

## **Production of Synthetic Zeolite from Ugwaka Clay (Black Clay) by thermal treatment**

### **ABSTRACT**

Application of response surface methodology in production of synthetic zeolite from Ugwaka clay has been demonstrated. In this study, optimization of synthetic zeolite production was carried out, in which the process variables such as reaction time (hours), NaOH concentration (M) and calcinations temperature (°C) were optimized using Box-Beken design. X-ray Florescence (XRF), Fourier Transform Infrared (FTIR) and Scanning Electron Microscope (SEM) were used in sample characterization. XRF analysis of raw Ugwaka clay gave silica-alumina ratio of 1.705 which falls within the specification for the synthesis of synthetic zeolite. The reaction time, NaOH concentration and calcinations temperature were varied between 1.5-2.5 hours, 600-900°C and 1-4 M respectively. A quadratic model was predicted and optimized which resulted to reaction time of 2hours, NaOH concentration of 2.5 M, and calcinations temperature of 800°C. Optimum conditions were validated at model desirability of 1. Experimental value of 92.03wt% yield of synthetic zeolite with 0.895% error was obtained.

Key words: Ugwaka clay, Synthetic Zeolite, Optimization

### **INTRODUCTION**

The material called Zeolites are hydrated aluminosilicate fashioned under hydrothermal setting. Naturally it can be found or even synthesized. According to the report in the work done by [1], Synthetic zeolites were first utilized commercially as molecular sieve adsorbent. Preferably, they are synthesized from solution of sodium silicate and sodium aluminates. Raw materials such as natural and synthetic glasses, aluminosilicate gels and clay materials, example kaolin can also be used in Zeolite Synthesis [2, 3]. Information from prior research work showed that the starting material and conditions for preparation have influence on the resulting types and amount of zeolites to be obtained. Based on available materials and publications, it could be concluded that due to their unique properties, zeolites have a great potentials as effective sorbent material for large number of water treatment applications such as water softening ammonia removal (from municipal sewage, animal farms, fertilizer factory waste water, fish breeding pond, swimming pools), removal of heavy metals (from natural water acid mines drainages, industrial wastewater), phosphates removal of dissolved organic compounds and dyes, oil spillage treatment and many others.

38 They belong to the class of minerals known as ‘Tectosilicate’ and consist of three  
39 dimensional frameworks of  $[\text{SiO}_4]^{4-}$  And  $[\text{AlO}_4]^{-5}$  tetrahedral. The aluminum ion is small  
40 enough to occupy the position in the centre of the tetrahedral four oxygen atoms and the  
41 isomorphous replacement of  $\text{Si}^{4+}$  by  $\text{Al}^{3+}$  produces a negative charge in the lattice. The  
42 negative charge is balanced by the exchangeable cation (sodium, potassium, or cadmium).  
43 These cations are exchangeable with certain solution such as lead, Cadmium, zinc and  
44 manganese [4, 1].

45 The composition of zeolites can be represented by the general formula  $\text{M}_{x/n}[\text{A}(\text{O}_2)_x(\text{SiO}_2$   
46  $)_y] \cdot z\text{H}_2\text{O}$ , where n is the charge of the cation M and the values of x, y and z depends on the  
47 type of zeolite [5].

48 Synthetic zeolites are generally produced by alkali treatment of silica and alumina-bearing  
49 raw materials of synthetic, natural or waste origin. The first synthetic zeolite, ZK-  
50  $5(\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12} \cdot 6\text{H}_2\text{O})$ , unknown as natural mineral, was obtained in the late 1940s by  
51 Richard Barrer who investigated the conversion of minerals under the action of strong salt  
52 solutions at high temperatures. Later, Milton pioneered the use of more reactive starting  
53 materials, enabling milder reaction conditions and leading to the discovery of zeolite A [6],  
54 which has become the most important synthetic zeolite, commercially used as a water  
55 softener in detergent industry, in radioactive waste treatment, and in the purification of  
56 industrial wastewaters. Typical

57 Since the principal raw materials used to manufacture zeolites are silica and alumina,  
58 which are among the most abundant mineral component on earth, the potential to supply  
59 raw material for zeolites synthesis is virtually unlimited. Clay minerals such as kaolin,  
60 illite, Smectite, montmorillonite, bentonite, perlite, have been used frequently for zeolite  
61 synthesis, due to their high contents of silicon and aluminum, which easily dissolve and  
62 form zeolite under alkaline condition [7]. Several important reactions involving organic  
63 molecules, Zeolites are extremely useful as catalysts [8]. Most of the reactions are  
64 cracking, isomerisation and hydrocarbon synthesis. Catalytic reactions including acid-base  
65 and metal induced reactions can be promoted by Zeolite. The reactions can take place  
66 within the pores of the zeolite - which allows a greater degree of product control. Sequel to  
67 the fact that the hydrated cations within the zeolite pores are bound loosely to the zeolite  
68 framework, and can readily exchange with other cations when in aqueous media, zeolite  
69 can be applied as water softening devices [9,10]. This research is aimed at optimizing the  
70 synthesis of zeolite from Ugwaka clay (Black clay) using Response surface methodology.

