Comparative Test For the Upgrading of Lead in Sabon Layi Lead-Zinc Ore (Alkaleri Local Government Area, Bauchi State), Using Gravity and Froth Flotation Beneficiation Methods

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Abstract—*This research work deals with the upgrading of lead in Sabon Layi lead-zinc ore using gravity and froth flotation beneficiation methods. Analysis of the chemical composition reveals that this crude ore contains 38.76%lead and other related minerals such as 29% silica, 22.80% Sulphur, 2.76%Zinc, 4.17%CaO and others in traces; these related minerals are impurities that hinder the lead grade found in this ore from appreciating. Fractional sieve and the grain size result revealed that the liberation size of the ore is at -710+500µm. At this sieve size, the lead –zinc ore was subjected to four different beneficiation methods using five kilograms (5kg) each as charge on Wilfley shaking Table, Humphrey spiral concentrator, Air floating Machine and one kilogram (1kg) for froth flotation. Resulting products –Concentrate and tailing from Processing were analyzed. The grade and weight of the resulting mineral were used in calculating percentage recovery of each applied process; which was used to ascertain the best method.*

Keywords— Sabon layi, Gravity, froth flotation, mineral, Fractional analysis.

I. INTRODUCTION

The development of solid minerals plays a pivotal role in the economic growth of any nation. The Federal Government of Nigeria (FGN) has therefore taken serious decision towards economic diversification; and as such, more interest is now directed towards the solid minerals sector. However, researches and studies are underway to explore and process the Country's solid mineral deposits.

Nigeria is blessed with much abundant of solid minerals, among them is lead ore which can be found in some locations across the Country, for example Zamfara, Plateau, Bauchi (Nahuta) States, to mention but a few. Lead is a relatively soft, malleable, blue gray, heavy metal and is probably the earliest discovered metal that does not occur naturally in its pure state. Lead is usually found in ore with zinc, silver, and (most abundantly) copper, and it is extracted together with these metals with the priority giving to our primary metal of interest (lead). Other impurities found in lead bullion are antimony, arsenic, etc. Lead is used in various applications such as lead-acid battery, projectiles for fire arms, radioactive shielding and coloring elements in ceramic glazes among others.

The main lead mineral is galena (PbS) which contains 86.6% lead. Other common varieties are cerusite ($PbCO_3$) and anglesite ($PbSO_4$) (Damisa, 2008). Among other methods, lead can be extracted from its ore using gravity and froth flotation methods. Both methods are employed in extractive metallurgy and several other processing industries. In extractive metallurgy particularly, the two are important unit operations used for the recovery and upgrading of sulphide ores. It is therefore due to the above stated fact, among other needs that this research aimed towards ascertaining the best method to be used in beneficiating Nahuta lead ore, Alkaleri Local Government Area of Bauchi State using gravity and froth flotation methods as the two comparative methods under study.

Most lead-zinc ore concentrate plant use flotation plant for the beneficiation. Froth flotation is the most widely used method for ore beneficiation. In ore beneficiation, flotation is a process in which valuable minerals are separated from gangue materials or other valuable minerals by inducing them to gather in and on the surface of a froth layer. Sulphide and non sulphide minerals as well as native metals are recovered by froth flotation. Flotation process is based on the ability of certain chemicals to modify the surface properties of the minerals. Other chemicals are used to generate the froth while others are used to adjust the pH. Certain chemicals are even capable of depressing the flotation of minerals that are either to be recovered at a later time or are not to be recovered. The process of froth flotation entails crushing and grinding the ore to a fine size. This fine grinding separates the individual mineral practices from the waste rock and other mineral particles (Chevron, 2016).

