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Froth Flotation Upgrading of Galena and Sphalerite Ore of Wase Plateau State, Nigeria

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Research Article

Abstract

This research is based on upgrading galena and sphalerite ores using the froth flotation method of mineral concentration. Samples of ores were taken from the surface and the underground openings at the Mining site. These samples were analyzed using sieve and x-ray refraction fluorescence (XRF) analysis. The sieve analysis determined the liberation size to be 0.355mm. The XRF analysis revealed that the samples have an average of 10.20% Zn and 40.78% Pb. After the froth flotation process, zinc concentration increased from 10.20% to 20.23% on average, and that of Lead increased from 40.78% to 57.53%. The enrichment ratio of the Lead was calculated to be 1.28, while that of Zinc was 1.98; this indicated that adding more value to the galena and sphalerite ores would lead to more returns on investment. The increase in return-over-investment will also encourage more local concentration before exports.

Keywords
Concentration; Economic Development; Enrichment Ratio; Froth-flotation; XRF

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1. Introduction

Nigeria has experienced double recession in the space of five years between 2015 and 2020 (Ini, 2020). Due to the sharp decline in the price of crude oil in the world market, the Federal Government (FG) of Nigeria has decided to consider mining as one of the means to generate more revenue. To increase the nation's gross domestic product (GDP), reduce inflation, and improve the nation's monetary exchange value (Ndubuisi,2020). The economy of Nigeria is monolithic and dependent on the oil and gas sector, which contributes about 40% of the nominal GDP and over 90% of export earnings, and 75% of gross revenues (Olade, 2019).

Looking at the mining sector, which has been neglected over years, we can see that there are few policies that are working while most are inappropriate or inadequate. The nation has discovered many mineral ores distributed across the country in different levels of exploration and exploitation. However, a deficient area is the value addition sector (Kayode and Onwurah, 2016).

Researchers have also demonstrated several challenges often associated with mining operations that affect their planning and design, operation and maintenance, financing and productivity, machinery and efficiency, revolution, and other economic-related factors. (Akinola *et al*., 2020)

According to Ogwata and Onwughalu, (2019), some vital mineral ores the nation is blessed with are galena and sphalerite. These are abundant in Ebonyi, Plateau, Cross-river States e.t.c. Most of these ores have been mined and exported in crude, which only brings small tax returns to the government. To maximize profit from mining these minerals, we, as a nation with operating companies inclusive, need to consider value addition and even transform them into final products such as batteries, weapons, and many other products.

Galena is a sulphide ore of Lead; some researchers and authors have supported this; for example, Edmudas *et al.*, (2016) and (Moradi and Monhemius, 2011) affirmed that galena is in association with the sulfide mineral group with a chemical composition of Lead and sulphide (PbS). Hobart, (2021) also affirmed that it is the world's largest lead ore.

Galena and sphalerite ore can be used to produce lead batteries, weapons, zinc, and other final products, which are extensively used and required in sustainable supplies. One way to meet this demand involves obtaining additional value from critical lead-zinc ores (Steve *et al.*, 2018). The Nigerian Customs Service (NCS) has revealed that 49,868 tons of Lead were exported between 2013 and 2017, while 30,768 tons of zinc were similarly exported within the same period in raw form (Kasim, 2018; Huseyin *et al*., 2020). However, Nigeria's solid mineral sector is underdeveloped, it is in a situation where minerals that can be easily produced and beneficiated within the country are being imported (Olade, 2019).

1.1 Future Prospect of Lead and Zinc

The Lead and zinc price is suggested to increase significantly in the coming decades, with scarcity and increased prices. The total supply of zinc will reach a maximum in 2030-2050 and Lead in 2025-2030 (Harald and Kristin, 2019). The predicted price increase will cause its processing to increase. Therefore, it is essential that Nigeria also look into the beneficiation of her galena and sphalerite deposits.

2. Materials and Methods

2.1 Sample Collection

Three (3) samples, A, B, and C from the surface open pits, were collected, and three samples from the underground tunnels D, E, and F were collected to make six (6) samples. These six samples were within the size range of 5cm to 2cm with an aggregate weight of 40kg. The coordinates of the samples collected are: A. 9º14’14.65’’N and 10º34’55.65’’E; B. 9º14’6.5’’N and 10º34’50.02’’E; C. 9º14’10.58’’N and 10º34’48.10’’E; D. 9º14’14.3’’N and 10º35’2.10’’E; E. 9º14’17.70’’N and 10º35’2.80’’E; F. 9º14’0.2’’N and 10º34’58.00’’E.

