Effectiveness of Gravity Separation Methods for the Beneficiation of Baban Tsauni (Nigeria) Lead-Gold Ore

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Abstract- The response of Baban Tsauni (Nigeria) lead-gold ore to gravity separation methods was investigated in this research work. Value addition to run-off mines is always necessary in order to reduce downstream metal extraction costs. Gravity separation methods (the focus of this work) are the cheapest beneficiation methods. This study applied three gravity separation methods: jigging, multi-gravity and shaking table and measured the grades/ recoveries of the valuable minerals. Beneficiation of this ore by jigging method yielded the highest lead recovery of 86.9% at a grade of 56% for a geometric mean particle size of 421.31microns. Shaking table separation produced high grades but very low recoveries while the multi-gravity method gave the best combination of grade and recovery. Beneficiation by jigging method gave good lead recovery (above 75%) when particle size was bellow 1000µm but above 250µm while in multi-gravity separation particle size was bellow 500µm but above 125µm.

Index Terms- jigging, multi-gravity, grade, recovery, mineral.

I. Introduction

Production of metals from their ores usually requires some form of energy (heat, electrical or chemical) and the energy consumption depends on the mass of feed (valuable mineral plus gangue). This implies that feeds of higher grades cost less to extract [10]. Thus grades of ores required for metallic extraction by the known metallurgical routes are much higher than their cut-off grades [7]. Lead extraction by pyrometallurgical process requires feed grades of 40% to 70% while copper extraction requires 20% to 30% [3]; [1]. Moreover the cost of transportation decreases with increase in ore grade [10]. Thus the mineral grade must be increased above that of the run-off-mine to the value required by extraction plants. It was indicated that the lead and gold grades of Baban Tsauni run-off-mine are 27.79% and 0.02938% respectively [4].

Beneficiation is the process by which the concentration of the valuable constituent in an ore is increased while impurities are reduced to practically acceptable levels. As applied to metallic minerals, it involves upgrading of the valuable metal while reducing the gangue and other minerals (which are deleterious to subsequent extraction process) to acceptable levels in the ore. Minerals which can be separated by gravimetric methods must have measurable difference in density. A concentration criterion was stated [6] as,

$$\text{Concentration criterion (CC)} = \frac{H_{MRD} - F_{RD}}{L_{MRD} - F_{RD}} \qquad 1$$

where H_{MRD} = relative density of heavy mineral, F_{RD} = relative density of fluid and L_{MRD} = relative density of light mineral. It was submitted that the concentration criterion should generally be greater than 2.5 for effective gravity separation [10]. Fully liberated galena has a relative density of 7.5 [6], while that of quartz is 2.61 [10], which give a CC of 4.34 in water medium. It is not always necessary to attain full liberation before separation. Moreover gravimetric separation is sensitive to particle size; hence CC is a function of particle size of the mineral [6]. The results of a gravity separation of Itakpe (Nigeria) iron ore by jigging indicated that the iron recovery increased with decrease in particle size [8]. This present study investigated the response of Baban Tsauni (Nigeria) lead-gold ore to jigging separation, multi-gravity and shaking table separation.

The responses often considered in beneficiation of metallic minerals are recovery and grade of the valuable minerals [8]; [9]; [6]; [10]; [2]; [4]. Recovery is the measure of the percentage of metal in the raw ore that is recovered to the concentrate through beneficiation while grade is the assay or concentration of a metal in a sample [5]. It was indicated [10] that recovery is calculated by applying Equation 2;

$$R = 100\frac{Cc}{Ff} \qquad 2$$

where R= recovery of valuable metal, C = the mass of the concentrate, c= the concentration of metal in concentrate, F = the mass of feed sample and f = concentration of metal in feed sample.

II. Experimental Methods

2.1 Sample Preparation

About 80kg of ore samples were collected from four mining pits at Baban Tsauni, Gwagwalada, Nigeria. All the samples collected were mixed together before crushing. An initial sample preparation aimed at ensuring a homogeneous feed for subsequent test runs was carried out. The crushed samples from the jaw crusher /roll crusher (in that order) were subjected to the same grinding conditions of mill speed, ore mass to ball mass ratio, ball size and grinding time of 15minutes. The products of this batch milling operations were subjected to particle sizing to generate sets of close sized particles based on ratio $1/\sqrt{2}$ between the consecutive sieve sizes. Each set of close sized particles from all the batch sieving operations were mixed thoroughly and passed through a Jones riffling sampler, until sets of 500g samples were obtained for subsequent tests.

