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Processing of Yandev quicklime for potential amelioration of acidic soil

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Abstract

This study focused on processing of Yandev quicklime for potential amelioration of acidic soil. It involved production of quicklime from the Yandev limestone, characterization and slaking of the quicklime. In a batch process, 10g of the limestone (90μm particle size) was calcined for 3hrs to produce the quicklime. Mineralogical composition of the quicklime was determined by X-ray Diffractometer (XRD), while scanning electron microscope (SEM) was used to examine its surface morphology. The CaO was hydrated for the production of slaked lime (Ca (OH) 2). The slaking process was carried out by digesting CaO in distilled water. During the slaking/hydration process, values of reactivity (rise in temperature) were recorded. Central composite design (CCD) tool of Design Expert Software 11 was used to design the experiment of the slaking process. Quicklime/water ratio, particle size and time were the considered slaking variables, while reactivity was considered as the response. Analysis of the results quicklime is made up of pure calcite with visible pores. Quadratic model adequately described the relationship between reactivity and the considered slaking factors of quicklime/water ratio, particle size and time. Optimum reactivity was obtained as 58.4 0C with the corresponding optimal factors of quicklime/water ratio (0.26 g/ml), particle size (93.0 μm) and time (16.4 minutes). Properties of the slaked lime showed that it is suitable for acidic soil amelioration.

Keywords: Yandev Quicklime; Amelioration; Acidic Soil; Slaking

1. Introduction

Most soils in sub-Sahara Africa are acidic [1]. The acidic soil causes poor plant growth. This problem can be solved by soil amelioration. Acidic soil amelioration is a process of reducing the acidity of the soil, thereby improving its quality. Reduction of soil acidity can be achieved through liming. Liming is defined as the application of lime on acidic soil. It is an agricultural practice that reduces soil acidity by counteracting the effects of excess H^+ and Al^{3+} ions [2]. Liming is a necessary practice that enhances soil productivity. It improves plant root environment and is a basic condition for increasing crop yield. Acidic soil treated with lime can produce high crop yields; reducing acidity, toxic effect of Al^{3+} and Mn^{2+} and providing Ca and Mg to plants. Liming is a viable technique for treating acidic soil [3, 4, 5, 6].

Soil pH is a measure of the number of hydrogen ions in the soil solution. It is an outstanding chemical indicator of soil quality. Farmers can improve the soil quality of acid soils by liming to adjust pH to the levels needed by the crop to be grown. Benefits of liming include increased nutrient availability, improved soil structure, and increased rates of infiltration. Understanding soil pH is essential for the proper management and optimum soil and crop productivity. Nigeria is blessed with numerous limestone deposits, which include that of Yandev. Yandev is a Town in Gboko Local Government Area (LGA) of Benue State, Nigeria, Africa. Limestone mining and cement production at Yandev, Nigeria commenced in 1980 [7]. The limestone and its burnt derivative lime are very important raw materials for the industry, enhancing the developmental economy of Nigeria [8]. The limestone exposed at Yandev quarry is a component of the sedimentary fill of the Benue trough. Though, Yandev limestone has largely been used for cement production, its

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application on lime production has not been fully developed. Thus, there is need to process Yandev quicklime in order to obtain slaked lime for potential acidic soil ameliorant

2. Material and methods

2.1. Production of Quicklime from Yandev Limestone

Quicklime (CaO) was produced from Yandev limestone by calcination process. In a batch process, 10g of the limestone of 90μm particle size was weighed into pre-weighed empty crucible plate. The pre-weighed crucible plate with the limestone was set to laboratory furnace and heated at temperature 1000 ^{0}C. The sample was removed at time of 3 hours. Then, it was allowed to cool for 15 minutes. The calcined sample was transferred to desiccator. The weight of the quicklime produced was measured.

2.2. Determination of Mineralogical Composition

Mineralogical composition of Yandev quicklime was determined by X-ray Diffractometer (XRD). Method used by previous researchers [9, 10] the mineralogical composition of the sample. The X-ray diffraction pattern was taken using Empyrean Pan Analytical. The sample was analyzed using reflection transmission spinner stage using the theta-theta (X-ray beams at certain angles of incidence) settings. Two-theta (2Θ) starting position was 4 degrees and ends at 75 degrees with a two–theta step of 0.026261 at 8.67 seconds per step. Tube current was 40 mA and the tension was 45VA. A programmable divergent ship was used (with width mask) to determine the mineral content of the quicklime.

