Nigerian Journal of Technology
Vol. 40, No. 3, May, 2021, pp. 387–392.
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v40i3.5

Determination of Work Index of Filin Kokuwa Gold Deposit in Toro Local Government, Bauchi State Nigeria

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Abstract

This report shows the work index of Filin Kokuwa Gold ore sample in Bauchi State, Nigeria. The "reference sample (granites)" were sourced from outcrops of granites around Toro town. The samples were crushed, ground, and pulverized using appropriate laboratory milling machine. 80% passing size for the gold ore and granites samples were obtained at 100μm sieve size for the ball mill feeds and products respectively. The work indexes of reference samples i.e. granites were used to calculate the work index of the Filin Kokuwa gold ore sample. The values of 13.277kWh/ton and 15.192kWh/ton were obtained respectively for the two different reference granites samples used and 14.21kWh/ton as their average which is the value of the work index of the Filin Kokuwa gold ore deposit. The energy required for grinding the ore was found to be 3.581kW.

Keywords: work index, gold ore, granites, comminution, modified bond's

1. INTRODUCTION

Nigeria is one of the most endowed countries in the world with a lot of minerals reserve. The vast reserve of mineral resources in Nigeria are sufficient enough without need for raw materials importation. Minerals that are known to exist in commercial quantities in Nigeria include iron ore, cassiterite, columbite, tantalite, titanium, rutile, feldspar, gold, limestone, lead, zinc, uranium, quartz and mineral fuel like coal etc [1, 2]. These industrial minerals cut across the entire states of the country.

Four gold fields, encompassing the main producing area, can be defined in the western province basement; Ilesha-Egbe, Minna Birnin-Gwari, Sokoto, and Yelwa [3]. All are generally associated with the schist belts although gold-quartz veins also occur in gneisses (e.g. Malele, Diko, and Iperindo gold mines). The Iperindo mineralization comprises a series of auriferous quartz-carbonate veins localized by a subsidiary fault within biotite gneiss and mica schist, presently defined by subparallel old workings extending overall for about 9 meters in the NNE direction. Gold quartz veins are generally conformable with the North-South to North North East-South South West structural grain of basement rocks. The schist belts of Nigeria are hosts to many mineral deposits.

Precambrian rocks within and around Maru Schist belt host some quartz veins that are gold bearing. The gold deposits were heavily mined during the colonial era approximately before 1960 and after that period by artisanal miners. General descriptive information on gold mineralization in Maru schist belt has been documented [4–6]. Gold occurs primarily in quartz veins and as placers in soil (eluvial) and stream sediments (alluvial). The quartz veins containing gold occur in association with metamorphosed rocks ranging in composition from semi-pelitic to pelitic and mafic. Primary gold mineralization produced chemical signature in the overburden and surrounding soil probably through weathering processes. Weathering processes provide samples (soils and stream sediments) that yield data on local hidden mineralization or on the potential existence of major or minor mineralization in a wide region. The residual soil is the geochemical sample that is often used to detect the location of hidden mineralization once a zone of economic interest is localized [7].

Gold production in Nigeria is believed to have started in 1913 and got to its peak from 1933-1943 [8]. Gold occurs with pyrite, pyrrhotite and minor chalcopyrite, galena, sphalerite, magnetite and ilmenite [9, 10].

1.1. *Theoretical Consideration for Comminution Process (Work Index)*

The modified Bond's equation called Berry and Bruce comparative Bond's equation is what was used to ascertain the work index of the ore. Work

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index is the comminution parameter which expresses the resistance of material to crushing and grinding; it is the kilowatt hour per short-ton required to reduce the material from theoretically infinite feed size to 80% passing 100 μm [2, 11]. Table 1 gives the work index of some minerals ores samples.

Table 1: Work index of some minerals ores samples.