## 71 MATERIALS AND METHODS

72 The indigenous aluminosilicate used in this research work was obtained from Otukpo local  
73 government of Benue State, Northern Province of Nigeria. Distilled water and sodium  
74 hydroxide (NaOH) used was purchased from Ogbete main market, Enugu, Enugu State  
75 Nigeria.

76  
77

## 78 PROCEDURES

79 The raw clay was collected with a Global Positioning System (GPS) Device, (Model; Etrex  
80 Germin), with Latitude; N05° 38.216<sup>1</sup>, Longitude; E07°19.664<sup>1</sup>, and elevation above sea  
81 level; 623ft. The clay was grinded with a laboratory mortar and pestle and sieved to a  
82 particle size of 500µm. 1.0g of clay was mixed with 200ml of 2.0M Sodium hydroxide  
83 (NaOH) for 2 hours at 700°C. The resultant suspension was placed in thermostatic water  
84 bath at 100°C and rotation Speed of 200rpm at a particular time. After cooling, the clay was  
85 filtered and washed Several times with distilled water until neutral pH of 7 was obtained.  
86 The experiment was repeated with temperatures between 600°C and 900°C and other factors  
87 as shown in table 1. The Clay was dried at 90°C for 1.5 hours and was stored.

## 88 Physical Characterization

89 The physical properties of the raw clay and synthetic zeolite were carried out using American  
90 Society for Testing and Materials ASTM D7263-09 [17].

## 91 Instrumental Characterization

92 Instrumental of the samples was done using X-Ray Fluorescence (XRF) which is controlled  
93 by a PC running the dedicated Mini-Pal analytical software. The Mini-Pal 4 version used  
94 was PW 4030 X-ray Spectrometer running with voltage (30KV maximum) and a current  
95 (1mA maximum) to determine the mineral composition of the aluminosilicate. Fourier  
96 transform infrared spectrometer was used to determine the chemical bond and functional  
97 groups in the aluminosilicate and synthetic zeolite. Consequently, Scanning Electron  
98 Microscopy (SEM) was used to determine the size and morphology of the aluminosilicate  
99 and synthetic zeolite. The SEM micro graph was obtained using JOEL scanning electron  
100 microscope model JSM 6400 Scanning electron microscopy recording at 15 KV with 8000x  
101 magnification

## 102 Experimental Design

### 103 Production and Optimization of Synthetic Zeolite Using Box-Behnken Design

104 The optimization and production of Zeolite was done using Box-Behnken experimental  
105 design method. This design was classically achieved using DOE software called *Design*  
106 *Expert 9.0.2.0*. Three important factors such as calcinations temperature, time and  
107 concentration of base were considered as independent variables in which their effects  
108 respectively and collectively were studied. The Box-Behnken experimental design method  
109 contains all possible combinations of a set of factors. Experimental runs were performed at  
110 every combination of the factor level:

- |     |      |                                       |       |
|-----|------|---------------------------------------|-------|
| 111 | i.   | Calcination temperature (°C)          | $X_1$ |
| 112 | ii.  | Time (Hours)                          | $X_2$ |
| 113 | iii. | Strength or concentration of NaOH (M) | $X_3$ |

114 Based on this research, two levels (-1, +1) and null experimental point (0) were essential to  
 115 reduce noise and systematic error in the experiment. These provided for near accuracy of  
 116 analysis.

117 **Table 1: Factors and Levels of Independent variables for synthetic zeolite production**

| Parameter                                           | Low Level (-1.000) | Null Point (0.000) | High Level (+1.000) |
|-----------------------------------------------------|--------------------|--------------------|---------------------|
| <b>X<sub>1</sub></b> : Time (Hours)                 | 1.5                | 2.0                | 2.5                 |
| <b>X<sub>2</sub></b> :NaOH Strength (M)             | 1                  | 2.5                | 4                   |
| <b>X<sub>3</sub></b> : Calcination Temperature (°C) | 600                | 750                | 900                 |

118

119 **Table 2: Box-Benken Design matrix with response for synthetic zeolite production**

| Std | Run | Factor 1                           | Factor 2                                               | Factor 3                                            | Response         |
|-----|-----|------------------------------------|--------------------------------------------------------|-----------------------------------------------------|------------------|
|     |     | <b>X<sub>1</sub></b> :Time (Hours) | <b>X<sub>2</sub></b> :Strength of Sodium hydroxide (M) | <b>X<sub>3</sub></b> : Calcination temperature (°C) | Percentage yield |
| 5   | 1   | -1.000                             | 0.000                                                  | -1.000                                              | 86.52            |
| 1   | 2   | -1.000                             | -1.000                                                 | 0.000                                               | 86.86            |
| 7   | 3   | -1.000                             | 0.000                                                  | 1.000                                               | 86.76            |
| 14  | 4   | 0.000                              | 0.000                                                  | 0.000                                               | 91.97            |
| 17  | 5   | 0.000                              | 0.000                                                  | 0.000                                               | 91.96            |
| 2   | 6   | 1.000                              | -1.000                                                 | 0.000                                               | 87.97            |
| 8   | 7   | 1.000                              | 0.000                                                  | 1.000                                               | 90.01            |
| 6   | 8   | 1.000                              | 0.000                                                  | -1.000                                              | 89.32            |
| 9   | 9   | 0.000                              | -1.000                                                 | -1.000                                              | 88.26            |
| 11  | 10  | 0.000                              | -1.000                                                 | 1.000                                               | 85.68            |
| 12  | 11  | 0.000                              | 1.000                                                  | 1.000                                               | 88.36            |
| 4   | 12  | 1.000                              | 1.000                                                  | 0.000                                               | 90.66            |
| 3   | 13  | -1.000                             | 1.000                                                  | 0.000                                               | 86.41            |
| 16  | 14  | 0.000                              | 0.000                                                  | 0.000                                               | 92.02            |
| 13  | 15  | 0.000                              | 0.000                                                  | 0.000                                               | 91.95            |
| 15  | 16  | 0.000                              | 0.000                                                  | 0.000                                               | 92.03            |
| 10  | 17  | 0.000                              | 1.000                                                  | -1.000                                              | 86.44            |

