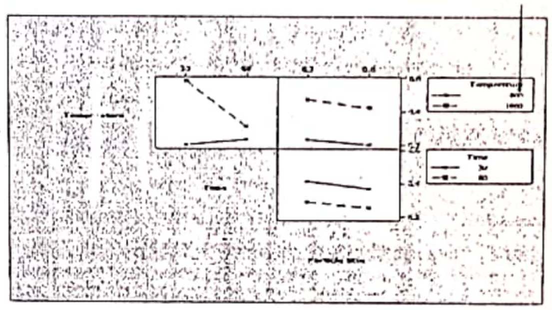

Figure 5: Interaction Plot for Quicklime Reactivity Response

The earlier estimated effects analysis in Table 4 shows the interaction of calcination temperature by calcination time had a p-value of 0.000. The interaction plot of Figure 5 shows that a change from the low to the high level of calcination temperature for the response mean depends on the level of calcination time. The plot further indicates that the degree of departure of the two lines of calcination temperature and time from being parallel is greater, this infer that the effect is stronger. The plot indicates that the increase in quicklime reactivity is greater as the calcination time is moved from the high level (60 min) to the low level (30 min) when the calcination temperature is high (red line) than when it is low (black line). In the calcination process, striking a balance between the soaking time and reaction temperature ~~is~~ necessary and Wang and Thomson (2005) reported that in most cases calcination process is carried out at low soaking time and high temperature. Lee *et al.* (1993)reported that it is better that the calcination time should be short, but enough time must be given for heat transfer to the inner core of $CaCO_3$ particles and for carbon dioxide gas to leave the core of the limestone particles. Calcination should be carried out either at low temperature for long duration time or at high temperature for short duration time.

The cube plot (Figure 6) corner point represents a different factorial design and illustrate the average quicklime yield result for that production based on the process variables level. The plot illustrates that if limestone of smaller particle size (0.3 mm) is used, the calcination temperature is high (1000 °C) and calcination time is low (30 min), the quality of quicklime reactivity is 0.32407 °C/s. This is corroborated by the work of Harrison (1999) which reported that quicklime quality and yield is increased when limestone is calcined at high temperature, low residence time and smaller limestone particles.

Surface plot of quicklime reactivity ~~against~~ time and temperature of Figure 4.29 shows how calcination temperature and calcination time are related to quicklime reactivity. To maximize quicklime reactivity, high setting of calcination temperature and low setting of calcination time while holding limestone particle size at 0.3 mm should be chosen. This is in agreement with the work of Wang and Thomson (2005) and Lee *et. al.* (1993).

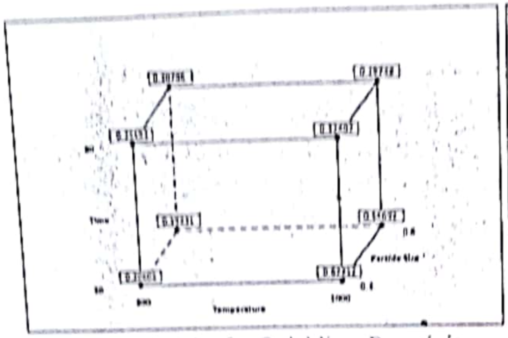

Figure 6: Cube Plot for Quicklime Reactivity Response

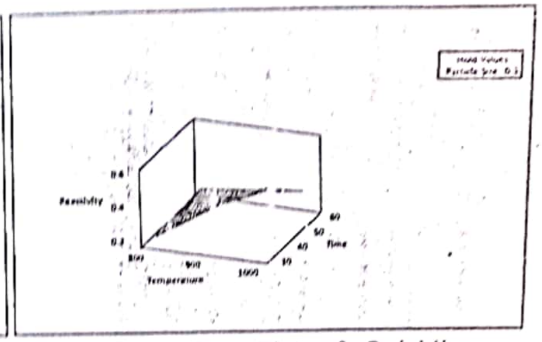

Figure 7: Surface Plot of Quicklime Reactivity against Time and Temperature

Contour plot of quicklime reactivity against time and temperature of Figure 7 shows how soaking time and calcination temperature affect quicklime reactivity. The darkest green area indicates the contour where the quicklime reactivity is highest (greater than 0.6) while holding limestone particle size at 0.3 mm. To maximize quicklime reactivity, the settings for calcination temperature and calcination time in the upper right corner of the contour plot of Figure 8 should be chosen as it produced the highest reactivity compared to other design points. This is in agreement with the study of Lee *et. al.* (1993) and Wang and Thomson (2005).