2.2 Gravity separation by jigging

Batch jigging of the samples was carried out on a laboratory jig (Denver jig) that was powered by 0.5hp motor. A screen that is slightly bigger than the size of materials to be jigged was laid in the jig. Steel balls of size 5mm diameter were arranged as ragging on the floor of the screen in three layers. 500g of each close sized sample were weighed and transferred to the jig. Water was supplied to the jig and the motor was switched on while addition of hutch water continued intermittently. Jigging was stopped after 5minutes and the hutch was opened to discharge the concentrate. Collection of the overflow was continuous through out the jigging cycle. The concentrates and tailings for each batch operation were dried at 110^oC, to constant weight, in well labelled trays. The mass of the concentrates and tailings were measured and recorded. Samples of concentrates and tailings were taken for energy dispersive x-ray fluorescence (EDXRF) analyses to determine the concentrations of all the elements in them.

2.3 Multi- gravity separation

The multi- gravity separation is a batch process in which an inclined bucket was subjected to linear oscillation and circular rotation. The inclination of the bucket was kept at 20^o to the horizontal. 500g of close sized particles was kept in the bucket and 1.5litres of water was added. Additional water was supplied at the rate of 500ml/minute. The tailing discharged continuously onto a bow while the concentrate was removed at the end of the process. The concentrates and tailings for each batch operation were dried at 110^oC, to constant weight, in well labelled trays. The mass of the concentrates and tailings were measured and recorded. Samples of concentrates and tailings were taken for EDXRF analysis to determine the concentrations of all the elements in them.

2.4 Shaking table separation

The inclination of the table was set at 45^o. Five hundred grams of each close sized sample was fed gradually to the feed trough of the shaking table at a rate of about 50g/minute. The feed water was supplied at a rate of about 250ml/minute. Collection of concentrates and tailings was continuous throughout the process. The concentrates and tailings for each size fraction were dried to constant weight in well labelled trays. The mass of the concentrates and tailings were measured and recorded. Samples of concentrates and tailings were taken for EDXRF analyses to determine the concentrations of all the elements in them.

III. Results and Discussion

Table 1 shows the results of chemical analysis on samples of concentrates for typical close sized particles subjected to jigging while Table 2 shows the results for the concentrates of a typical multi-gravity separation. The results on concentrates and tailings of a typical shaking table separation are shown in tables 3 and 4 respectively. All the results revealed that the major valuable mineral in the concentrates is lead mineral with a lead grade of 61% for jigged samples at particle size of -1400µm +1000µm, 59% for multi-gravity (particle size of -355µm +250µm) and 57% for shaking table at particle size of -710µm +500µm. The detailed results showed that the major valuable mineral that reported to the tailings is gold. The results in Table 4 indicate a gold grade of 0.11%. The foregoing indicate that beneficiation by shaking table resulted in gold enrichment of 3.744 at a particle size of -710µm +500µm [Table 4] while lead enrichment in the concentrates was 2.051 [Table 3]. Thus a higher gold enrichment was achieved than lead even though a lead grade of 57% is generally acceptable for smelting.

Table 1: XRF analysis results of jigged sample (-1400 + 1000µm) - concentrate assay.

Element	Energy (keV)	Concentration %	Error %
Pb	10.540	61	± 0.835
Sr	14.142	0.139	0.04955

Table 2: Assay of multi-gravity (-355+250mic concentrate) test.

Oxides	Concentration (%)	Elements	Concentration (%)
PbO	63.66	Pb	59.051
CuO	0.478	Cu	0.382
ZnO	0.069	Zn	0.055
Al2O3	1.7	Al	0.899
SiO2	15.5	Si	8.680
CaO	0.33	Ca	0.236
Cr2O3	0.11	Cr	0.075
MnO	0.02	Mn	0.015
Fe2O3	1.86	Fe	1.300

NiO	0.063	Ni	0.050
CdO	2.9	Cd	2.537
BaO	1.53	Ba	1.371
WO3	0.2	W	0.159
Re2O7	0.1	Re	0.077
OsO4	0.1	Os	0.075

Table 3: Assay of shaking table (-710 +500mic -concentrate) test.