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## Results and Discussion

Physico-chemical properties of the raw clay and synthetic zeolite are presented in Table 3. From the table, it was observed that most of the properties increased after calcination except carbon and organic matter. The porosity was observed to have increased after calcination owing to increase in bulk density [18]. The Surface area of raw clay was 698.20m<sup>2</sup>/g but increased to 827.35m<sup>2</sup>/g after calcinations as shown in table 3. The results are in agreement with the report by [16], that chemical calcinations of clay increase the surface area and porosity.

Table 3: Physio-chemical characterization of the raw clay and synthetic zeolite

| Sample            | pH   | Surface Area ( m <sup>2</sup> /g) | Bulk Density (g cm <sup>-3</sup> ) | Carbon (%) | Organic Matter (%) | Particle Density (g cm <sup>-3</sup> ) | Total Porosity (%) |
|-------------------|------|-----------------------------------|------------------------------------|------------|--------------------|----------------------------------------|--------------------|
| Raw Clay          | 6.01 | 698.20                            | 1.62                               | 2.43       | 7.01               | 2.48                                   | 21.80              |
| Synthetic zeolite | 7.52 | 827.35                            | 1.98                               | 1.32       | 2.53               | 3.92                                   | 44.96              |

## X-ray Florescence (XRF) analysis results of the raw clay and Synthetic zeolite

XRF was performed to determine the chemical compositions and combinations of the minerals that are present in the natural ugwaka clay and synthetic zeolite. The results of the analysis are presented as shown in table 4a and 4b. It was observed that ugwaka clay had high silicon Oxide content 57.41wt%. The result agree with the report by [7] which states the clay with high concentration of silicon oxide can be used as a source of silica for the production of floor tiles. The aluminosilicate had Alumina (Al<sub>2</sub>O<sub>3</sub>) content of 33.67wt % and silica-alumina ratio of 1.705, which is greater than 1. This is in accordance with [1] for clays that can be used for zeolite synthesis which implies that ugwaka clay can be used in Zeolite synthesis. Other major oxides in the clay are Ferrous and Titanium Oxide though in varying compositions. There were also traces of other Oxides such as Calcium, Zinc, Nickel and Copper among others in very small quantities. Oxides of Manganese, Vanadium, Zinc, Chromium, Nickel and Copper were in minute quantity.

147 Table 4a Result of XRF analysis of Ugwaka clay

148

| Chemical Compounds             | Composition (%) |
|--------------------------------|-----------------|
| SiO <sub>2</sub>               | 57.41           |
| Fe <sub>2</sub> O <sub>3</sub> | 6.90            |
| Al <sub>2</sub> O <sub>3</sub> | 33.67           |
| CaO                            | 0.81            |
| MgO                            | 0.53            |
| K <sub>2</sub> O               | 0.03            |
| TiO <sub>2</sub>               | 4.05            |
| CaO                            | 0.08            |
| MnO                            | 0.072           |
| V <sub>2</sub> O <sub>5</sub>  | 0.23            |
| Cr <sub>2</sub> O <sub>3</sub> | 0.051           |
| ZnO                            | 0.001           |
| NiO                            | 0.003           |
| CuO                            | 0.008           |

149

150 Table 4b Chemical Composition of synthetic zeolite

151

| Chemical composition           | Percentage composition |
|--------------------------------|------------------------|
| SiO <sub>2</sub>               | 65.25                  |
| Fe <sub>2</sub> O <sub>3</sub> | 4.77                   |
| Al <sub>2</sub> O <sub>3</sub> | 17.89                  |
| CaO                            | 0.92                   |
| MgO                            | 0.44                   |
| K <sub>2</sub> O               | 0.04                   |
| TiO <sub>2</sub>               | 3.02                   |
| CaO                            | 0.09                   |
| MnO                            | 0.041                  |
| V <sub>2</sub> O <sub>5</sub>  | 0.11                   |
| Cr <sub>2</sub> O <sub>3</sub> | 0.064                  |
| ZnO                            | 0.002                  |
| NiO                            | 0.004                  |
| CuO                            | 0.006                  |
| Na <sub>2</sub> O              | 0.745                  |
| Si/Al                          | 3.647                  |

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153 It was observed from table 4b that synthetic zeolite had an increased Silicon Oxide content of  
 154 65.25wt% against 57.41wt% earlier observed in raw clay as shown in table 4a, indicating a

7.84wt% increase. The increase in silicon oxide could be attributed to the effect of chemical treatment. The chemical treatment also resulted to the removal of some fraction of the alumina content as observed from table 4b with alumina content (17.89 wt %) against (33.67 wt %) present in raw clay as shown in table 4a.