1.1 Beneficiation of Lead Ore

Beneficiation is the process by which the concentration of the valuable constituent in an ore is increased while impurities are reduced to practically acceptable level. As applied to metallic minerals, it involves upgrading of the valuable metal. Minerals which can be separated by gravimetric methods must have measurable difference in density (Gupta and Yan, 1994). Before the advent of floatation process in the early 1900's, gravity concentration was the chief method by which lead and lead-zinc ore are concentrated (US DOI, Bureau of mines, 1984; 1985 in USEPA, 1994).

1.2 Gravity Concentration Process

Gravity concentration is the process for the separation of minerals of different specific gravities by including valuable movement in response to gravitational force and one or more natural or applied force with the aid of a flowing film. It is widely used sometimes along with other processes in particle flotation, magnetic separation and chemical treatment. The method is adopted for fine-grained ores of size range between 1.5 and 0.1 mm. usually, the ore is ground to such a degree that the metal bearing constituents are mechanically liberated from the gangue. The most important unit which is often used on an industrial scale is the spiral separation i.e. Humphrey's spiral, due to its simplicity and environmental friendliness (Will, 2006).

Yunana *et al*.(2015) characterized and beneficiated Zurak lead/zinc ore, Plateau State, Nigeria using froth flotation method at liberation sizes -90 +63 µm and -180+125 µm. he found out that froth flotation is the most suitable method of beneficiating the Zurak Pb/Zn ore deposit at a liberation size of -90+63 µm. similarly, Egbe et al (2013) worked on gravity separation of lead-gold ore in Baban Tsauni, Gwagwalada, Abuja using three (3) gravity separation methods. He however, opined that Baban Tsauni (Nigeria) lead-gold ore responded well to beneficiation by Jigging, Multi-gravity and Shaking table separations.

1.3 Froth Flotation Process

This is the most widely used method for ore beneficiation. In ore beneficiation, flotation is a process in which valuable minerals are separated from the worthless material or other valuable minerals by inducing them to gather in and on the surface of a froth layer. Sulphide and non sulphide minerals as well as native metals are recovered by froth floatation. Floatation process is based on the ability of certain chemicals to modify the surface properties of the mineral(s) Tyurnikova and Naumov (1981).

Some chemicals are used to generate the froth while others are used to adjust the pH. Certain chemicals are as well capable of depressing the flotation of minerals that are either to be recovered at a later time or are not to be recovered. The process of froth flotation involves crushing and grinding of the ore to a fine particles size. This fine grinding separates the individual mineral particles from the waste rock and other mineral particles. The grinding is normally done in water with the resultant slurry (pulp). The pulp is processed in the flotation cells, which agitate the mixture and introduce air as small bubbles Whelan and Brown (1956).

The ability of the minerals to float depends on its surface properties. Chemical modification of these properties enables the mineral particles to attach to an air bubble in the flotation cell. The air bubble and mineral particle size rise through the pulp to the surface of the froth of foam that is present in the flotation cell. Even though the air bubbles often break at this region, the mineral remains on the surface of the froth. The mineral is physically separated from the remaining pulp material and is removed for further processing according to Rubinstein (1995). .

The response of some minerals to the flotation process is often affected by pH. Flotation circuits are most often separated at a pH range of 7.5 to 11.5. The exact range at any given plant is optimized for the ore at the site. Lime is often used to raise the pH of the pulp and also reduce the flotation of iron pyrite. The particle size to which an ore is ground depends on the nature of the ore. The grind must be fine enough to liberate the mineral grain from associated rock; but producing too small a particle size is both expensive and detrimental to recovery Yoon and Luttrell (1986). Froth flotation is however generally limited to size fractions between roughly 65 and 100 mesh. Particles larger than 65 mesh Tyler (210 micron) are difficult for the air bubble to lift while particles smaller than 400 mesh (37 micron) often will not attach to the air bubble.

II. MATERIALS AND METHODS

Lead – zinc ore used in this research was sourced from Sabon Layi, in Alkaleri Local Government Area, Bauchi State, Nigeria.

