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BENEFICIATION OF LOW GRADE GURUM CASSITERITE, JOS, PLATEAU STATE OF NIGERIA

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ABSTRACT
Beneficiation of low grade Gurum cassiterite (SnO_2) was investigated using Gravity separation, magnetic separation and a combined process of gravity-magnetic separation. The sample was sourced from Gurum village, in Jos North Local Area of Plateau State, Nigeria. Shaking table gave a concentrate of 14.08%Sn (17.88%SnO_2) with a recovery of75.03%, High intensity magnetic separator gave 16.08%Sn (20.42%SnO_2) with a recovery of71.98% and the combined process of Gravity-Magnetic gave 30.02%Sn (64.22%SnO_2) with a recovery of 99.26%.As compared to the 10.48%Sn (13.30%SnO_2) in the ore before concentration. This suggest that the combined beneficiation (Gravity-Magnetic) technique is the most recommended method for the beneficiation of Gurum Cassiterite ore.

Keywords: Gurum Cassiterite Ore, Gravity Beneficiation, Magnetic Beneficiation, Gravity-Magnetic Beneficiation (Combined Process).

1.0 INTRODUCTION
Exploitation of mineral has assumed prime importance in several developing countries including Nigeria. Nigeria is endowed with abundant natural resources, which has contributed immensely to the national wealth with associated socio-economic benefits (Ogwuegbu *et al.,* 2011).
The main commercial tin fields in the world are Malaysia, Australia, Nigeria, Bolivia, Thailand and China (Falcon, 1982). Nigeria is an important tin producing country with most tin deposits concentrated in Jos Plateau State Nigeria Ogwuegbu *et al,* (2011). The world demand for tin is quite steady, and is growing at about 5% yearlyCowie, (2010). Circuit-board for television, computer, microwave etc. contains tin because it has a low melting point which makes it ideal for this purpose. Also for health reasons it is recommended to use solder with 97.5% tin instead of solder with 40% lead and 60% tin. This single policy change increased global tin demand by over 20% Cowie, (2010).
Cassiterite is associated with impurities especially those that occur in pegmatite. They are found to contain iron oxide, manganese oxide, zirconium oxide, titanium oxide, silica, columbite, mozanite, topaz etc. some of which are impediments in the extraction of tin from its cassiterite ore. Hence, the need to beneficiate the ore in order to remove or reduce the impurities associated with it before smelting Thomas and Yaro, (2016)
Research has shown that every mineral deposit is unique in its nature. Therefore; the process flow sheet for the beneficiation of an ore must be designed to suit the particular ore deposit.). Low grade deposits located in many places within and outside plateau state need to be beneficiated to metallurgical grade before smelting.

Table1: **Some Nigeria Cassiterite Resources (in millions tones)**

S/N	Location	State	Metal type	Estimated Reserved (Million Tonnes)
1	Tare Nandu	Kaduna	Sn, Ta, Nb	Partially investigated
2	Akwanga	Nasarawa	Sn, Ta, Nb	Partially investigated
3	Gurum	Plateau	Sn, Ta, Nb	Partially investigated
4	Jos-Bukuru	Plateau	Sn, Ti, Nb	Partially investigated
5	Haita-Vom	Plateau	Sn, Ti, Nb	Partially investigated
6	Barkin Ladi	Plateau	Sn, Ti, Nb	Partially investigated
7	Kuru	Plateau	Sn, Ti, Nb	>200 inferred resources
8	Akata	Kogi	Sn, Ta, Nb	>20 Tonnes have been shipped in the 1940s
9	Isanlu	Kogi	Sn, Ta, Nb	Partially investigated

Source: Ministry of Mines and Solid Minerals Development, (2012).

This is because there has been depletion of high grade casseterite ore therefore, the low grade require upgrading before they can be smelted.

The economic downturn in the country has prompted the need for the diversification of the economy and solid minerals sector is one of the viable options. The nation will require among others, the beneficiation of tin ore deposits (cassiterite). Tin has wide applications in metal coating, alloying, soldering, as well as electronics etc. (ref.) which can be exported and serve as means of foreign exchange. This need, prompted the research on beneficiation of Gurum cassiterite deposit, Plateau State, Nigeria.

Nigeria Cassiterite Ore Deposit

Nigeria is one of the countries in the world that is endowed with several mineral resources which are widely distributed across the country. There are over thirty-four minerals spread across the entire country.(ref.) Some of the known mineral resources include: Cassiterite, Gold, Coal, Bitumen, Iron Ore, Tantalite/Columbite, Lead/Zinc Sulphides, Barytes, Gemstones, Talc, Feldspar, Marble, etc. (Akanbi *el al.*, 2012).Table 1: Show some Nigeria Cassiterite Resources, their location and estimated reserves.

Gurum Cassiterite Ore Deposit

The Gurum cassiterite deposit in Jos Plateau State Nigeria, is of alluvial origin from the biotite granite within the jurassic alkaline ring complex (the younger granite), (Pastor and Ogezi, 1986). Mallo (2007) reported that mineralized rock with disseminated cassiterite mineralization may have invaded the basement structure that leads to the concentration of the tin mineral in its basement structure. Denudations of the basement exposed the roof zone of the younger granite of early alluvial deposit intrusion rise to primary deposits of high grade enriched silicified deposits. Further denudation erodes and robes the roof zone giving rise to alluvial deposits associated sand and gravels that have been transported by water. With the roof zone eroded, further denudation attracts poorly mineralized main body of the granite giving rise to the deposition or comparatively barren over burden sediments covering the area (Mallo, 2007); (Thomas and Yaro, 2016).