Material	Work index	Material	Work index
Barite	4.28 – 6.24	Fluorspar	2.98 – 9.76
Bauxite	2.38 – 9.45	Granite	2.68 – 15.13
Coal	1.63 – 11.37	Graphite	1.75 – 45.03
Dolomite	2.82 – 11.27	Limestone	2.69 – 11.61
Emery	3.48 – 58.18	Quartzite	2.71 – 17.4
Columbite	3.94 – 10.81	Titanium ore	4.23 – 11.88
Tantalite	3.6 — 11.90	Silica sand	2.65 – 16.46
Gold Ore	3 – 42	Silver Ore	13 – 22

Sources: [1, 2, 11–13]

The work index of an ore can be determined by using Berry and Bruce method developed in (1966) also known as modified Bond's equation, which is a comparative method of determining ore grindability. The method requires the use of a reference sample of known work index. Work index is the energy required in kWh/short-ton to reduce a given material from theoretically infinite size to 80% passing size, 100 microns [2, 14]. The reference ore is ground for a certain time (T) in a laboratory tumbling mill and an identical weight of the test ore is then ground for the same time. Since the power input to the mill is constant (P), the energy input Eq. (1) is the same for both reference and test ore. If r is the reference ore and t the ore under test, then we can determine it from Bond's Equation which is written as [11]:

$$(E = P \times T) \tag{1}$$

$$W = 10 \times Wi\left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) \tag{2}$$

$$\begin{aligned} Wr = Wt &= Wi_r\left[\frac{10}{\sqrt{P_{80r}}} - \frac{10}{\sqrt{F_{80r}}}\right] \\ &= Wi_t\left[\frac{10}{\sqrt{P_{80t}}} - \frac{10}{\sqrt{F_{80t}}}\right] \end{aligned} \tag{3}$$

therefore

$$Wi_t = Wi_r \frac{\left[\frac{10}{\sqrt{P_{80r}}} - \frac{10}{\sqrt{F_{80r}}}\right]}{\left[\frac{10}{\sqrt{P_{80t}}} - \frac{10}{\sqrt{F_{80t}}}\right]} \tag{4}$$

where Wr = Work input of reference sample; Wt = Work input of test ore; Wi_r = Work index of reference sample; Wi_t = Work index of test ore P_{80r} = 80% of discharge reference sample passes; P_{80t} = 80% of discharged test ore passes; F_{80r} = 80% of feed reference sample passes; F_{80t} = 80% of feed test ore passes.

1.2. Literature Review

The work index expresses the resistance of the material to grinding. It represents the kilowatt hours per tonne required to reduce the material from theoretically infinite feed size to 80 percent passing 100μm [15]. Bond devised several methods for predicting ball-mill and rod-mill energy requirements and provided an accurate measure of ore grindability [16]. The standard Bond test requires constant screening out of undersized material in a closed-circuit operation. The standard Bond experiment has been applied for the determination of Bond work indices of several minerals by different researchers [17–19].

Egbe et al. [20] adopted Bond's equation to determine the work index of Baban-Tsauni (Nigeria) Lead-Gold ore. The bond work index of Baban-Tsauni lead-gold ore was found to be 11.52 kW.h/ton. Oladunni et al. [2] worked on Gyel-Bukuru columbite work index using modified Bond's equation, it was discovered that Gyel-Bukuru has an average work index of 3.07 kW.h/ton. Adeoti et al. [21] determined the work index of Saman-Burkono graphite using modified bond's method and found the work index to be 11.047kWh/short ton. In the same vain, Adetula et al. [22] using Modified Bond's Index Equation to determine the work index of Iperindo lode gold deposit. The work index was determined to be 11.92 kW.h/ton. This research is aimed at determining the work index of Filin Kokuwa Gold ore, using granite with known work index as reference sample, through modified Bond's equation.

2. MATERIALS AND METHOD

2.1. Materials

Fifty kilograms (50 kg) of the alluvial ore sample used in this research was obtained from Filin Kokuwa Gold deposit mined at various pits 7 meters apart. This location is about seven (7) kilometres off Bauchi-Jos express road. The granite samples used as reference samples were sourced from granite outcrops around Toro Local Government Area.