2.1 Material

50kg of Lead – Zinc ore was sourced for from Sabon Layi a town in Alkaleri Local Government Area of Bauchi State, Nigeria covering a land mass of about $526m^2$ with co-ordinate Latitude 10.26611^0N, longitude10.35528^0E or Latitude 10^0 $15^'$ $58^{''}$N Longitude 10^0 $20^'$ 07" located between Yalan and Kungimbar town and an un estimated commercial quantity lead ore reserve was sourced from mining site dug at an average dimension of 1.5meters by 1.5meters by 3meters deep, using random sampling method.

2.2 Methods

Samples collected were in boulders form with size ranging from 20cm to 50cm diameter. This was size reduced by crushing using a Denver Jaw crusher which reduced the size of the sample to about 5cm, with a further crushing in the Denver cone crusher and finally size reduced in Deco roll crusher to sieve size analysis size of below 2mm in the mineral laboratory of the National Metallurgical Development Centre (NMDC), Jos. And was further size reduced to froth floatation size of -90+63µm using Bico Sprecher Schuh laboratory ball Milling Machine.

2.3 Chemical Composition of Crude Lead Sample

This was done by chemical analysis of the ground Sabon Layi lead – zinc sample; which was carried out by mixing the sample thoroughly to homogenized stage, followed by sampling using riffles sampler. The resulting sample was then charged into analysis cup, pressed to a well compacted stage; which was then introduced for analysis using PanAnalytical Minipal Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRFS) analyzer of the Spectrum Mineral Laboratory, Industrial Estate, Rayfield Area Jos, Plateau State.

2.4 Fractional Sieve Size Analysis of the Lead Sample

2kg of lead-zinc ore sample was collected from the 50kg lot meant for the entire research work using cone and quartering sampling method; 100g of this was charged into array of sieves placed on an Automated Endecott test sieve shaker with complete set of sieve, model EFL2mk11 (5471) ranging from +1400µm to -63µm using the root two (√2) formula. This machine was then operated for 30 minutes after which the contents of each sieve were discharged, weighed, recorded using Camry 25k5055 digital weighing balance to determine the liberation size of the lead-zinc ore under study.

2.5 Grain Size Analysis

Grain size analysis was determined in the Mineralogy division of NMDC, Jos; by the use of Leco optical microscope. Sample was cut, molded by mounting the lead-zinc sample using bakelite powder in a mounting press at setting temperature of 350^0C.Grinding and polishing of the sample prepared was done using various grits paper on a calibrated microscope. This shown the grain size of the Lead-Zinc ore sample at varying shapes, colours, measured in class interval of 0.002. Finally, class interval and frequency were used to calculate the standard deviation which gave the required grain size of the Lead Zinc ore and invariably its liberation size.

2.6 Beneficiation Methods

2.6.1 Wilfley Shaking Tabling Method

5.0kg of the Sabon Layi lead-zinc ore crushed to required liberation size of -710+500µm was charged into the laboratory size wilfley shaking table model 130 A of the Mineral Beneficiation Pilot Plant of NMDC, Jos after forming slurry mixed with water at ratio of 1:5 with deck tilted at 180^0 at feed rate of 50litres per hour, deck's speed set at 250 revolution per minute (RPM) (Vissca, 1976 and Alabi, 2015). The resulting products were weighed, sampled and analyzed for chemical composition.

2.6.2 Spiral Concentrator Method

5.0kg of the prepared lead sample was used at its liberation size of -710+500µm.This was mixed with 25 liters of water to form slurry of ratio 1:5 with pulp density at 3.2 i.e 25% (Davies, 1991 and Alabi, 2015).This was fed into the charging chamber of Humphrey Spiral Concentrator Model B124TA at a feed rate of 50 liters per hour and its valve set at 2cmm wide. The resulting products (concentrate and tailing) were collected in a 30 liters bucket, it was left over night (12 hrs.) to settle after which it was decanted, sundry, weighed and sample picked for chemical composition analysis using ED-XRFS analysis machine.

