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Effective Communition Energy of Faya Clay, Using Determined Work Index (Modified Bond Energy Method)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The work index of Faya clay in Faya Village, Plateau State, Nigeria was determined for effective communition design using Berry and Bruce method. Samples of Faya clay were collected from three veins on the mine. The samples were homogenized, crushed and ground and further sampled using conning and quartering to obtain 5.0 kg representative fraction of the ore. 1.0 kg was used for composition study while 4.0 kg for experimental work. Azara barite from Nassarawa state, with work index 6.24 kwh/ton was used as the reference sample. The test and reference samples were subjected to sieve size analysis under the same condition to obtain 80% passing for both the mill feeds and products. The chemical analysis of test and reference samples shows that they both contain; SiO_2, K_2O, CaO, Fe_2O_3, TiO_2 and BaO as major oxides. This is an indication that Azara barite is a suitable reference sample for Faya clay. The mineral composition of Faya clay was determined by the use of the X-ray diffraction (XRD) analysis. The major mineral phases in the clay sample are 61.7% wt. quartz (SiO_2) 28.59% wt. dickite (Al_2 Si_2O_5 (OH)). 8.89% wt. geothite (FeO $(OH)_4$) and 0.83% wt. muscovite ($K_{0.92}$ $Na_{0.08}$) ($Al_{1.86}$ $Fe_{0.07}$ $Ti_{0.02}$) ($Si_{3.03}$ $Al_{0.97}$) $0_{10}(OH)_2$, at 2θ. The SEM/EDS revealed that the dominant elements in the clay are oxygen with average weight

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composition of 43.75% wt. at 60 µm and 45.78 % wt. at 6 µm and silicon with 21.24% wt. at 60 µm and 27.58% wt. at 6 µm. The result of the particle size analyses of the mill feeds and products of milling indicated that 80% passing and retained as obtained from the semi-log plots were 180 µm and 125 µm for the test sample, and 250 µm and 180 µm for the reference sample. The results were validated by calculation using the Guadin- schuhman logarithm equation (log-log plots) and were in agreement with those of the semi-log plots. The value of the work index of the test sample (Faya clay) was found to be 4.83 kwh/ton. This is in line with the SEM/EDS result, indicating that Faya clay has large grains, requiring little energy to dissociate the gangue from the mineral of interest.

Keywords: Faya clay; work index; reference sample; mill feed; communition; test sample.

1. INTRODUCTION

Bentonite clay is an absorbent aluminium phyllosilicate, generally impure clay consisting mostly of montmorillonite. It was named by Wilbur C. Knight in 1898 after the Cretaceous Benton Shale near Rock River, Wyoming [1] (Abdullah et al*.,* 2007). The different types of clays are each named after the respective dominant element, such as potassium (K), sodium (Na), calcium (Ca), and aluminium (Al). The presence of these element influences the properties of the clay as well as its applications [2,3]. Montmorillonite (Na,Ca)O, 3(Al,Mg)2 Si_4O_{10} $(OH)_2$. n(H_2O),on the other hand is a 3-layered clay made up of an octahedral sheet sandwiched between two tetrahedral sheets. The space between the units is large and occupied by exchangeable cations and large amounts of water which account for its greater swelling capacity [4] (Carlson, 2006). The plates glide past each other more easily than in kaolinite hence the greater plasticity of montmorillonite. Montmorillonite also has a higher cation exchange capacity than kaolinite [5]. Reserves of Bentonitic clays have been identified in Plateau state, Edo state, Adamawa state, and Borno state (NGSA, 2010).

Faya is an area in Langtang South Local Government area of Plateau State, Langtang South as shown in Fig. 2.1 is a Local Government Area in Plateau State, Nigeria. Its headquarters is Mabudi Town. It has an estimated area of 838 km² and a population of 106,305 at the 2006 census *(Alexander, 2005)*, with a postal code of the area is 941. Plateau State is located in Nigeria's middle belt, with an area of 26,899 square kilometers, the State has an estimated population of about three million people. It is located between latitude 80°24'N and longitude 80°32' and 100°38' East. Bare rocks are scattered across the grasslands, which cover the Plateau [6,7,8].