Contour plot of quicklime reactivity against temperature and limestone particle size of Figure 9 shows how calcination time and limestone particle size are related to quicklime reactivity. The darkest green area indicates the contour where the quicklime reactivity is highest (greater than 0.6) while holding calcination time at 30 min. Figure 9 shows that to maximize quicklime reactivity, the settings for calcination temperature and limestone particle size should be selected. This agrees with the work of Escardino *et al.* (2008).

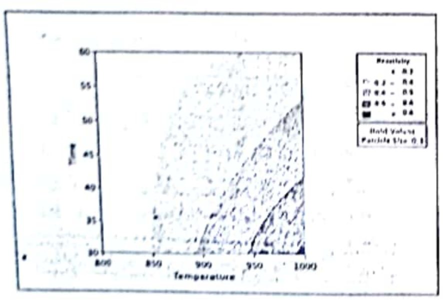

Figure 8: Contour Plot of Quicklime Reactivity against Time and Temperature Limestone

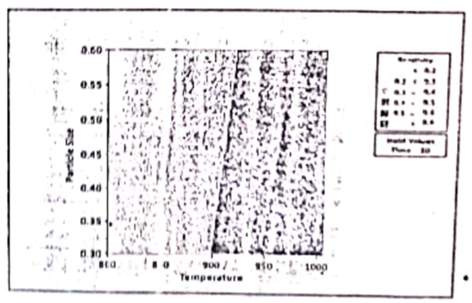

Figure 9: Contour Plot of Quicklime Reactivity against Temperature and

The plot of residual against fitted values for quicklime reactivity of Figure 10 shows the residuals follow a straight line. Also, evidence of skewness, outliers and non-normality does not exist. This Figure shows the residuals follow the normal probability distribution as all points scatter around a straight line.

The plot of residual against observation order for quicklime reactivity of Figure 11 shows the residuals is randomly scattered about zero. Also, there is no suggestion that the error terms are interrelated to one another. This shows that the residuals scatter randomly. Based on normal probability plot, residual against fit plot and the residual against run order, the estimated regression model is adequate.

The model Equation can be built up from estimated coefficients for quicklime reactivity of Table 4.

$$Y_p = 0.33104 + 0.1166x_1 - 0.06081x_2 - 0.0199x_3 - 0.07606x_1x_2 - 0.0055x_1x_3 + 00982x_1x_2x_3 \quad 7$$

Based on Main Effect plot, the combinations of factors that will produce the highest quicklime reactivity are:

- High level of calcination temperature
- Low level of calcination time
- Low level of limestone particle size

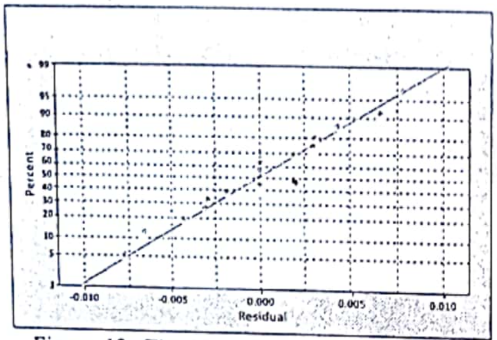

Figure 10: The Normal Probability Plot for Quicklime Reactivity

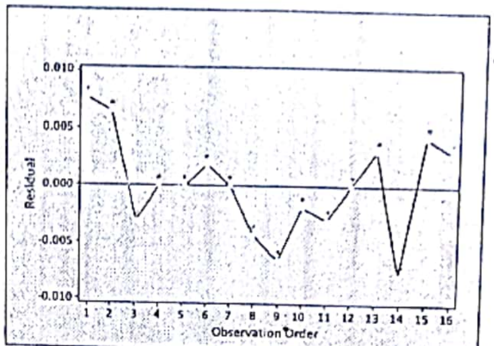

Figure 11: The Plot of Residual against Observation Order for Quicklime Reactivity.