2.3. Determination of Surface Morphology of the Quicklime

Scanning electron microscope, (Phenom Pro X-ray, phenom world Emdhoven Netherlands) was used to examine the surface morphology of the quicklime, in accordance with the technique used by previous author [10]. The scanning electron microscope (SEM) produced the image of the quicklime sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.

2.4. Slaking of the Yandev Quicklime

Method used by previous author [11] was employed in the slaying of Yandev quicklime. The quicklime (CaO) was obtained by calcination of Yandev limestone. Then, the CaO was hydrated for the production of slaked lime (Ca (OH) 2). The slaking process was carried out by digesting CaO in distilled water. After being dissolved, spontaneous chemical reaction (exothermic reaction) occurred between CaO and distilled water. During the slaking/hydration process, values of reactivity (rise in temperature) were recorded. The reactivity measurement continued till the reaction was completed. Central composite design (CCD) tool of Design Expert Software 11 was used to design the experiment of the slaking process. Quicklime/water ratio, particle size and time were the considered slaking variables, while reactivity was considered as the response.

2.5. Determination of Activation Energy and pH

The activation energy of the reactivity was determined using Arrhenius model [12, 13], Equation 1, while pH meter was used to record the pH of the slaked lime.

$$K = K_o e^{-E_a/RT} \quad (1)$$

Considering different temperatures of the slaking process, the linear form of the Arrhenius equation was used to obtain the activation energy, Equation 2:

$$E_a = (Ln\ (K_2/ K_1))*(2.303*R)*((T_1T_2)/ (T_2-T_1)) \quad (2)$$

Where K is rate constant, K_o is pre-exponential (frequency) factor, T is absolute temperature, R is universal gas constant (8.314kJ/kmol.K), and Ea is the activation energy, K_1 and K_2 are the rate constants at T_1 and T_2 respectively.

3. Results and discussion

3.1. Mineralogical Compositions of the Quicklime

The mineralogical composition of Yandev quicklime, as determined by XRD, is shown in Figure 1. It revealed that Yandev quicklime is made up of pure calcite. This is an indication that the Yandev quicklime is suitable for versatile applications [14, 15, 16].

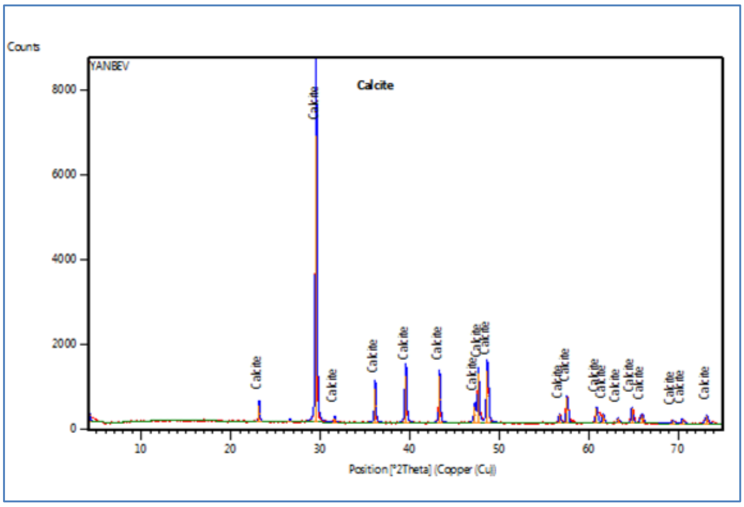

Figure 1 Mineralogical Compositions of Yandev Quicklime

3.2. SEM Analysis of the Quicklime

The scanning electron microscopic analysis of Yandev quicklime is shown in Figure 2. The surface morphology of the quicklime was revealed. The micrograph showed that the particles are packed together in powdered form with visible pores. Revealed visible pores indicate that Yandev quicklime has good hydration characteristics.

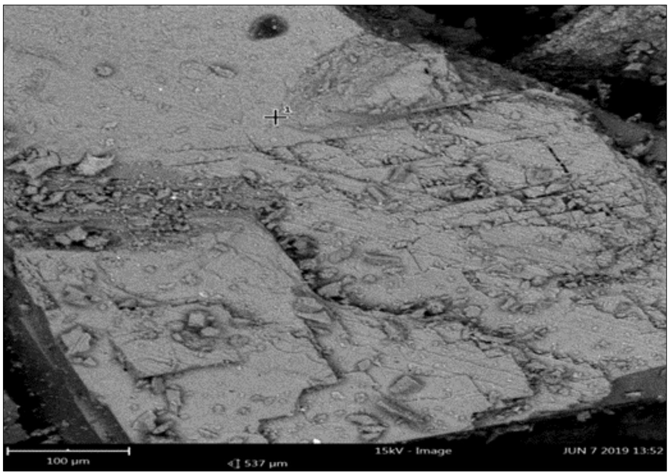

Figure 2 SEM Analysis of the Yandev Quicklime

3.3. RSM Results of the Slaking Process

The RSM results of the reactivity of Yandev quicklime are shown in Table 1. The results showed the effects of the interactions among the factors of quicklime/water ratio, particle size and time on the reactivity of the quicklime. In the results of 20-run experiment, the maximum reactivity values were observed around the mid-points of the factors of quicklime/water ratio, particle size and time of the slaking process. It depicts parabolic relationship between response and the considered factors [13].