#### **Scanning Electron Microscope (SEM)**

The SEM analysis of the clay indicates coarse and loosely packs with some well formed flakes and irregular and hexagonal edges (Kaolinites). Others appear as plates of variable thickness and size with relatively well defined edges (Illites) or showing some elements of curling layers in the particles (Smectite). Chlorites appeared as inter-relating platy particles with well defined sub-angular borders. Vermiculite manifested that the reference clay micrographs in the form of aggregate of very small particles with curled edges.

Although the preliminary study by [13] suggested that clay minerals could be characterized and identified by exploiting their morphological features (using as many as possible clay minerals as standards to cover a range of morphological features).

As shown in fig 1a, the image showed moderately ordered flakes, with poorly developed hexagonal outlines. Psuedohexagonal morphology is suggested, hence the edges of the particles are beveled, somewhat ragged and irregular which is very similar to an observation earlier reported by [4].

From fig 1b, it was observed that larger pores of different shapes appeared for scanning electron microscope of synthetic zeolite. This could be attributed to the effect of the chemical treatment that caused a serious morphological change and did enormous harm to the surface of clay by removing some of the inorganic elements and therefore, increases the surface area and porosity of clay. This buttresses the report by [14] which states that chemical treatment increases the porosity of clay.



181

182 Fig 1a SEM analysis of ugwaka clay at 30μm

183



195 Fig 1b SEM analysis of synthetic zeolite at 200μm

#### 196 **Fourier Transform Infrared (FTIR) analysis results**

197 The chemical structure of the zeolite is of vital importance in understanding its  
 198 application. The FTIR technique is an important tool to identify the characteristic functional  
 199 groups, which are instrumental in removal of aromatic compounds. FTIR studies of the

zeolite help in the identification of various forms of the minerals present in the clay. The coupled vibrations are appreciable due to the availability of various constituents [15].

The result of the FTIR spectrum for ugwaka clay and synthetic Zeolite is shown in Fig 2a and 2b respectively. It was seen that there were strongly structural modification on the clay sample that was calcined with sodium hydroxide which is different from the raw clay as can be seen from the figures.

The transmission level bands for both natural and Calcined clays are dissimilar. Comparing results, it is clear there were structural modifications on the clay sample after calcination. This result is in agreement with the findings reported by [16]