Oxides	Concentration (%)	Elements	Concentration (%)
PbO	61.5	Pb	57.047
CuO	0.159	Cu	0.127
Al2O3	1.4	Al	0.741
SiO2	27.4	Si	15.344
SO3	2.9	S	1.160
CaO	0.22	Ca	0.157
Cr2O3	0.044	Cr	0.030
MnO	0.006	Mn	0.005
Fe2O3	0.787	Fe	0.550
NiO	0.028	Ni	0.022
CdO	4	Cd	3.500
BaO	0.578	Ba	0.518
WO3	0.54	W	0.428
OsO4	0.15	Os	0.112
HgO	0.27	Hg	0.250

The EDXRF analysis of tailings (Table 4) showed that gold reported to the tailings and this occurred in all cases. This occurred because the gold is finely disseminated in the quartz. Liberated gold (free gold) is heavier than galena and would not have been preferentially floated in jigging operation involving lead and gold. However when bound in quartz matrix the relative density of the composite became lower than that of galena and it reported to the tailings.

Table 4: Assay of shaking table (-710 +500mic -Tailing) test.

Oxides	Concentration (%)	Elements	Concentration (%)
PbO	9.74	Pb	9.035
CuO	0.052	Cu	0.042
Au	0.11	Au	0.110
Al2O3	5.89	Al	3.116
SiO2	80.3	Si	44.968
K2O	0.497	K	0.412
CaO	0.539	Ca	0.385
TiO2	0.059	Ti	0.035
Cr2O3	0.043	Cr	0.029
MnO	0.02	Mn	0.015
Fe2O3	0.535	Fe	0.374
NiO	0.013	Ni	0.010
BaO	0.49	Ba	0.439

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WO_3	0.087	W	0.069
OsO_4	0.088	Os	0.066
IrO_2	0.04	Ir	0.034
HgO	0.19	Hg	0.176
P_2O_5	0.8	P	0.349
Ga_2O_3	0.01	Ga	0.007
ZrO_2	0.5	Zr	0.370

Applying Equation 2 for the jigging products of size -1400µm to +1000µm (Table 5), the lead recovery became,

$$R = 100\frac{Cc}{Ff} = 100\frac{109.41x61}{484.49x20.9} = 65.91\%$$

The lead recoveries for the remaining sieve fractions were calculated in the same way. The summaries of lead recoveries for jigging, multi-gravity and shaking table are presented in Tables 5, 6 and 7 respectively.

Table 5: Summary of lead assays and recoveries for samples subjected to gravity separation by jigging.

Sieve size	Lead assay in feed (f)	Concentrates		Tailings		Lead recovery
		Mass (g)	Lead assay (%)	Mass (g)	Lead assay (%)	(%)
-1400 +1000µm	20.9	109	61	355.08	8.93	65.91
-1000 +710µm	19.2	142	54	335.4	5.8	83.63
-710 +500µm	27.3	183	59	296.43.4	9.3	81.88
-500 +355µm	25.2	185	56	289.8	7.4	86.9
-355 +250µm	25.5	165	56	311.52	9.52	75.76
-500 +355µm	7.4	22.21	48.88	267.59	3.96	50.62

The results showed that one step jigging of Baban Tsauni ore yielded lead recovery which was highest at a particle size of less than 500µm to +355µm while the assay was highest at the coarsest particle size of -1400 to +1000µm. Thus the grade of lead ore dropped as the recovery increased due to the fact that more gangues were also recovered to the concentrates. Plate I shows typical samples of concentrate, midlings and tailings from jigging operation. The last row of Table 5 shows the results of a second stage jigging of tailing samples for -500 to +355µm. The total lead recovery from the two stages of jigging operations was found to be 95.66% and a weighted mean lead grade of 55.237%. The lead recoveries from shaking table experiments were obtained by substitution into Equation 2 in the same way as it was done for jigging. The summary of these recoveries are presented in Table 6.

Table 6: Summary of lead assays and recoveries for samples subjected to gravity separation by shaking table.