It was also revealed that minimum reactivity values were recorded at the extreme points of the considered factors. In The lowest reactivity of the quicklime occurred at the highest particle size. It showed that reactivity increases with increase in surface area (decrease in particle size). Minimum reactivity of the quicklime was obtained at lowest quicklime/water ratio, highest particle size and lowest time of slaking. This observation is in agreement with the previous reports [11, 17, 18].

Table 1 RSM Results of the Slaking of Yandev Quicklime

Std	Run	Factor 1 A: Quicklime/Water Ratio g/ml	Factor 2 B: Particle Size µm	Factor 3 C: Time min.	Response 1 Reactivity °C
14	1	0.25	90	20	50.1
16	2	0.25	90	16	59.3
13	3	0.25	90	12	46.3
1	4	0.2	80	12	26.1
12	5	0.25	100	16	47.1
4	6	0.3	100	12	36.2
3	7	0.2	100	12	15.3
2	8	0.3	80	12	31.0
15	9	0.25	90	16	59.3
20	10	0.25	90	16	59.3
8	11	0.3	100	20	33.2
10	12	0.3	90	16	50.5
9	13	0.2	90	16	42.4
18	14	0.25	90	16	59.3
5	15	0.2	80	20	33.0
6	16	0.3	80	20	35.1
7	17	0.2	100	20	21.6
17	18	0.25	90	16	59.1
19	19	0.25	90	16	59.3
11	20	0.25	80	16	59.3

3.4. Analysis of Variance (ANOVA)

Table 2 presents ANOVA of reactivity the Yandev slaked lime. The model F-value of 149.10 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The predicted R^2 of 0.9217 is in reasonable agreement with the adjusted R^2 of 0.9859; the difference is less than 0.2. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 36.353 indicates an adequate signal. This model can be used to navigate the design space.

Table 2 ANOVA of Reactivity the Yandev Slaked Lime

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	3892.62	9	432.51	149.10	< 0.0001	Significant
A-Quicklime/Water Ratio	226.58	1	226.58	78.11	< 0.0001	
B-Particle Size	96.72	1	96.72	33.34	0.0002	
C-Time	32.76	1	32.76	11.29	0.0072	
AB	81.28	1	81.28	28.02	0.0004	
AC	18.30	1	18.30	6.31	0.0308	
BC	7.41	1	7.41	2.55	0.1410	
A^2	461.51	1	461.51	159.10	< 0.0001	
B^2	105.87	1	105.87	36.50	0.0001	
C^2	345.24	1	345.24	119.02	< 0.0001	
Residual	29.01	10	2.90			
Lack of Fit	28.97	5	5.79	869.24	< 0.0001	Significant
Pure Error	0.0333	5	0.0067			
Cor Total	3921.63	19				
Std. Dev.	1.70		R^2			0.9926
Mean	44.14		Adjusted R^2			0.9859
C.V. %	3.86		Predicted R^2			0.9217
			Adeq Precision			36.3532

3.5. Mathematical Model of the Reactivity of the Slaked Lime

The mathematical models of the reactivity of Yandev slaked lime is as expressed in Equation (3). The models (in terms of significant terms) can make adequate predictions about the response for given levels of each factor, and they are useful for identifying the relative impact of the factors by comparing the factor coefficients. As revealed by the analysis of variance, each model adequately described the relationship between the reactivity and the factors of quicklime/water ratio, particle size and time. Thus, the reactivity is a function of quicklime/water ratio, particle size and time. The positive signs in the model signified synergistic effect, while the negative signs signified antagonistic effect [19]. As such, there is a synergistic effect on the interaction of quicklime/water ratio and particle size on the model. On the hand, the negative sign of the coefficients of AC indicates antagonistic effect of the interaction of quicklime/water ratio and time on the model. The highest power of at least one of the variables is two, which showed that the mathematical model is a quadratic equation.

$$\text{Reactivity} = +\,59.32 + 4.76A - 3.11B + 1.81C + 3.19AB - 1.51AC - 12.95A^2 - 6.20B^2 - 11.20C^2 \quad (3)$$

3.6. Graphical Analysis of the Reactivity of the Slaked Lime

Graphical representations of the quicklime slaked lime are presented in Figures (3 – 6). Plot of predicted versus actual yield was used to test the performance of the generated model. It gave linear graph, with the points clustered along the line of best fit. The 3-dimentional surface plots showed the relationship between the factors and response of the process. The revealed the optimum reactivity as 58.4 ^{0}C with the corresponding optimal factors of quicklime/water ratio (0.26 g/ml), particle size (93.0 µm) and time (16.4 minutes).