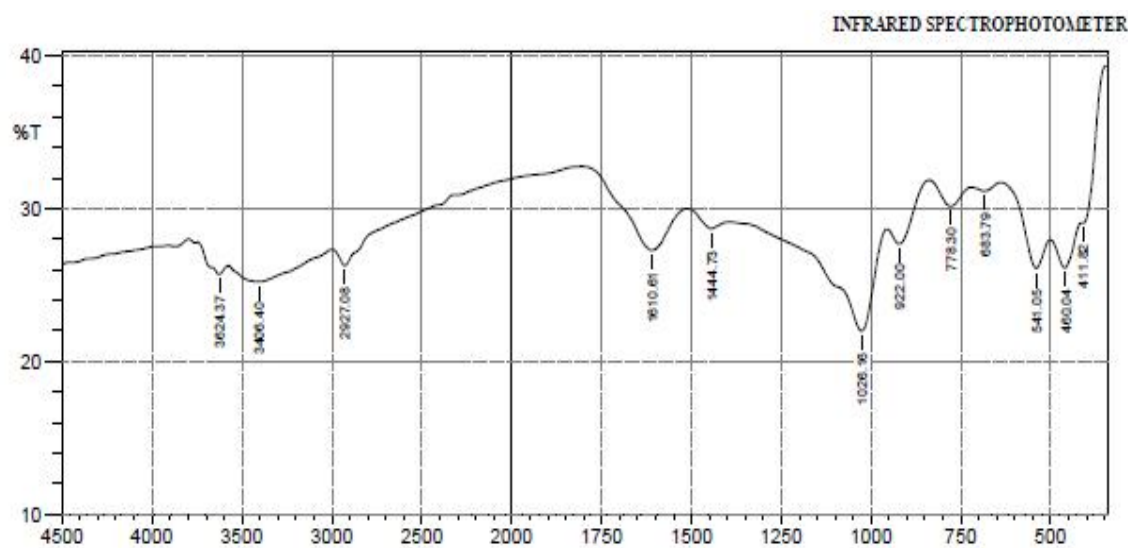


Fig 2a FTIR Spectrum of Ugwaka clay @30μm

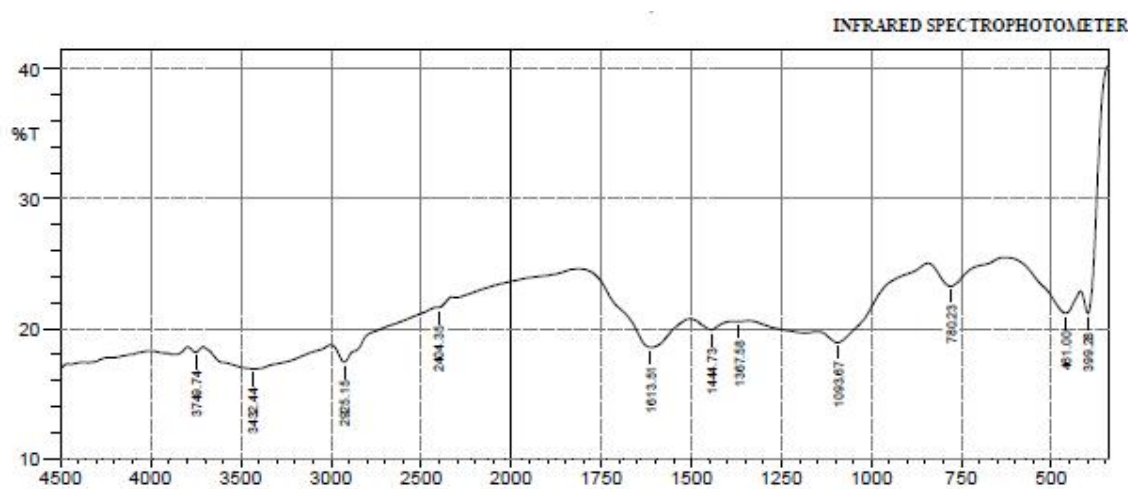


Fig 2b: FTIR Spectrum of Synthetic Zeolite @30μm

## Statistical analysis of the results for the synthetic zeolite production

The variables studied using Box-Benken experimental design were time (hours), sodium hydroxide concentration (M) and calcination temperature (°C). Box- Benken as discussed earlier was used to develop correlation between these selected operating variables and the percentage removed. The complete matrixes together with the response are shown in Table 2. The runs at the center points were used to estimate the quadratic terms in the model.

The ANOVA table is given in table 6, A significance of 5% was used, hence all terms whose P-value are less than 0.05 are considered significant. Therefore  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_1^2$ ,  $X_2^2$ , are significant

As shown in table 6, the regression F-value of 36.55 implies that the model is significant which is validated by the P-values been less than 0.0001 (<0.0001).

The final model equation in terms of coded factors is shown in equation 1:

$$\text{Yield of Synthetic zeolite(\%)} = 84.83 + 2.41X_1 + 7.57X_2 + 4.88X_3 + 1.39X_1X_3 - 1.14X_1^2 - 1.80X_2^2 \quad (1)$$

The final model equation in terms of the actual factor is shown in equation 2:

$$\text{Yield of synthetic zeolite (\%)} = 19.00804 - 0.98393\text{reaction time} + 19.84554 + \text{sodium hydroxide concentration} + 0.013562 \text{ calcination temperature} + 0.027750 \text{ reaction time , calcination temperature} - 2.12500E - 003 \text{ sodium hydroxide concentration*calcination temperature} - 4.54286 \text{ reaction time}^2 - 1.79821\text{sodium hydroxide concentration}^2 \quad (2)$$

The coefficient with one factor represent the effect of the particular factor, while the coefficients with two factors and those with second order terms represent the interaction between two factors and quadratic effect respectively [12].

In a regression equation, when an independent variables has a positive sign, it means that an increase in the variable will cause an increase in the response, while a negative sign will result a decrease in the response. Hence an increase in temperature, NaOH concentration and calcination temperature will cause an increase in the percentage adsorbed. NaOH concentration and calcination temperature will have more significant effect in the increment of the response since their coefficient were higher.

The test of adequacy of the regression models, significance of individuals of models coefficients and the lack of fit test were performed using the same statistical package.

The P-values were used as a tool to check the significance of each of the coefficients, which in turn are necessary to understand the pattern of the mutual interactions between the process variable

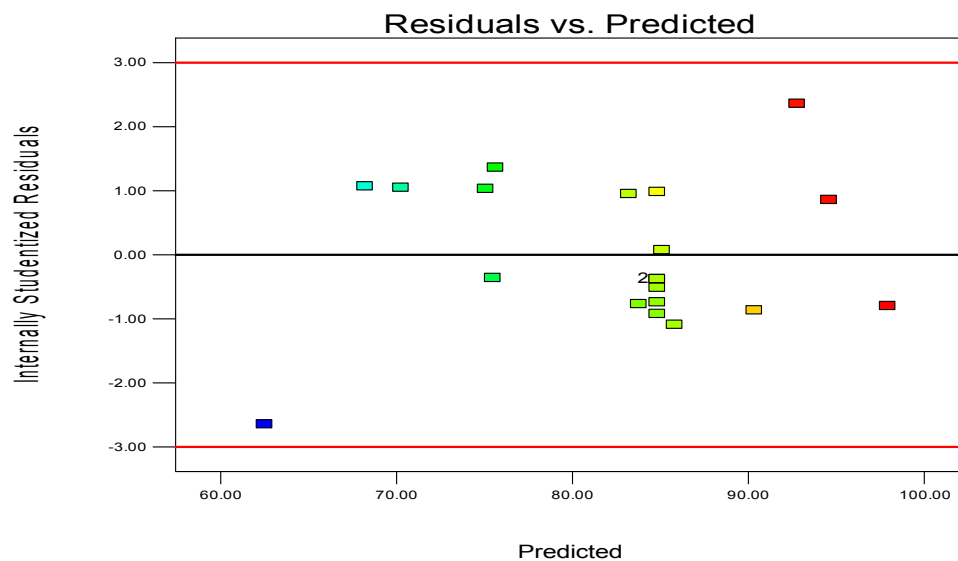
**Table 6: Analysis of Variance (ANOVA)**