2.6.3 Gravity Concentration Method

5.0kg of the ore at a sieve size of -710+500µm was weighed and fed through the charging hopper to the deck of the Kip Kelly Air floating machine model My-1151, size 300 at a feed rate of 50kg per hour with an inlet air opening at 2cm at a deck slope of tilted at an angle of 180^0 (Taggert, 1987 and Alabi, 2015) respectively. The resulting middling in bucket 3 and 4 was recycled, while the concentrate and tailing sample were weighed and taken for chemical compositional analysis using ED-XRFS analyzer.

2.6.4. Froth Floatation Method

1.0kg of prepared Sabon layi lead-zinc ore sample of sieve size -710+63µm was fed into Denver froth flotation cell, with 1000mls of water introduced, it was agitated for 5 minutes, the pH was tested and adjusted to 8 using Sodium Hydroxide (NaOH) (Klimpel, 1995 and Sinclair, 2009) followed by the addition of Sodium Cyanide as depressant,2 drops of sodium isopropyl xanthate($Na^+[CS_2\text{-}O\text{-}C_3H_7]$), (Srdjan,2013). Air was then introduced, froth was formed, bubbles of froth was skimmed out into the receiving container. These products were allowed to settle for 24 hours after which it was decanted, dried, weighed and sampled for chemical composition using ED-XRFS.

III. RESULTS AND DISCUSSION

3.1 Results

The results of the research work carried out are as shown in Tables 1-6

Table.1: Chemical analysis of crude Lead-zinc ore

Composition in %	CaO	MgO	Al_2O_3	SiO_2	TiO_2	CuO	Fe_T	Pb	S	P	Zn	Cd	Ag
Crude Lead-Zinc ore	4.17	0.01	1.62	29.40	0.16	0.03	0.15	38.78	22.8	0.04	2.76	0.10	0.03

Table.2: Result of Screen Size Analysis of Lead-Zinc Ore.

Sieve Size (mm)	Weight (gm)	Weight (%)	Cumulative Wt. % Retained.	Cumulative Wt. % Passing.	%Pb
+1.0	24.2	24.25	24.25	75.75	32.43
- 1.0 + 0.71	13.2	13.23	34.48	65.52	31.64
- 0.71 + 0.500	12.7	12.73	50.21	49.79	42.54
- 0.500 + 0.355	12.3	12.33	62.54	37.46	35.76
- 0.355 + 0.25	11.5	11.52	74.06	25.94	29.93
- 0.25 + 0.180	9.3	9.32	83.38	16.62	34.23
- 0.180 + 0.125	7.5	7.52	90.90	9.10	34.46
-0.125 + 0.09	5.8	5.81	96.71	3.29	33.91
-0.09 + 0.063	2.8	2.81	99.52	0.50	41.98
- 0.063	0.5	0.50	100.0	0.00	38.43
	99.8	100.0			

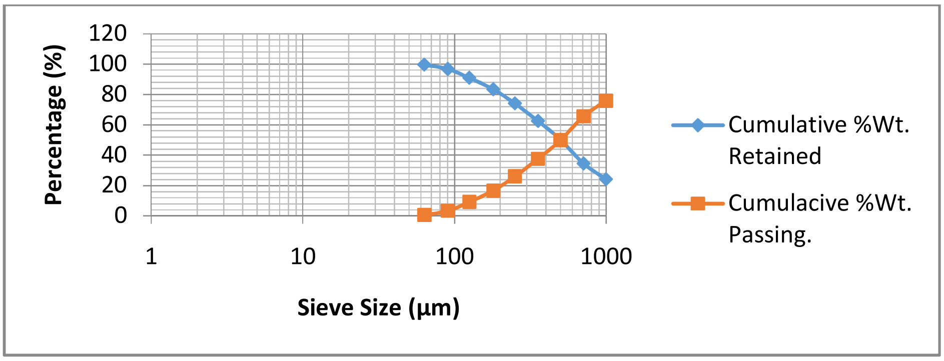

Fig.1: Log – Log Plot of Cumulative %Weight Retained against Cumulative %Weight Passing of Sabon Layi Lead Zinc Ore