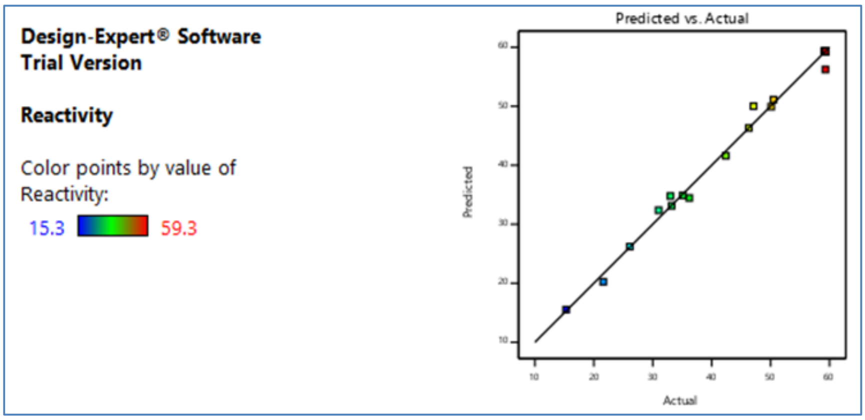

Figure 3 Predicted versus Actual Reactivity of Yandev Slaked Lime

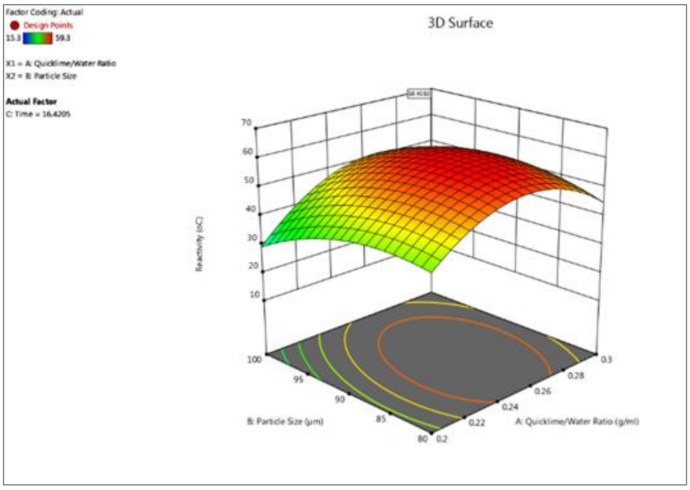

Figure 4 Reactivity versus Quiklime/Water Ratio and Particle Size for the Yandev Quicklime

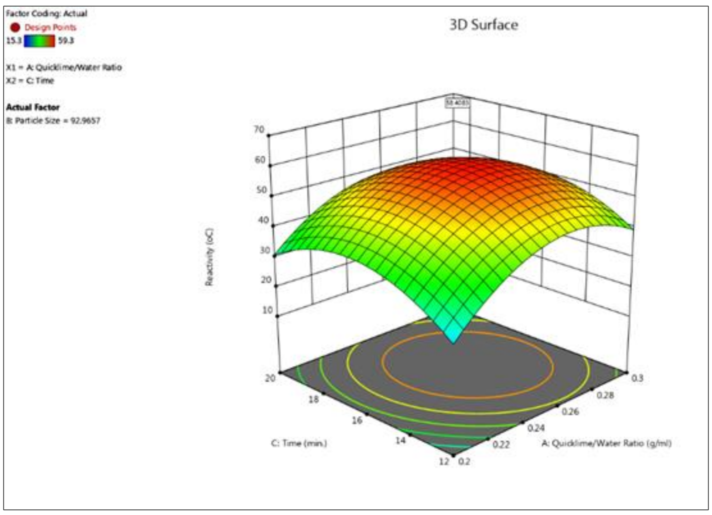

Figure 5 Reactivity versus Quiklime/Water Ratio and Time for the Yandev Quicklime