Faya clay cannot be used directly in its lumps size. It has to subjected comminution operations to ensure that the valuable constituents are physically liberated from the waste constituents before physical or chemical separations are attempted. One of the greatest challenges faced by the Mineral Engineers, is the efficient design and operation of industrial comminution circuits. This is traceable to the fact that energy intensive comminution operations use on the order of 50% of a mineral processing plant's operating costs and often carry and even larger percentage of the capital cost, tag for a plant (Maurice, 2003). It has been generally observed that in the process of size reduction, as the size of particles diminishes, the surface area of particles increases, and breakage resistance increases as well.

1.1 Determination of Work Index Using Modified Bond's Method

The modified Bond Ball relationship was adopted to determine the Work Index of the test sample (Faya clay). The relationship is given by.

$$W_r = W_t = W_{it}\left(\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}\right) = W_{it}\left(\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}\right) \quad (1)$$

$$\text{Therefore, } W_{it} = W_{ir}\left(\frac{\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}}{\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}}\right) \quad (2)$$

Hence, it is fundamental to establish the energy requirement for a desired size reduction, which would result to a change in surface area [9,10]. The work index of a mineral is the energy in kwhr/t, required to comminute it from an infinite size to 80% passing 100µm [10,11] (Wills, 2007).

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Representative samples of Faya clay was collected from Faya in Langtang South Local Government area of Plateau State. A total of 25

kg sample was sourced each from three different veins. The sourced samples were homogenized to form the head sample. It was further crushed with laboratory crusher (A-H206 Atico) and ground using ball mill model X509 Shambavi impact, facility of the Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna. Nigeria. The crushed and ground sample was further sampled using conning and quartering sampling method, to obtain 5.0 kg representative fraction of the clay. 1.0 kg of the head sample was taken to the laboratory for compositional study.

2.2 Characterization of the Sample Collected

Faya clay was characterized using X – ray fluorescence (XRF), X – ray diffractometer (XRD) and Scanning Electron Microscopy with Energy Dispersive Spectrometer (SEM/EDS).

2.3 Chemical Characterization of Faya Clay Sample

The lab –X3 503 ICI model XRF, a facility of Nigeria Geological Survey Agency (NGSA) Kaduna was used for the analysis. The sample was pulverized (ground to fine powder) approximately 75 µm, packed and labelled. 15 g of the prepared sample was weighed each into a sample cup and placed in their respective measuring position on the sample changer. The set up was allowed to run until the wavelength – dispersive spectroscopy provides for elemental identification.

2.4 Mineralogical Characterization of Faya Clay

Mineralogical composition analysis of as received Faya clay sample was carried out using, XRD 6000 Shimadzu XRD instrument of Nigerian Geological Survey Agency (NGSA) Kaduna. A representative fraction of the sample of Faya clay was ground to a fine powder of about 75 µm (75µm/0.029 mesh). A standard (silicon standard) was also ground to the same size.The powder was charged into milled well on aluminum holder and press with glass slide to cause the powder to stick well. It was then labeled or marked. It was then introduced into the XRD machine to identity the electronic output. The calibration of the XRD machine was checked with silicon (Si) standard and the silicon standard peak adequately scanned, before starting the operation.

2.5 SEM/EDX Analysis

The sample of Faya Bentonite was completely dried in a drying oven at 60°C for three hours and left overnight in the oven. The sample was placed on the aluminium holder stub using a double sticking carbon tape. It was ensured that the values of the two nitrogen gas tanks were open thereby ensuring enough supply of nitrogen. The vent button located at the display panel of the microscope table was pressed. The Z axis down arrow key was pressed down to move the sample mounting stage and EVAC button pressed. The sample was allowed for 2 minutes until a green light display was allowed. It was further allowed for 30-45 minutes to achieve high vacuum ($<5 \times 10^{-5}$ pa).

2.6 Particle Size Analysis for Test and Reference Ore

i. Both the test and reference ores were ground to about 100% passing 500µm sieve.
ii. 200 g each of the ground samples was sized between 500, 355, 250, 180, 125, 90, 63, 45, and 32µm respectively.
iii. The weights retained on each sieve was recorded.
iv. A spread sheet was prepared for the size analysis to determine 80% passing for both the test and reference samples.
v. The feed to the milling process for both the test and reference samples was subjected to size analysis and 80% passing was determined as well.
vi. Equation i and ii was then used for calculate the work index and the energy used in comminuting the or to its liberation size.