Table.3: Result of Measured Grains Crystals of Lead Zinc Ore

Class Interval	Mid-Point X	Frequency F	Fx
0.001-0.200	0.100	443	44.3
0.201-0.400	0.300	277	83.1
0.401-0.600	0.500	275	137.5
0.601-0.800	0.700	252	176.4

0.801-1.000	0.900	178	160.2
1.01-1.200	1.100	75	82.5
Total		ΣF = 1500	ΣFx = 684.0

From Table 2, grain crystal of Lead Zinc ore was measured using Standard deviation to be 0.456mm, which is scientifically 0.456mm (456μm).

$$X = \frac{\Sigma Fx}{\Sigma F} = \frac{684.0}{1500.0} = 0.456mm = 0.456mm\ (500\mu m)$$

Table.4: Chemical composition of processed Lead – zinc ore using Wilfley, Spiral, Air floatation and Froth Floatation methods.

Composition in %		CaO	MgO	Al_2O_3	SiO_2	TiO_2	CuO	Fe_T	Pb	S	P	Zn	Cd	Ag
Wilfley	Conc.	1.62	0.06	0.71	0.26	1.01	0.09	0.08	66.24	16.24	0.02	2.34	0.13	0.09
	Tailings	3.26	0.01	2.63	60.92	1.21	2.11	1.67	16.82	7.24	0.26	1.94	0.06	0.03
Spiral	Conc.	1.98	0.05	0.82	12.34	1.58	0.09	1.34	57.71	19.42	0.04	4.41	0.07	0.05
	Tailing	4.03	0.01	2.76	64.71	1.86	1.96	10.93	16.24	6.23	0.04	3.02	0.08	0.03
Airfloat	Conc.	1.51	0.01	0.53	1.07	0.01	0.01	0.07	72.11	23.92	0.02	0.01	0.26	0.15
	Tailing	2.63	0.03	1.02	68.35	1.32	1.06	1.72	12.23	3.62	0.32	7.63	0.01	0.01
Froth Flotation	Conc.	1.32	0.06	0.071	12.61	2.04	1.94	3.73	61.89	10.61	0.03	1.23	0.32	0.14
	Tailing	3.02	0.13	1.02	60.04	1.26	1.12	1.71	19.72	4.63	0.03	6.34	0.01	0.00

Table.5: Recovery of Lead in Sabon Layi lead zinc ore

		Wt. Charge (kg)	Wt. % of Products	%Pb	Recovery
Wilfley	Conc.	5.0	1.96	66.24	66.96
	Tailing		3.04	16.82	26.37
Spiral	Conc.	5.0	2.11	57.71	62.80
	Tailing		2.89	16.24	24.21
Airfloating	Conc.	5.0	1.58	72.11	58.76
	Tailing		3.42	12.23	21.57
Froth Flotation	Conc.	1.0	0.36	60.89	56.84
	Tailing		0.64	19.72	32.55

3.2 Discussion of results

The result of the chemical analysis (XRF) of Sabon Layi crude lead-zinc ore as presented in Table 1, shows that the crude lead-zinc ore contains 38.78 % Pb, and is also associated with gangue which require beneficiation to be isolated from the mineral of interest (lead). Among these gangue minerals are SiO_2 (29.40%), Zn (2.76%), Sulphur (22.8%), and other gangue such as Fe, P, CaO etc.

Based on the result, it is evident that the ore meets the typical standard requirement of 1 – 5% Pb and 1 – 10% Zn for exploration of a mine field for this particular mineral (Will, 2006).