Sieve size	Lead assay in feed (f)	Concentrates		Tailings		Lead recovery
		Mass (g)	Lead assay (%)	Mass (g)	Lead assay (%)	(%)
-710 +500µm	22.45	80.4	57.1	398	9.035	42.71
-500 +355µm	29.13	61.91	66.8	435	23.02	29.797
-355 +250µm	32.19	79.45	69.5	395	23.6	36.15
-250 +125µm	37.615	87.58	70.4	387	29.75	34.56
-125 +90µm	37.1	98.54	61.2	335	28.52	37.51

The lead recoveries obtained for the shaking table method were generally low while the lead ore grades were higher than those obtained by jigging and multi-gravity methods. This implied that shaking table requires more stages of operation in order to achieve a reasonable level of recovery. Higher premium is placed on recovery than ore grade when pre-concentration operation is in view. The objective is to remove bulk gangue at fairly coarse particle size, at reduced cost and generate products which may further be treated by froth flotation method. Thus a pre-concentration treatment of Baban Tsauni lead ore by jigging method is preferred to shaking table method. However when production of finished concentrates is in view the grades of products become very important and a compromise must be struck between ore recovery and grade [10]. Under such consideration the shaking table offers the best beneficiation approach even though several stages of tailing cleaning are required.

Table 7: Summary of lead assays and recoveries for samples subjected to multi- gravity separation (shaking and rotating bucket).

Sieve size	Lead assay in feed (f) [%]	Concentrates		Tailings		Lead recovery (%)
		Mass (g)	Lead assay (%)	Mass (g)	Lead assay (%)	
-500 +355µm	25.22	159.89	61.5	324	7.8	80.67
-355 +250µm	25.5	185.02	59.1	291	3.91	90.09
-250 +125µm	24.9	145.24	62.9	327	7.86	77.71
-125 +90µm	24	124.36	52	352	13.95	56.59

The best lead grade and recovery combination of 59.1% and 90.09% respectively, was obtained at a particle size of less than 355µm to +250µm (that is, geometric mean size of 297.91microns).

The effectiveness of lead separation is higher with multi-gravity separation than jigging method (Figures 1 and 2). On the other hand, shaking table gave the worst recovery (Figure 1) but the best grade (Figure 2). The results showed that combination of lead recoveries and grades were highest with multi-gravity method (Figures 1 and 2).
The results also revealed that beneficiation by jigging method gave good lead recovery (above 75%) when particle size was bellow 1000µm but above 250µm while in multi-gravity separation particle size was bellow 500µm but above 125µm. Plate II shows typical samples of concentrate and tailings from multi-gravity operation.