2.2 Methodology

2.2.1 Sample Preparation

Crushing: The entire samples from A-F were crushed using the Denver jaw crusher to reduce the size of samples to10mm, the Cone crusher was also used to reduce the size of the samples to 5mm, and the roll crusher finally reduced the size of the sample to 2mm.

Sampling: After crushing to a size of 2mm, the Riffler sampler was used to obtain a representative fraction of the entire sample. 100g from each of the 2mm samples was kept and later homogenized for the sieve analysis.

Pulverization: 200g of the 2mm size for each sample was fed into the Bico pulverizer and pulverized for about 30minutes. 5grams from each of the samples from A-E, which were pulverized, were then taken for XRF-Analysis.

2.3 Liberation size determination of Samples using Fractional Sieve Analysis

Riffle Sampler was used to obtain 100grams of the 2mm size of homogenized samples (A-F) which was fed into the array of sieves. These were placed on an Automated Endecott test sieve shaker with the complete set of sieves, model EFL2mk11 (5471) ranging from +1400µm to -63µm, using the root two ($\sqrt{2}$) formula. The machine was then operated for 20 minutes, after which the content of each sieve was discharged, weighed, and recorded using Camry 25k 5055 digital weighing balance.

2.4 Concentration of Samples by Froth Flotation Method

a. Recovery of lead Concentrate:

A representative sample of a 2mm size range was ground using the ball mill for about 30minutes. It was sieved using the 0.355mm sieve, and 300g was weighed and fed into the Denver froth flotation cell. For each weighed sample, 1000mls of water was added and was agitated for 5 minutes. After which the pH was tested to be 8 using the pH meter, followed by the addition of Sodium Cyanide (NaCN) and Zinc sulfate ($ZnSO_4$) to depress Zinc (Zn), 0.07g Potassium Ethyl Xanthate (PEX), and (0.05g) of pine oil was also added, as shown in plate 1. Air was then introduced; froth was formed, and the froth bubbles were skimmed out into the receiving container, which was the lead concentrate, shown in plate 2.

Lead was cleaned using 200ml water while underflow was also collected and allowed to settle for 24hours before the water was decanted. Finally, the Lead concentrate and its underflow were dried and weighed.

Plate 1: Reagents used

Plate 2: Collection of Lead Concentrate

b. Recovery of Zinc Concentrate:

In order to activate Zinc (Zn), 0.07g of $CuSO_4$ was added, and the solution was agitated for about 5 minutes; the pH was tested to be 9.2 using the pH meter. 0.07g of PEX and 0.05g of Pine oil were added to collect the Zinc and stabilize the froth. Air was then introduced, froth was formed, and the froth bubbles were skimmed out into the receiving container, the Zinc concentrate, as shown in Plate 3.

The Zinc was also cleaned using 200ml of water, and the Zinc underflow was also collected. Finally, the Zinc concentrate, Zinc underflow, and tailings were also allowed to settle for 24 hours, water was decanted, and the products were dried and weighed.

Plate 3: Zinc Concentrate

c. Chemical Contents Determination using XRF Analysis

After value addition on Galena and Sphalerite Ore samples, 5grams of the Zinc and Lead concentrate for each sample was sent for XRF analysis to know the percentage of upgrade.

3. Results and Discussion

3.1 Results

3.1.1 Sieve Analysis Result for Homogenized Sample A-F of Galena and Sphalerite Ore

Table 1 presents the sieve analysis result with the sieve size range between 1.44 and 0.063mm, the weight of sample retained on each sieve (g), percentage (%)weight of the retained sample, the cumulative weight of retained (%), and the cumulative weight of passing (%), for all the samples A-F of galena and sphalerite ore.

From Table 1, the sieve size range was plotted against the cumulative percent passing, and cumulative percent retained, as shown in Figure 1 below. The curve observed indicate that the intersection between the two curves is precisely at the sieve size of 0.355mm, with 49.34 cumulative percent passing and 50.66 cumulative percent retained. According to Nuhu, (2017) and Alabi *et al.*, (2016)states that the plot between the cumulative percent passing and retained against the sieve size, the intersection mostly gives the liberation size. Hence, can be said that the liberation size of the samples from the study area is 0.355mm.