2.2. Method

The sample of the test ore (Gold sample) was crushed manually with a sledge hammer to provide required size acceptable as feed to the Denver laboratory jaw crusher. The sample was crushed and ground, part of the ground sample was weighed for sieve analysis. The modified Bond's method of determining the net-work index of ore involves use of reference sample of which grindability is known. The procedure is as follows;

1. 100 g each of samples of the ore under test and the reference ore were crushed and ground in the laboratory mill machine for an hour,
2. The samples of test ore and reference sample were taken and sized by sieving into a number of size fractions using the automatic sieve shaker for 15 minutes.

Table 2: Sieve analysis of crude sample of Filin Kokuwa gold ore (feed to the ball mill).

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	9.28	9.281	9.281	90.719
-1000 +600	5.93	5.931	15.212	84.788
-600 +500	8.33	8.331	23.543	76.457
-500 +350	17	17.001	40.544	59.456
-350 +210	13.43	13.431	53.975	46.025
-210 +180	12.98	12.981	66.956	33.044
-180 +125	2.99	2.99	69.946	30.054
-125 +90	10.7	10.701	80.647	19.353
-90 +63	4.01	4.011	84.658	15.342
-63	15.34	15.342	100	
Total	99.99	100		

Table 3: Sieve analysis of granite 1 sample feed to the ball mill.

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	12.48	12.514	12.514	87.486
-1000 +600	8.35	8.373	20.887	79.113
-600 +500	9.65	9.676	30.563	69.437
-500 +350	17.26	17.307	47.87	52.13
-350 +210	11.78	11.812	59.682	40.318
-210 +180	11.88	11.912	71.594	28.406
-180 +125	2.76	2.767	74.361	25.639
-125 +90	8.93	8.954	83.315	16.685
-90 +63	3.44	3.449	86.764	13.236
-63 13.2	13.236	100		
Total	99.73	100		

3. Each size fractions of the test ore and the reference sample were weighed and the value noted as "feed".
4. The "feed" test ore and reference sample were each gathered together and introduced into the Laboratory ball milling machine and ground for 1 hour.
5. The test ore and the reference sample from the laboratory ball mill machine were sized and each sieve fraction was weighed and the value noted as the discharge or product [9].
6. Sieve analysis was done, the ground samples were sieved into the following sieve size fractions; +1000 μm, -1000 + 600 μm, -600 + 500 μm, -500 + 350 μm, -350 + 210 μm, -210 + 180 μm, -180 + 125 μm, -125 + 90 μm, -90 + 63 μm, -63 μm using Denver automatic sieve shaker for 15 minutes.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Test Ore (Filin Kokuwa Gold)/References (Granites 1 and 2) samples as Feeds to the Ball Mill

Table 2 gives the sieve analysis result of the feed to ball mill of test ore (gold ore).

Calculation using the values in Table 2.

If 710 μm = 84.788

Then X = 80% Using Gaudin Schumann Expression

$$P(X) = 100[X/K]^a \tag{5}$$

$$a = \frac{[\log P(X_2) - P(X_1)]}{\log(X_2) - (X_1)} \tag{6}$$

$$\text{Size}_2 = \frac{(\text{Percentage passing size}_2)^2}{(\text{Percentage passing size}_1)^2} \times \text{size}_1 \tag{7}$$

$$X\mu m = \left(\frac{\frac{80}{100}}{\frac{84.788}{100}}\right)^2 \times 710 = 631.367\mu m \ at \ 80\%$$

Table 3 gives the sieve analysis of the feed of reference sample 1 to the ball mill. Using data from Table 3

If 710 μm = 79.113

The $X\mu$ m = 80%

$$X\mu m = \left(\frac{\frac{80}{100}}{\frac{79.113}{100}}\right)^2 \times 710 = 726.249\mu m \ at \ 80\%$$

Calculations using data from Table 4

If 710 μm = 81.944

Then

$$X\,\mu m = \left(\frac{\frac{80}{100}}{\frac{81.944}{100}}\right)^2 \times 710 = 677.440\mu m \; at \; 80\%$$

3.1.2. Test Ore (Filin Kokuwa Gold Ore)/References Sample Discharges as Product from the Ball Mill

Table 5: gives the sieve analysis of the product of test material in the ball mill (Filin Kokuwa Gold) product from ball mill.