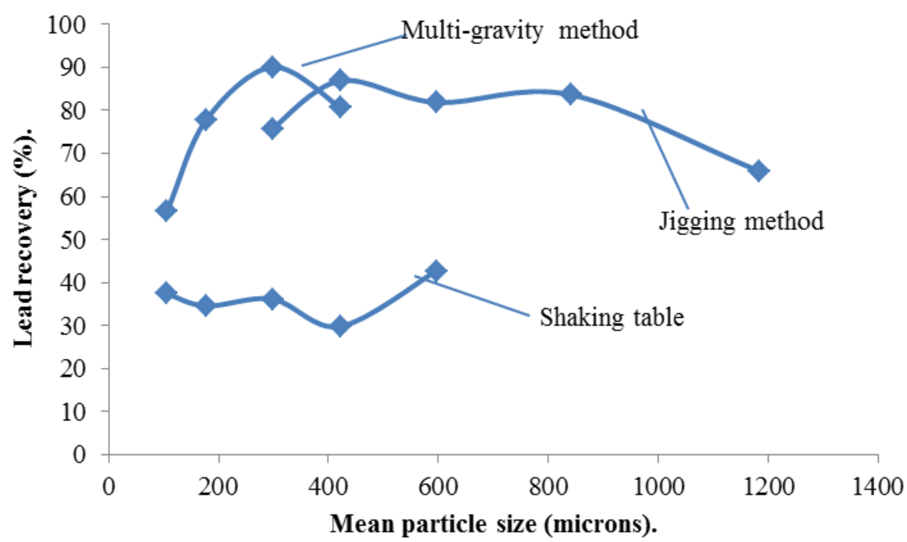

Figure 1: Lead recovery plotted against mean particle size

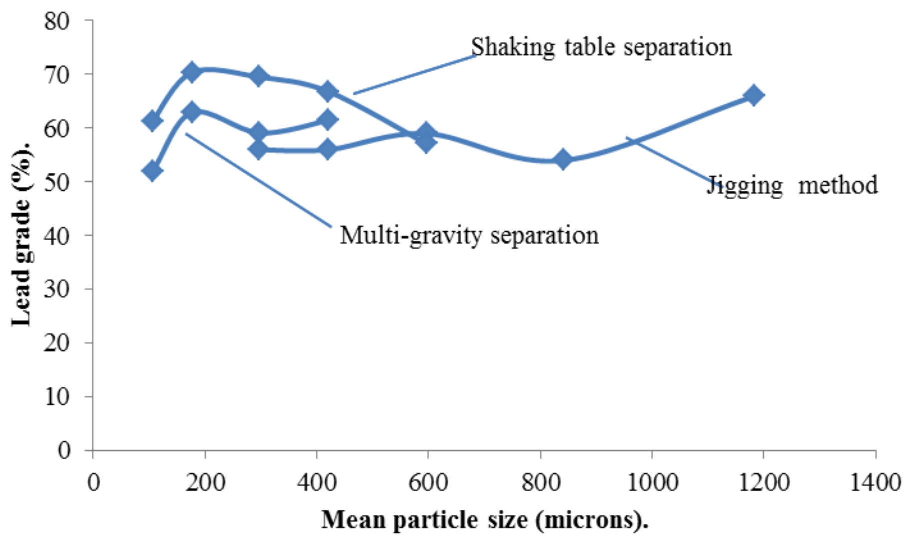

Figure 2: Lead grade plotted against mean particle size

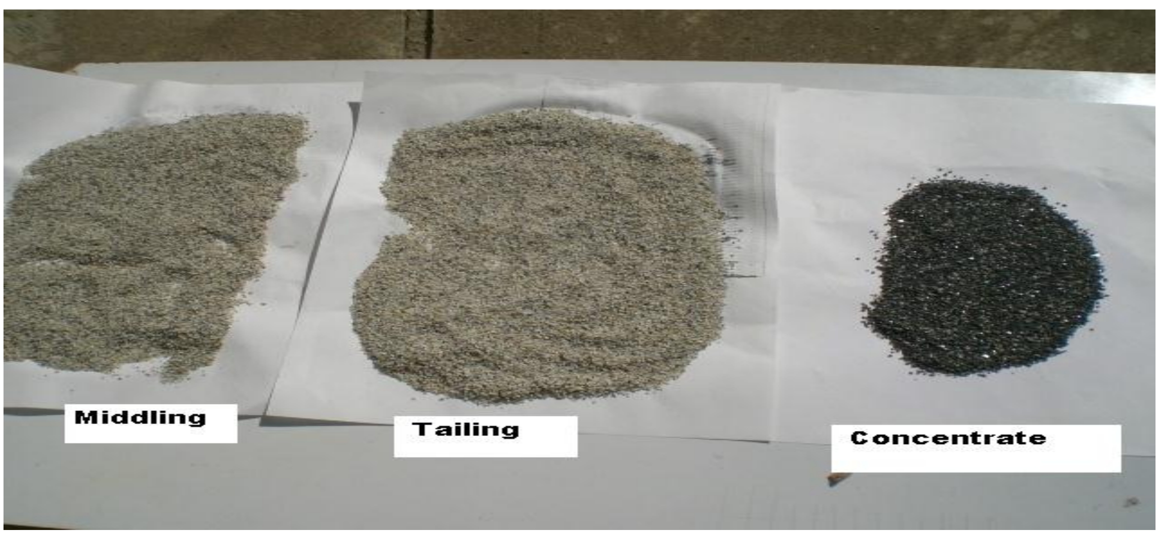

Plate I: Typical beneficiation products from jigging.

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Plate II: Typical products of multi-gravity separation.

IV. CONCLUSION

The results from this study indicated that Baban Tsauni (Nigeria) lead-gold ore responded well to beneficiation by jigging, multi-gravity and shaking table separations. The best combination of grade and recovery was obtained with multi-gravity and followed by jigging separation. Higher lead grades could be achieved by subjecting the products of gravity separation to froth flotation. The gravity separation methods increased the value of gold in the tailings. Further work is required to extract free gold from the tailings.

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