3. RESULTS AND DISCUSSION

3.1 Chemical Characterization of the Test and Reference Ore

Table 1 represents the results of chemical analysis of the test sample (Faya clay), and reference sample (Azara Barite). From the table, Faya clay contains 26.6% Al_20_3, 56.6% SiO_2, 0.084% CaO, 0.349% K_2O, 9.133% Fe_2O_3 and 3.87% BaO. In the same vain the reference

sample contains, 11.0% SiO_2, 0.068% CaO, 0.05%K_2O, 1.78% Fe_2O_3 and 62.09% BaO. Other components similar to both clays include Ag_2O, Cuo and Ti. These results are in comparable with other chemical compositions of clay minerals. This therefore gives a good justification for selection of reference sample.

3.2 Mineralogical Characterization of Faya Clay Using XRD

Fig. 1 presents the XRD pattern of Faya clay, indicating the major diffraction peaks of the minerals in the clay, the major compounds found, there appearance in the clay and corresponding chemical formulae. Fig. 1 further shows result of mineralogical analysis of Faya clay. The main minerals found at 2Θ error in the clay are Quartz (61.70%), Dickite (28.59%), Geothite (8.89%) and Muscovite (0.83%). Hence, Faya clay is more of Quartz (SiO_2) and Dickite (Aluminium phylosilicate $Al_2SiO_2O_5$ (oH_4).

Table 2 present the results of the particles size analysis of the test and reference ore. The 80% passing for both feeds and products of the test sample (Faya clay), and reference sample (Azara Barite) obtained from the semi - log plot of the size analysis where found to be 180 µm and 125 µm (test sample) and 250 µm and 180 µm (reference sample).

Table 1. Result of chemical composition of the head sample of faya clay

S/N	COMPOUND	FAYA CLAY	AZARA BARITE
1	Al_2O_3	16.6	-
2	SiO_2	35.6	11.0
3	SO_3	0.56	22.1
4	K_2O	0.559	0.051
5	CaO	0.084	0.068
6	TiO_2	0.912	1.85
7	MnO	0.051	-
8	Fe_2O_3	6.133	1.78
9	CuO	0.022	0.044
1	Ag_2O	0.737	0.862
11	BaO	38.7	62.09
12	CeO_2	0.02	-
13	Eu_2O_3	0.02	-
14	Ga_2O_3	-	0.02
15	OsO_4	-	0.07

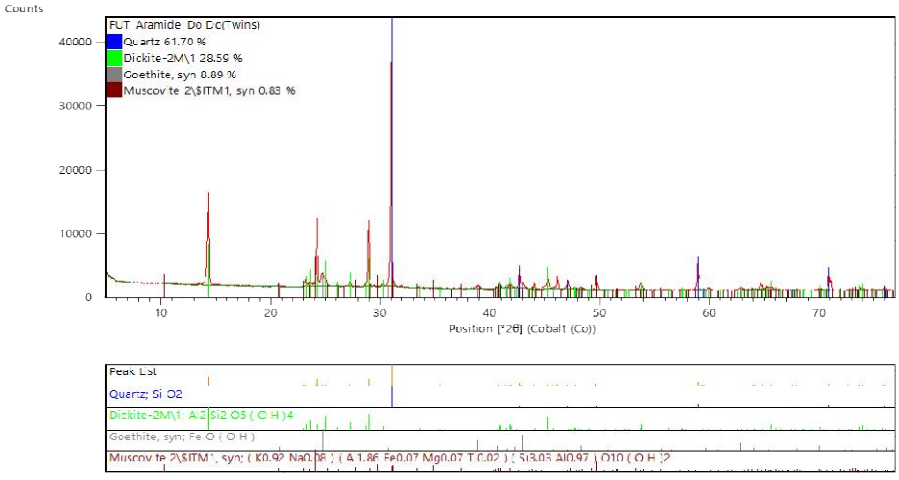

Fig. 1. XRD Analysis of Faya clay sample

Plate 1 and 2 present the results of surface morphology of Faya clay head sample. The result shows that Faya clay has large grains within the matrix of inclusion. The EDX peaks of spectrums of the clay reveals that the dominant elements are oxygen and silicon, followed by Aluminium and iron at 6 and 60um respectively (Fig. 2 a and b). The weight percent abundance of dominant elements in the clay for spectrums at 60µm and 6µm, reveals 49.8% oxygen and 33.15% silicon. The percent composition at 6µm, indicates 40.42% oxygen and 44.7% silicon (Table 3 and 4). The result agrees with the XRD result which revealed silica.