| Source                         | Sum of squares | Df | Mean square | F-Value | P-Value |
|--------------------------------|----------------|----|-------------|---------|---------|
| Model                          | 1619.44        | 7  | 231.34      | 36.55   | <0.0001 |
| X <sub>1</sub> - Reaction time | 102.64         | 1  | 102.64      | 16.21   | 0.0014  |
| X <sub>2</sub> -NaOH Conc      | 923.38         | 1  | 923.38      | 145.87  | <0.0001 |
| X <sub>3</sub> - Calc Temp     | 393.23         | 1  | 393.23      | 62.12   | <0.0001 |
| X <sub>1</sub> X <sub>3</sub>  | 16.20          | 1  | 16.20       | 2.56    | 0.1185  |
| X <sub>2</sub> X <sub>3</sub>  | 0.46           | 1  | 0.46        | 0.073   | 0.8012  |
| X <sub>1</sub> <sup>2</sup>    | 33.35          | 1  | 33.35       | 5.27    | 0.0280  |
| X <sub>2</sub> <sup>2</sup>    | 87.31          | 1  | 87.31       | 13.79   | 0.0019  |
| Residual                       | 64.36          | 12 | 6.33        | -       | -       |
| Lack of fit                    | 54.30          | 7  | 7.76        | 3.50    | 0.0935  |
| Pure error                     | 11.09          | 5  | 2.22        | -       | -       |
| Cor total                      | 1575.03        | 19 |             | -       | -       |

Statistical analysis obtained from the analysis of variance (ANOVA) for response surface quadratic model is shown in table 6. The value of “Prob>F” indicated that the model is significant which is desirable as it indicated that the terms in the model have a significant effect on the response. The P-value of 0.0001 indicated that there is only a 0.01% chance that a “model F – value” this large could occur due to noise.

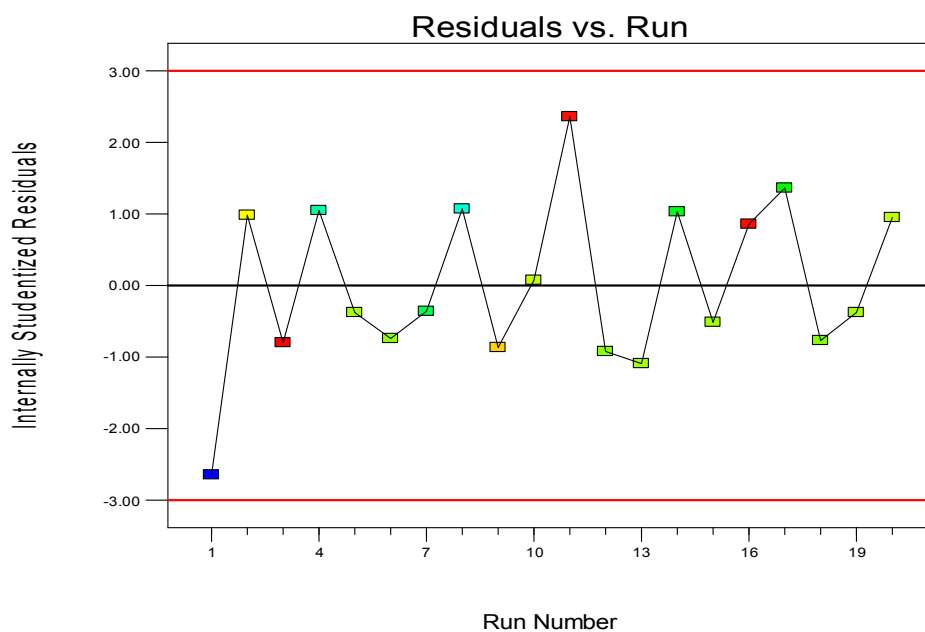
Generally P – value lower than 0.01 indicated that the model is considered to be statistically significant at the 99% confidence level [5]. Values of “Prob>F” less than 0.0500 indicated the model terms are significant. In this case, X<sub>1</sub>, X<sub>2</sub>, X<sub>1</sub><sup>2</sup>, X<sub>2</sub><sup>2</sup> are significant model terms.