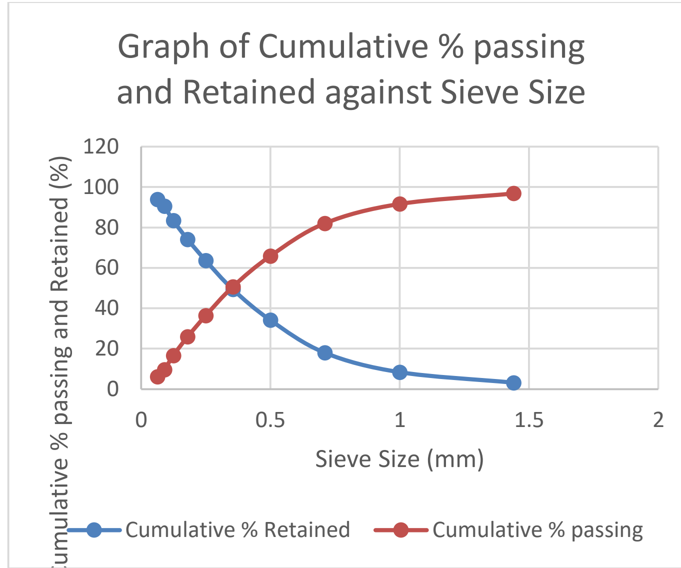

Figure 1: Graph of Cumulative % Passing and Retained against Sieve Size

3.1.2 Average Chemical Analysis for Galena and Sphalerite for Composite Sample A-F

Table 2 shows Average Results from chemical analysis results for galena and sphalerite ore sample A-F.

Table 2: Average Results from Chemical Analysis Results for Galena and Sphalerite Ore Sample A-F

Al_2O_3	**S_iO_2**	**SO_3**	**K_2O**	**CaO**	**T_iO_2**	**Cr_2O_3**	**MnO**
ND	2.80	5.70	0.31	1.13	0.15	0.12	0.79
Fe_2O_3	**N_iO**	**CuO**	**ZnO**	**Ga_2O_3**	**La_2O_3**	**PbO**	**Pb**
14.50	0.02	0.12	10.20	0.04	0.04	44.70	40.78

Table 1: Sieve Analysis Result.

S/N	Sieve Size (mm)	Weight Retained (g)	% Weight Retained	Cumulative Weight Retained (%)	Cumulative Weight Passing (%)
1	1.44	3.1	3.15	3.15	96.85
2	-1.44 +1.0	5.1	5.18	8.33	91.67
3	-1.0+0.71	9.5	9.64	17.97	82.03
4	-0.71+0.5	15.9	16.14	34.11	65.89
5	-0.5+0.355	15.0	15.23	49.34	50.66
6	-0.355+0.250	14.1	14.31	63.65	36.35
7	-0.250+0.180	10.3	10.46	74.11	25.89
8	-0.180+0.125	9.1	9.24	83.35	16.65
9	-0.125+0.09	7.0	7.11	90.46	9.54
10	-0.09+0.063	3.3	3.35	93.81	6.19
11	Bottom	6.1	6.19	100	0
Σ		**98.5**	**100**		

Table 3: Average of Results from the Froth-Flotation Process.

Sample	Pb Conc.	Zn Conc.	Tailings	Total
Average Weight(g)	234	22.5	18.5	275
Weight (%)	85.1	8.1	6.7	100

Table 4: Chemical Analysis of Lead and Zinc Concentrates

Lead Concentrate						
SiO_2	**K_2O**	**CaO**	**Cr_2O_3**	**MnO**	**Fe_2O_3**	**NiO**
2.70	0.10	0.93	0.12	0.77	13.67	0.03
CuO	**Zn**	**Pb**	**Sc_2O_3**	**TiO_2**	**SO_3**	
0.15	19.56	57.53	0.02	ND	ND	
Zinc Concentrate						
SiO_2	**K_2O**	**CaO**	**Cr_2O_3**	**MnO**	**Fe_2O_3**	**NiO**
4.80	0.36	1.83	0.15	1.21	21.74	0.03
CuO	**Zn**	**Pb**	**Sc_2O_3**	**TiO_2**	**SO_3**	
0.40	20.23	39.93	ND	1.16	6.85	

Table 5: % weight and an assay of lead and zinc concentrate.