($Si0_2$) as the predominant mineral in the sample with percent composition of 61.7% wt quartz in the form of silica ($Si0_2$).

Table 2 and Fig. 3 presents the result of particle size analysis of both reference sample (Barite) and test sample (Faya clay).

The value of 80%passing for feeds and products for both reference and test sample were obtained using the semi-log plots and calculated using the Gaudin-Schuhman logarithm equation for validity and reliability (Figs. 3-6). The value of the work index of the reference sample (6.24Kwh/ton) and 80% passing 100µm of both the reference sample and test sample determined were used to determine the work index of Faya clay from modified Bond's method.

3.3 Determination of Work Index (W_{it}) and Energy (W_t) used to Comminute Faya Clay

From the relationship from equation 1 and 2 and Figs. 3 – 6 ;

For Product of Test Sample (Faya Clay)

Using Gaudin-Schuman's plot (Fig. 3)

Considering points 710, 98.5 and 90, 53

x_2 y_2 x_1 y_1

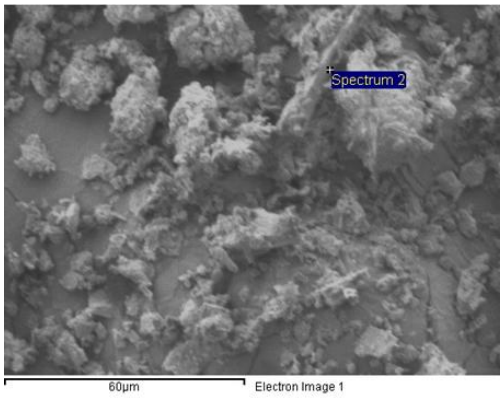

Plate 1. Spectrum at 60µm

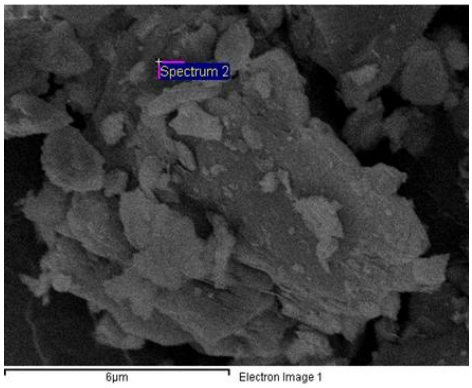

Plate 2. Spectrum at 6µm

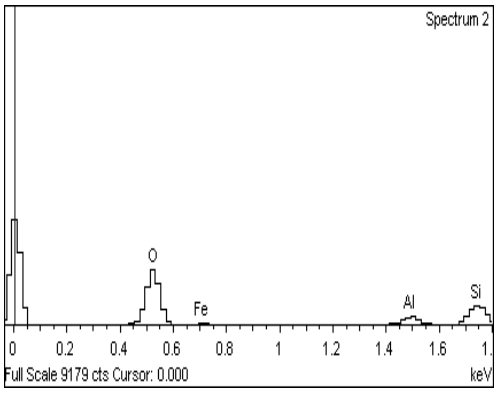

Fig. 2a. EDX peaks of spectrum 2 at 60µm

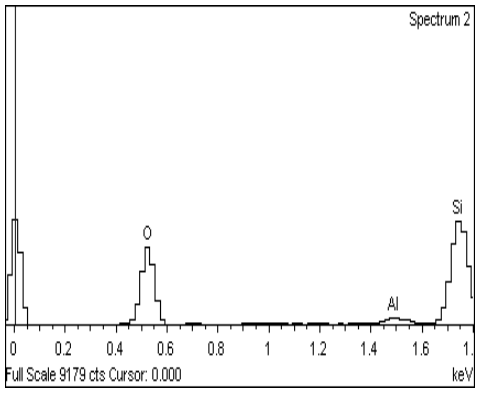

Fig. 2b. EDX peaks of spectrum 2 at 6µm

Table 2. Result of sieve size analysis of mill feeds and products of milling for both test and reference sample