The quality of the model developed was further assessed using residual plots. Residual is the difference between the experimental value and value predicted by the model. Some of the residual plots used were: plot of residual vs. predicted values which tests the assumption of constant variance, plot of residuals vs. run which checks for lurking variables that may have influenced the response during the experiment, normal plot of residuals which indicates whether the residuals follow a normal distribution, and plot of predicted vs. Actual response values which helps to detect a value, group of values that are not easily predicted by the model. The residual plots are shown in Figs. 4-7



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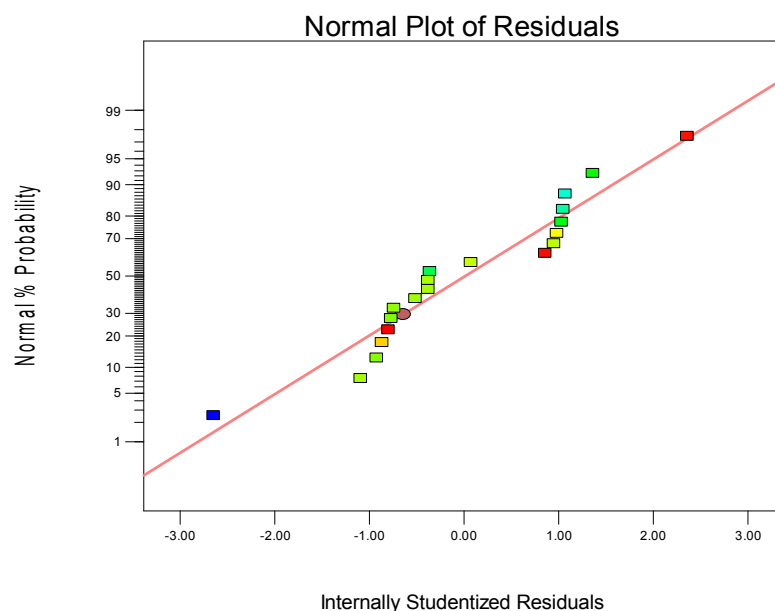
269 Fig 4: Plot of residual vs predicted for synthetic zeolite production



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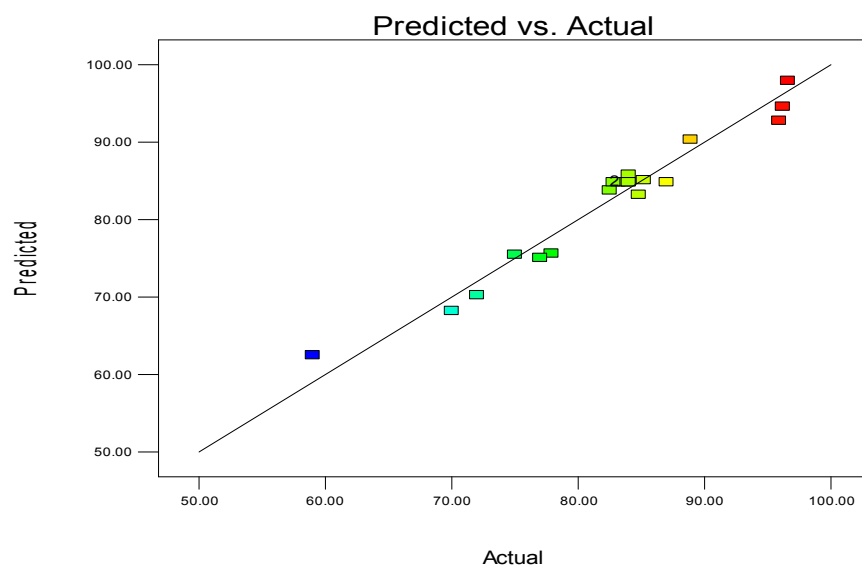
271 Fig 5: Plot of residuals vs experimental run for synthetic zeolite production

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274 Fig 6: Normal plot of residuals for synthetic zeolite production



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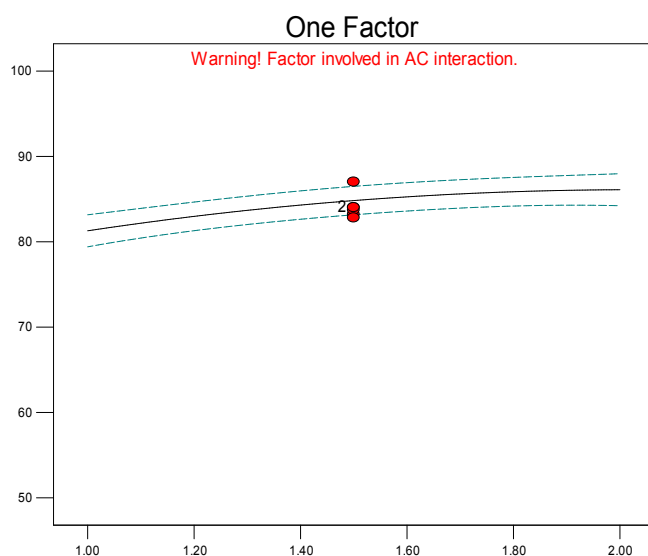
276 Fig 7: Plot of actual response vs predicted response for synthetic zeolite production

277

### 278 **Influence of individual factors**

279 The individual effect of Reaction time ( $X_1$ ), NaOH Concentration ( $X_2$ ), and Calcination  
 280 temperature ( $X_3$ ) were plotted in figs. 8(a-c) from the graph it showed that Reaction time  
 281 ( $X_1$ ), NaOH Concentration ( $X_2$ ), and Calcination temperature ( $X_3$ ) had effect on the