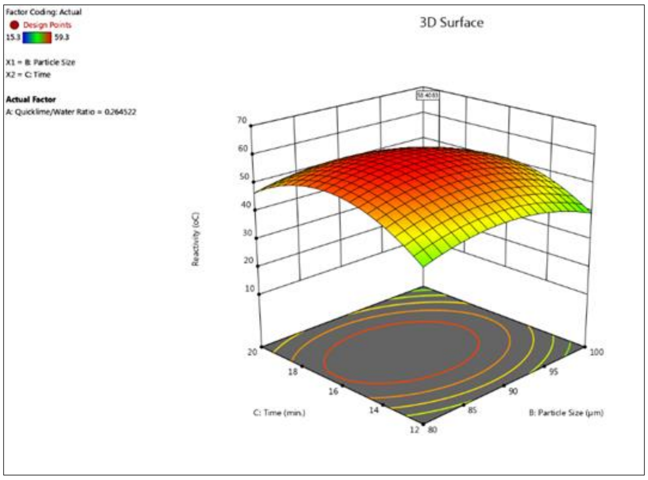

Figure 6 Reactivity versus Particle Size and Time for the Yandev Quicklime

3.7. Validation of the Result of the Slaking Process

Data for the validation of the results are presented in Table 3. The experimental result was validated by the determination of percentage deviation of experimental reactivity from the predicted reactivity. The percentage deviation is less than 5%, an indication that RSM is adequate for the optimization of the slaking process. It is also an affirmation that the generated model sufficiently described the slaking process [13].

Table 3 Validation of the Result of the Slaking Process

Quicklime/ Water Ratio (g/ml)	Particle Size (µm)	Time (min.)	Experimental Reactivity (oC)	Predicted Reactivity (oC)	Percentage Deviation (%)
0.26	93.0	16.4	59.7	58.4	2.18

3.8. Rate of the Reactivity, Activation Energy and pH of the Slaked Lime

The rate of the reactivity of Yandev slaked limes is shown in Figure 7. The graph showed the relationship between reactivity and time at various temperatures. The reactivity versus time plot revealed a straight line graph. The straight line graph was confirmed by linear equation obtained by Trend line Function of Microsoft Excel. The correlation coefficient (R^2) is close to 1. The rate constant was useful for the determination of the activation energy using Arrhenius Equation [12, 23, 20].

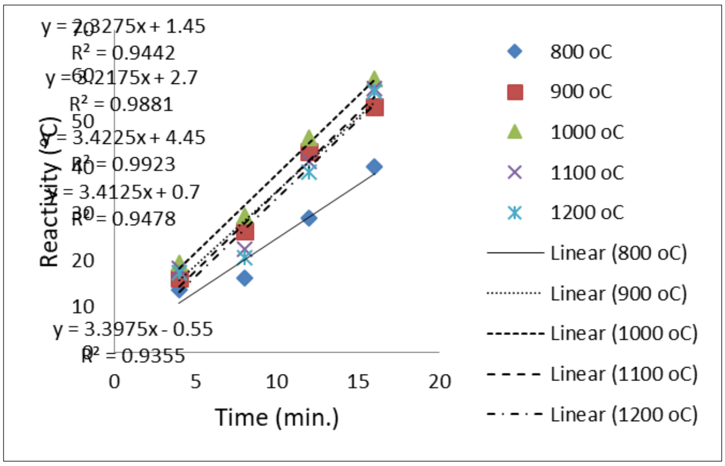

Figure 7 Reactivity versus Time for the Yandev Slaked Lime

Table 4 presents the activation energy and pH of Yandev slaked lime. The activation energy of slaked lime sample was obtained using Arrhenius law and it was observed that the reaction temperature has a direct effect on the rate of reactivity. This observation corroborates with the assertion of previous author [20]. Yandev has moderate activation energy of 50.42 kJ/mol, indicating that it requires moderate energy to activate its reactivity. High pH of 11.1 showed that Yandev slaked lime is suitable for acidic soil amelioration.

Table 4 Activation energy of the slaked lime

Slaked lime Sample	Activation Energy, E_a (kJ/mol)	pH value
Yandav	50.42	11.1

4. Conclusion

XRD and SEM analyses revealed the characteristics of the Yandev quicklime. The quicklime is made up of pure calcite with visible pores that make it suitable for hydration and versatile applications

Quadratic model adequately described the relationship between reactivity and the considered slaking factors of quicklime/water ratio, particle size and time. Optimum reactivity was obtained as 58.4 ^{0}C with the corresponding optimal factors of quicklime/water ratio (0.26 g/ml), particle size (93.0 μm) and time (16.4 minutes).

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Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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