Sieve size (um)	Mill feed cumulative under size		Product of milling cumulative % under size	
	Test sample	Reference sample	Test sample	Reference sample
500	99.7499	99.8999	99.8999	99.4975
355	99.1980	98.9990	98.4598	99.2965
250	98.4963	97.9980	94.9950	97.9960
180	96.9924	97.4975	91.9920	94.9749
125	82.4561	89.9899	87.9880	87.9397
90	49.3734	65.9659	82.9830	73.8693
63	26.3158	35.9359	61.9619	40.7003
45	21.3033	26.9269	52.9529	31.6583
32	13.2830	13.9139	33.9339	18.5930
-32	00.0000	00.0000	00.0000	00.0000
Pan				

Table 3. Analysis of spectrum 2 at 60µm

Element	Weight%	Atomic%
O K	49.24	63.13
Al K	2.06	1.56
Si K	44.70	32.65
P K	4.01	2.65
Total	100.00	

Table 4. Analysis of spectrum 2 at 6µm

Element	Weight%	Atomic%
O K	49.86	65.17
Al K	9.43	7.31
Si K	33.15	24.69
Fe L	7.56	2.83
Total	100.00	

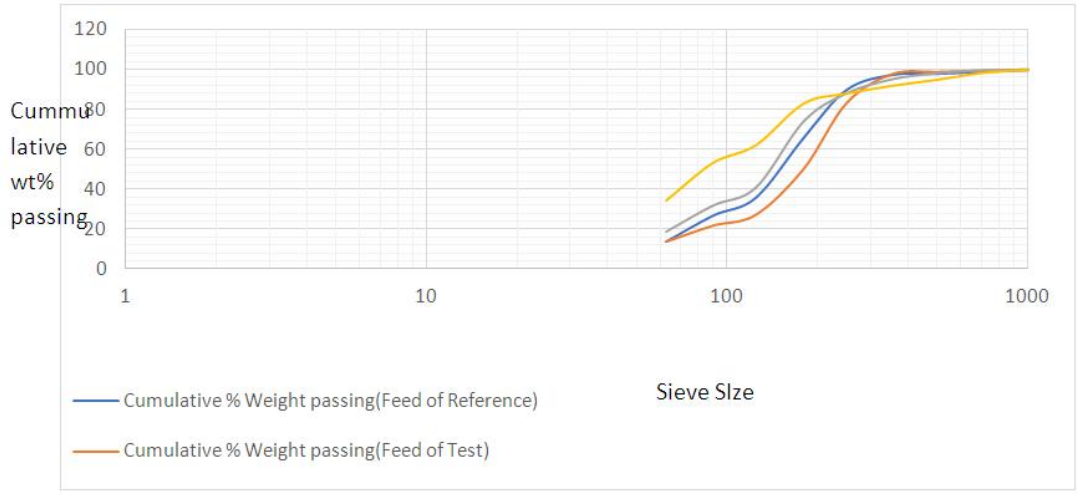

Fig. 3. PDS lines for test and reference sample

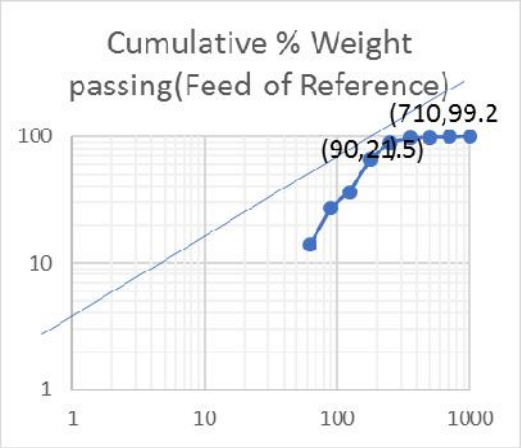

Fig. 3. Guadin Shuman's plot for feed of reference sample

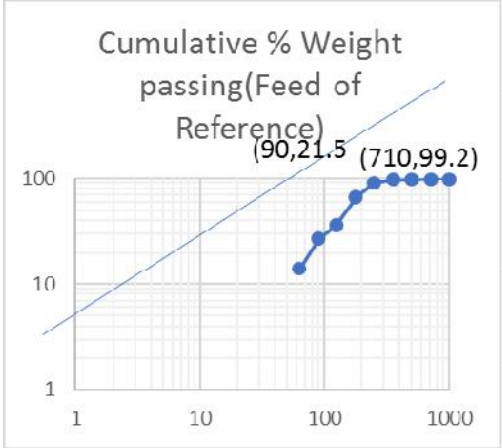

Fig. 4. Guadin Shuman's plot for feed of test sample

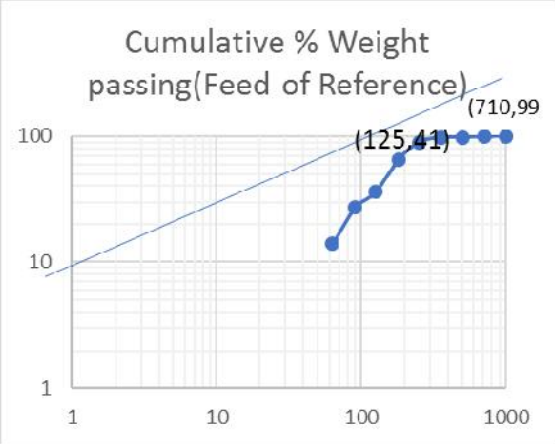

Fig. 5. Guadin Shuman's plot for product of reference sample

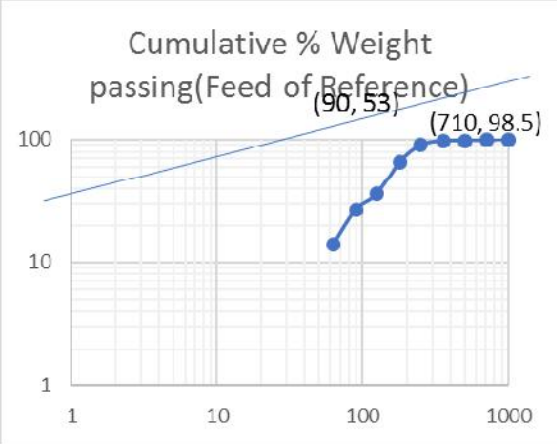

Fig. 6. Guadin Shuman's plot for product of test sample

$$S = \frac{\log y2 - \log y1}{\log x2 - \log x1} \quad (3)$$

$$S = \frac{\log 98.5 - \log 53}{\log 710 - \log 90}$$

$$S = \frac{1.9934 - 1.7243}{2.8513 - 1.9542} = \frac{0.2691}{0.8971}$$

$$\text{Slope} = 0.3000$$

$C = 18.8$ ∴ log 18.8 = 1.274

∴ from Y=mx + c

∴ for 80% passing

Log 80 = 0.3 log x + 1.274

1.9031 = 0.3 log x + 1.274

$$\frac{1.9031 - 1.274}{0.3} = \log x$$

$$\frac{0.6291}{0.3} = \log x$$

X = $\log^{-1}$ 2.097

X = 125.025

Product of Test sample P_t = 125μm