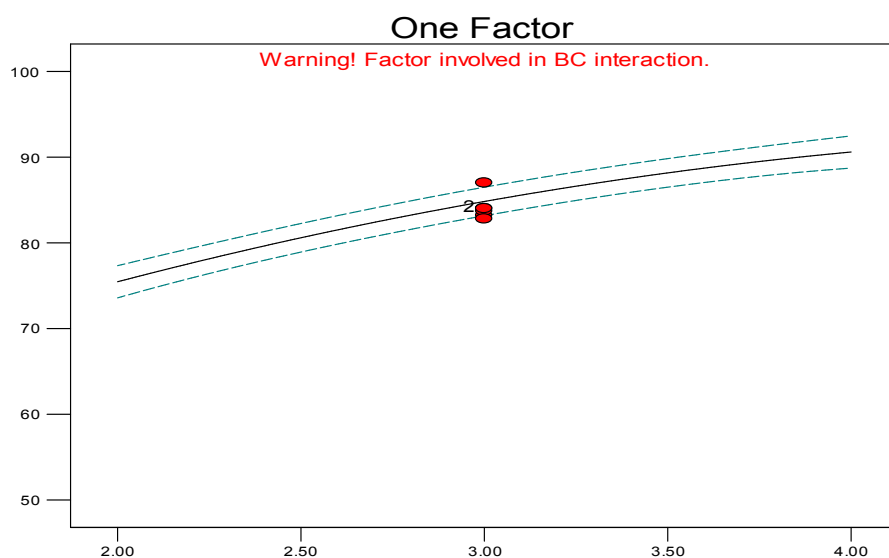
282 response. This meant that any increase or decrease on the factor will have an effect on the  
 283 response.



A: Reaction Time

284

285 Fig 8a; Effect of reaction time



B: NaOH

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287 Fig 8b; Effect of NaOH Concentration

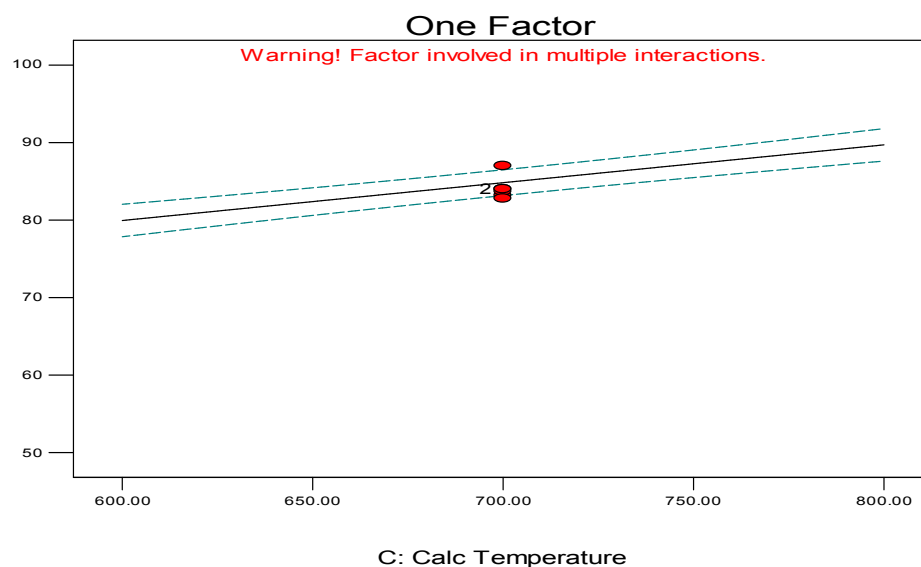


Fig 8c; Effect of Calcination temperature

### Process Optimization

In synthetic zeolite production from an indigenous alluminosilicate using response Surface Methodology, optimization was done using Design expert software **9.0.2.0** version. With the aim of maximizing the response, the condition that gave the highest desirability of 1 was selected. The Optimal yield of 92.03wt% was obtained using Reaction time of 2 hours, Calcination Temperature of 800°C and Sodium hydroxide concentration of 2.5M. These result showed an improvement in the production of synthetic zeolite when compared with the work reported by [19], where 90wt% yield of zeolite was recorded at concentration of 5M sodium hydroxide, temperature of 95°C after 24hours.

**Table 7: Validation of Optimum Conditions**

| Model desirability | Reaction Time (hrs) | Calcination Temperature (°C) | NaOH Concentration (M) | Percentage Yield |              |         |
|--------------------|---------------------|------------------------------|------------------------|------------------|--------------|---------|
|                    |                     |                              |                        | Predicted        | Experimental | % error |
| 1.0                | 2.0                 | 800                          | 2.5                    | 92.925           | 92.03        | 0.895   |

### Conclusion

A quadratic model was predicted, and diagnostics of the model revealed a strong correlation between the prediction and observed response values. Silica to Alumina ratio obtained after

XRF analysis of Zeolite produced showed that Ugwaka clay is a good source of synthetic zeolite. Also, increase in calcination temperature and concentration of sodium hydroxide had a significant effect on the yield of synthetic zeolite.

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