Table 2 shows the results of the sieve size analysis, it is observed that at -0.71+0.500mm, the % cumulative weight retained and % cumulative weight passing are 50.21 and 49.79 respectively, hence giving an assay of 42.54% Pb. At sieve size -0.09+0.063mm, it can be observed from the table that the % cumulative weight retained was 99.52% while the % cumulative weight passing was 0.50%, but assayed 41.98% Pb, thus suggesting that at this two particle sizes, beneficiation could be said to be most effective as compared with other particle sieve sizes, hence at -0.71+0.500mm, the gravity method of beneficiation would be effective since particle sizes at liberation size are coarse (Adepoju and Olaleye, 2000) while at -0.09+0.063mm, the froth flotation method could be employed since particle sizes are finer (Ajayi, 2005).

Figure 1 shows the plot of the % cumulative weight retained against % cumulative weight passing for the ore, it can be observed that from the graph, there was an intersection of the two curves at 500 µm sieve sizes which could be considered the optimum sieve size for beneficiation. This optimum sieve size is further confirmed by the results in table 2, with -0.71+0.500mm having a % cumulative weight retained and % cumulative weight passing of 50.21 and 49.79 respectively, which fall within the same range, and also the result in table 3 showing the grain crystal size which is considered optimum to be 0.456mm (approximately 500 µm). However, energy required to reduce the ore to sieve size -0.09+0.063mm would be enormous and uneconomical as reported by Wills (2006);Since at particle size -0.71+0.500mm, an assay of 42.54% Pb can be obtained as compared with 41.98% for the -0.09+0.063mm.

Table 4 shows the chemical composition of the processed lead-Zinc ore using the gravity and froth flotation techniques, while table 5 presents the assays and recovery of lead after beneficiation. It can be observed from table 4, that the assays of the concentrate and tailings for lead (Pb) are 66.24% and 16.82% for the Wilfley shaking table respectively, while their recoveries are 66.96 and 26.37 as shown in table 5 respectively. On the other hand, the assays of the concentrate and tailings for Pb in air float method are 72.11% and 12.23%, while their recoveries are 58.76 and 21.57 as shown in table 4 and 5 respectively, thus showing that the air float method produces a higher grade of 72.11% Pb but with a low recovery (58.76) as compared with Wilfley method which produces an assay of 66.24% Pb which is slightly above the acceptable feed grade required as charge in the blast furnace and a recovery of 66.96% which is better than any of the other processes. The spiral method has an assay of concentrate and tailings of 57.71% and 16.24% and recovery of 62.80 and 24.21 respectively, while the froth flotation method has concentrate and tailings assaying 61.89% and 19.72%, and recoveries of 56.84 and 32.55 respectively. It can be said that the spiral method and the froth flotation methods are not suitable for this particular ore, as they do not meet the acceptable assay as feed for charge in the blast furnace even though they have high recoveries. This is in line with the work of Atrafi *et al*. (2012).

Therefore, both Wilfley and air float met the condition required for the production of concentrate for the production of Lead (Pb) required as charge in the blast furnace.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

In conclusion, Air float and Wilfley produced concentrate required as standard towards feed into production of Lead metal using Sabon layi Lead- Zinc ore. However, because of the high assay of Lead in air float (72.11%) and at a recovery of 58.76 as against Wilfley shaking tabling method with assay of 66.24 and recovery of 66.96, it is therefore advisable to use air floating method for this production, invariably, considering the economic implication of grinding so far as 66.24% assay and 66.96 recovery met the required standard of 65% Pb required as charge, Wilfley shaking table method with high recovery is preferred to the air floatation method.

4.2 Recommendations

It is here by recommended that, where a high assay of 72.11%Pb with low recovery of 58.76% is required, the air float tailing method should be considered. Whereas when a relatively lower assay of 66.24% Pb with high recovery of 66.96% which are all within standard requirements as charge is required, the wilfley shaking tabling method of processing is advisable.

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