Calculations using data from Table 5 If 210μm = 75.271

$$X\,\mu m = \left(\frac{\frac{80}{100}}{\frac{75.271}{100}}\right)^2 \times 210 = 237.090\mu m \; at \; 80\%$$

Table 6: gives the sieve analysis of the product of test material from the ball mill (of Granite 1).

Calculations using data from Table 6

If 350μm = 87.946

$$X\,\mu m = \left(\frac{\frac{80}{100}}{\frac{87.946}{100}}\right)^2 \times 350 = 289.256\mu m \; at \; 80\%$$

Table 7: gives the sieve analysis of the product of reference sample from the ball mill (granite 2).

Calculations using data from Table 7

If 210μm = 77.068

$$X\,\mu m = \left(\frac{\frac{80}{100}}{\frac{77.068}{100}}\right)^2 \times 210 = 226.095\mu m \; at \; 80\%$$

Combining Bond's Eq. (2) and (3), we have;

$$Wi_t = Wi_r \frac{\left[\frac{10}{\sqrt{P_{80r}}} - \frac{10}{\sqrt{F_{80r}}}\right]}{\left[\frac{10}{\sqrt{P_{80t}}} - \frac{10}{\sqrt{F_{80t}}}\right]} \tag{8}$$

where, Wi_r = work index of the reference sample; Wi_t = work index of test ore; P_r = the diameter of the reference sample product, 80% of which passes through 100μm aperture; P_t = the diameter of the test ore product, 80% of which passes through 100μm aperture; F_r = the diameter of the reference sample feed, 80% of which passes through 100μm aperture; F_t = the diameter of the test ore feed, 80% of which passes through 100μm aperture; W_r = work input in kilowatt hour/short ton for reference sample and; W_t = work input in kilowatt hour/short ton for test ore.

Therefore, using granite 1 as the reference sample and Filin Kokuwa Gold ore as the test ore $P_r = 289.256$ μm $F_r = 726.249$ μm $P_t = 237.09$ μm $F_t = 631.367$ μm $W_{ir} = 15.13$ (granite work index value [11]).

Hence;

$$W_{ir} = 15.13 \frac{\left(\sqrt[10]{289.256} - \sqrt[10]{726.249}\right)}{\left(\sqrt[10]{289.256} - \sqrt[10]{726.249}\right)}$$

Also, by using granite 2 as the reference sample and Filin Kokuwa Gold ore as the test ore P_r = 226.095 μm F_r = 677.44 μm P_t = 237.09 μm F_r = 631.367 μm W_{ir} = 13.57 (granite work index value [11]).

Therefore:

$$W_{ir2} = 13.57 \frac{\left(\sqrt[10]{226.095} - \sqrt[10]{677.44}\right)}{\left(\sqrt[10]{237.09} - \sqrt[10]{631.367}\right)}$$

From the above, the Average work index = W_t = $(W_{it1} + W_{it2}/2$ = (13.227 + 15.192)/2 = 14.21kW.h/ton

While, Energy used for grinding Filin Kokuwa Gold ore is;

$$\begin{aligned} W &= 10 \times W_t \left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) \\ &= 10 \times 14.21 \left(\frac{1}{\sqrt{237}} - \frac{1}{\sqrt{631.367}}\right) = 3.581 \; kW \end{aligned}$$