Products	**% Weight**	**% Pb Assay**	**% Weight**	**% Zn Assay**
	Lead (Pb)		**Zinc (Zn)**	
Feed	100	44.70	100	10.20
Concentrate	85.1	57.53	8.1	20.23
Tailings	14.9	38.54	91.9	16.93

Table 6: Results from Metallurgical Accounting

Parameters	**Lead (Pb)**	**Zinc (Zn)**
Concentration ratio	1.18	12.34
Percentage (%)of recovery	89.503%	9.53%
Percentage (%)of loss	10.497	90.47
Enrichment Ratio	1.28	1.98

3.2 Discussion

From the average XRF analysis of galena Ore in Table 2, it was observed that the ore contained 44.70% of PbO, during the floatation of galena in the presence of sphalerite, Sodium Cyanide (NaCN) and Xanthate was used as reagents, which changes the surface characteristics of the slurry to depress the Sphalerite. After the lead was collected, Sphalerite was floated by adding $CuSO_4$. After the upgrading, the percentage of Lead increased to 57.53%, as presented in Table 4. From the results in Table 5, metallurgical accounting was used to calculate: the ratio of concentration which was found to be 1.28, percentage of Pb recovery was found to be 89.50%, the percentage loss of Lead in tailings was found to be10.5%, and the enrichment ratio was found to be 1.98 as presented in Table 6.

From the enrichment ratio, it can be seen that the Zinc concentrate has 1.98 times of sphalerite ore in the feed, while the lead concentrate is 1.28 times more concentrated than that of the galena in the feed

Analysis of ore samples shows an average of 14.50 % of Fe_2O_3, which is within the standard of 1%-5% requirement for exploration and exploitation (Yunana, 2015). The result implies that the company can consider the concentration of iron to increase income and increase the nation's GDP.

From the average XRF analysis of Sphalerite ore, it was observed that the ore contained 10.20% of Zn, and after the concentration was done, it was observed that it increased to 20.23% Zn. The results from metallurgical accounting were used to analyze Table 5. The concentration ratio was found to be 12.34, the percentage recovery of Zn recovery was found to be 9.5%, the percentage loss of zinc in tailings was found to be 90.5%, and the enrichment ratio was found to be 1.98.

From Tables 4 and 6, the value added to the Sphalerite ore was about 1.98 times more than that of the ore. However, the difference looks minimal. Nevertheless, suppose the price of zinc increases; in that case, it can be considered crucial to process this mineral. Also, from the low recovery of Zinc and a high Zinc assay, this research affirmed Oladunnmi *et al.*, (2016) who concluded that an alternative method like the shaking table method should be considered rather than the froth flotation method.

In the case of the Lead concentration, it can be seen that there was a high recovery and high assay, but the enrichment ratio was still 1.28, which is to say that the concentrate is 1.28 times richer than the ore. The ratio can be considered relevant as it has a multiplication impact on the profit to be made by the company/nation.

4. Conclusion

From the analysis of galena and sphalerite ores, it can be determined that the ores were of high grade. The value was further upgraded when froth flotation process was used. The chemical analysis indicated three (3) significant compounds in the Wase galena and sphalerite ore: PbO, ZnO, and Fe_2O_3.

Results from the concentration indicate an increase in PbO and ZnO percentage values from 44.70% to 57.53% for Pb and 10.20% to 20.23% for Zn. The sieve analysis determined the liberation size was 0.355mm, with 49.34% cumulative percent passing and 50.66% cumulative percent retained. The enrichment ratio of 1.28 was calculated for Lead and 1.98 for zinc. These enrichment ratios expounded the numerical value addition of the concentration of these ores, which invariably shows that the return on investment is positive, thereby serving as encouragement to the local producers.

It is expected that more indigenous entrepreneurs can go into the local concentration of the galena and sphalerite to reduce the economic loss incurred due to the exportation of solid crude minerals. The foreign exchange will lead to more stress on our exchange rate because the importation of finished products from Lead and Zinc, such as batteries, gun bullets, and machine parts, is far costly than the crude ores exported.

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