Based on Interaction plot, the combinations of factors that will produce the highest quicklime reactivity are:

- High level of calcination temperature of 1000 °C and low level of calcination time of 30 min.
- High level of calcination temperature of 1000 °C and low level of limestone particle size of 0.3 mm.
- High level of calcination temperature of 1000°C, low level of calcination time of 30 min and low level of limestone particle size of 0.3 mm.

The model Equation via the combination above of main effects and the Interaction plot is:

$$\hat{Y} = 0.33104 + 0.1166(1) - 0.06081(-1) - 0.0199(-1) - 0.07606(1)(-1) - 0.00[illegible]5(1)(-1) + 00982(1)(1)(-1) = 0.629595$$

In order to validate the experimental model developed from the factorial analysis, confirmatory experiments were performed as shown in Table 5 and the Mean Absolute Percentage Error (MAPE) to evaluate and compare the model performance (Montgomery, 1999).

Table 5: Confirmatory Experimental Run for Model Validation

Confirmatory Experimental Run	Calcination Temperature (°C)	Calcination Time (min)	Limestone Particle Size (mm)	Quicklime Reactivity (°C/s)	FITS	$\left\lvert\frac{yi-\hat{y}}{yi}\right\rvert$
1	1000	30	0.3	0.6275	0.6260	0.0024
2	980	28	0.3	0.5886	0.6260	0.0634
3	960	26	0.3	0.5617	0.6260	0.1143
4	940	24	0.3	0.5422	0.6260	0.1545
5	920	22	0.3	0.5150	0.6260	0.2155
					MEAN	0.5502

$$MAPE = \frac{1}{5}\sum_{i=1}^{5}\left\lvert\frac{yi-\hat{y}}{yi}\right\rvert \times 100\% = 3.4388\% \quad 8$$

It can be inferred that the predicted ability of the estimated model Equation is good as the MAPE is 3.4388%. If the MAPE is less than 15%, the predicted ability of the estimated regression Equation is acceptable (Montgomery, 1999). Table 6 shows the model proportion of the response variability that is (R^2) is 99.92%, while predicted R^2 the level of prediction of the future data by the model is 99.70%, and the adjusted R^2 useful for comparing models from the same data with different numbers of terms is 99.86%.

The R^2 value lies between 0 and 100%. The model predicts better when R^2 value is closer to 100% (Doddapaneni *et al.*, 2007). The sum of squares of the prediction errors (PRESS) for assessing model's predictive ability from Table 6 is 0.00598. ~~Low~~ PRESS value of 0.00598 is an indication that the model fits the data as Montgomery (2005) reported that the model fits the data better when the PRESS is smaller. (R^2) of 99.92%, adjusted R^2 of 99.86%, predicted R^2 of 99.70% and PRESS value of 0.00598 indicate that the model adequately represents the experimental data.

Table 6: Statistical Parameters of the Model Correlating Quicklime Reactivity to Calcination Temperature, Time and Limestone Particle Size

Statistical Parameters	Values
S	0.00598
PRESS	0.00114
R^2	99.92%
R^2adjusted	99.86%
R^2predicted	99.70%

Conclusions

This work has demonstrated the application of factorial analysis in determining the specific process variables that are responsible for the variability in quicklime reactivity for calcination process. Magnitude of the effect of the calcination process variables and their interaction were investigated. In order to gain a better understanding of the effect of the calcination factors for suitable calcination performance, the models were presented as factorial plots, 3-D response surface and 2-D contour graphs. Based on results obtained from the analysis conducted in this study, the following conclusions can be drawn;

1. From the factorial analyses, the calcination temperature, calcination time and limestone particle size have significant effects on the quicklime reactivity.
2. The factorial analysis suggested that there is a significant interaction between calcination temperature and calcination time to produce quicklime of high reactivity.
3. The factorial analysis further suggested that quicklime of high reactivity of 0.6221 °C/s was produced at calcination temperature of 1000 °C and calcination time of 60 minutes using limestone particle size of 0.3 mm.

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