Using the same calculation in Figs. 3 – 6

Product of reference ore P_r = 180 µm

Feed to test sample F_t = 180 µm, and

Feed to reference ore F_r = 250 µm

Work index of reference ore = 6.24 KWh/ton

Therefore work index of test ore = W_{it} = 4.83 KWh/ton

While energy used calculated to be = 1.781 KWh

Therefore the value of the work index determined was found to be 4.83Kwh/ton. This implies about 4.83 Kilowatts hour of energy is required to grind the clay from infinite size to 80% passing 100 microns in line with Bonds work index using energy value of 1.781 KWh. The work index obtained applies to particle size in the range of 500µm to -32µm.The result obtained when compared with other clays, lies favorably within the work indices and energy used of clay minerals.

4. CONCLUSION

i. Faya clay contains, 16.6% Al_2O_3, 35.6% SiO_2, 6.133% fe_2O_3, 0.912% TiO_2, 0.559% K_2O, 0.084% CaO, and 38.7% BaO. Other compounds in traces are: Eu_2O_3, CeO_2, CuO, Ag_2O and SO_3.

ii. Azara barite with work index 6.24 Kwh/ton is a suitable reference sample for the determination of work index of Faya clay using modified Bond's method.

iii. Faya clay is predominantly aluminum phyllosilicate in the form of Dickite ($Al_2Si_2O_5(OH)$) 28.59% with a considerable amount of quartz (SiO_2), 61.70%.

iv. Work index and Energy required to grind Faya clay using ball mill from an infinite size to 80% passing 100 microns is 4.83Kwh/ton and 1.781 KWh respectively.

It is therefore expected and strongly recommended that that the work index and energy requirement (4.83Kwh/ton, 1.781 KWh) respectively, will aid the design of communition plant for beneficiation of Faya clay and hereby recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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