3.2. Discussion

Tables 2 –7 give the results of the particle sieve size analysis of the test ores (Gold Ore) and reference sample (Granite). The 80% passing for both the feeds and products sieves size fractions for the Filin Kokuwa gold ores and the references (granite) samples. The 80% passing particle size fraction for both feed and product of the as-received Filin Kokuwa Gold ore sample was found to be 631.367μm and 237.09μm respectively while the work index of the as received Filin Kokuwa Gold ore sample was computed to be 14.21 kWh/ton on the average which when compared to the work index of exiting gold ores in literatures, the result obtained lies favourably within the work indexes of 3 - 42 kWh/ton for gold ores as sighted in the literatures [1, 11, 23]. The 14.21kWh/ton work index obtained for the Filin Kokuwa gold ore sample means that 14.21kWh of energy is required to reduce one ton of the as-received Filin Kokuwa gold ore sample from 80% passing size of 631.367μm to 80% passing size of 237.09μm. Furthermore, using the Standard Denver grindability test curves the Filin Kokuwa gold ore is classified as a medium texture type ore, the value obtained compares well with range for standard work index for gold which is between 3 - 42kW.h/ton [13, 24], while the energy utilized in grinding of the Filin Kokuwa Gold ore calculated to be 3.581kW.

4. CONCLUSION

In conclusion the work index of Filin Kokuwa gold ore sample from Toro Local Government Area of Bauchi state, Nigeria has been determined and found to be 14.21kWh/ton on average and energy utilized to be 3.581kW. These parameters are significant in the design of a process route for the beneficiation of the Filin Kokuwa gold ore sample.

Table 4: Sieve analysis of the granite 2 sample feed to the ball mill.

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	10.38	10.395	10.395	89.605
-1000 +600	7.65	7.661	18.056	81.944
-600 +500	8.67	8.682	26.738	73.262
-500 +350	16.64	16.663	43.401	56.599
-350 +210	11.66	11.676	55.077	44.923
-210 +180	11.64	11.656	66.733	33.267
-180 +125	2.88	2.884	69.617	30.383
-125 +90	9.94	9.954	79.571	20.429
-90 +63	3.52	3.525	83.096	16.904
-63	16.88	16.904	100	
Total	99.86			

Table 5: Sieve analysis for sample of Filin Kokuwa gold ore (product of test gold) from ball mill .

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	0.27	0.272	0.272	99.728
-1000 +600	0.26	0.262	0.534	99.466
-600 +500	1.03	1.037	1.571	98.429
-500 +350	9.03	9.092	10.663	89.337
-350 +210	13.97	14.066	24.729	75.271
-210 +180	17.37	17.489	42.218	57.782
-180 +125	3.09	3.111	45.329	54.671
-125 +90	18.4	18.526	63.855	36.145
-90 +63	13.1	13.189	77.044	22.956
-63	22.8	22.956	100	
Total	99.32	100		

Table 6: Sieve analysis of granite 1 product from ball mill.

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	0.19	0.191	0.191	99.809
-1000 +600	0.29	0.292	0.483	99.517
-600 +500	2.02	2.034	2.517	97.483
-500 +350	9.47	9.537	12.054	87.946
-350 +210	14.26	14.361	26.415	73.585
-210 +180	16.24	16.354	42.769	57.231
-180 +125	4.11	4.139	46.908	53.908
-125 +90	15.22	15.327	62.235	37.765
-90 +63	11.57	11.652	73.887	26.113
-63	25.93	26.113	100	
Total	99.3			

Table 7: Sieve analysis of reference sample 2 product from ball mill.

Sieve Size (μm)	Weight Retained	% Weight Retained	Cummulative % Retained	Cummulative % Passing
+1000	0.3	0.302	0.302	99.698
-1000 +600	0.12	0.121	0.423	99.577
-600 +500	1.06	1.068	1.491	98.509
-500 +350	9.02	9.088	10.579	89.421
-350 +210	12.26	12.353	22.932	77.068
-210 +180	16.54	16.665	39.597	60.403
-180 +125	3.31	3.335	42.932	57.068
-125 +90	16.2	16.322	59.254	40.746
-90 +63	11.4	11.486	70.74	29.26
-63	29.04	29.26	100	
Total	99.25			

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