Asuke, Thomas & Dogara, (2018). Reported that chemical analysis of the head sample of Gurum cassiterite ore revealed 8.90%SnO_2, 12.6%TiO_2, 6.20%ZrO_2, 47.3%SiO_2, and15.7%Fe_2O_3 as the major minerals, with 1%P_2O_5, 1.2%SO_3, 0.52%CaO, 0.48%V_2O_5, and 0.40%MnO as the minor minerals and 0.01%Yb_2O_3, 0.03%OsO_4, 0.06%PtO_2 and 0.04%Au as traces. The mineral phases of the ore are cassiterite (SnO_2), Rutile (TiO_2), Silicon oxide (SiO_2) and Hematite (Fe_2O_3) and the petrological composition are cassiterite, silica, rutile and hematite are the major minerals separated by grain boundaries. Dogara, Thomas & Asuke, (2018). Studied the determination of liberation size and work index of Gurum cassiterite ore. Hereported that the liberation size and work index of the Gurum cassiterite ore are -250+180µm and 12.50kWh/t respectively.

Beneficiation

Cassiterite of low grade cannot be used in metallurgical plants and need to be upgraded to increase the tin content and reduce the gangue. A process adopted to upgraded ores is called beneficiation(Klein, 2002). Cassiterite is upgraded to higher tin content via concentration. Cassiterite is being beneficiated all round the world to meet the quality requirement for smelting industries. However, each source of cassiterite has its own peculiar mineralogical characteristics and requires the specific beneficiation and metallurgical treatment in other to get the optimum product out of it. The choice of the beneficiation treatment depend on the nature of the gangue and it association with the ore structure (Alabi *et al.* 2015). Several techniques such as washing, magnetic separation, gravity separation, froth floatation etc. have been employed to enhance the qualityof cassiterite.

The aim of this research is to investigate the possibility of using gravity, magnetic and gravity-magnetic (combined) separation methods in other to upgrade the cassiterite ore and to determine the best of these processes methods, considering the grade of the cassiterite produced.

2.0 EXPERIMENTAL PROCEDURE

Equipment

The equipment used for this research work are: Stop watch, Denver pulverizer,sieve shaking machine, Setra BL-401S digital weighing machine, Mini Pal 4 X-ray fluorescence machine (XRF), wifley shaking table and Mastermag dry high intensity magnetic separator.

Sample Collection and Preparation

The ore used in this research work was sourced from Gurum village in Jos North Local Government Area of Plateau State Nigeria.

Table 2: Chemical Composition of the ore before concentration.

Compound	Assay (%)
SiO_2	42.20
P_2O_5	2.70
CaO	0.33
TiO_2	17.20
V_2O_5	0.71
MnO	0.50
Fe_2O_3	14.49
ZnO	0.03
Y_2O_3	1.98
ZrO_2	7.06
Nb_2O_3	1.62
Ag_2O	0.37
SnO_2	13.30
Nd_2O_3	0.44
Yb_2O_3	0.10
WO_3	0.02
PtO_2	0.23
Au	0.05
PbO	0.10
Bi_2O_3	0.29
ThO_2	0.77
U_3O_8	0.11

Source: Dogara(2018)

The sample was collected from four different pits at interval of 10m apart at 5m depth in order to have a representative of the ore deposit. One kilograms (1kg) of the ore sample was collected from each pit and thoroughly mixed to obtained a homogenous sample which was used for further analyses.

The sample used in this research work was prepared to the liberation size of -250+180µm as earlier reported by Dogara *et al* 2018(this statement not needed!)

Methods

The processing methods employed during this research are gravity beneficiation using wifely shaking table, magnetic beneficiation using dry high intensity magnetic separator lastly, combine beneficiation (Gravity-Magnetic) and determination of chemical composition of the mineral before and after each process.

Determination of the Chemical Composition of the Ore Head Sample Before and after Concentration using X-ray Fluorescence (XRF)

The chemical composition of the ore sample was determined using Mini pal 4 X-ray fluorescence machine. The required parameters of the machine were set to standard. As described in Asuke, Thomas & Dogara, (2018).

Gravity Separation

450g of Gurum cassiterite at liberation size of -255+180µm was charged into wifely shaking table, the table deck tilted at 180º, air inlet opened at 2mm running 600rpm. The resulting concentrate, tailings and middling was obtained in different bucket, the middling was then charged back into the wifley shaking table in other to obtain only two components i.e. Concentrate and tailing. The resulting concentrate and tailings were weighted and analyzed separately using XRF (Model Pal-4).

Magnetic Separation

450g of Gurum cassiterite at liberation size of -255+180µm was charged into the vibratory feeder via the hooper of a three-disc dry belt high intensity magnetic separator, model 83-375. The sample further dropped unto the conveyor belt, which moves over two rollers across three magnetized discs which has different electromagnetic fields. The magnetic and the non-magnetic constituents were collected as two separate products which were weighed and analyzed separately using XRF (Model Pal-4).
(Model Pal-4).

Table 3: Chemical Analysis of the Beneficiated Gurum cassiterite using shaking table and magnetic separator.

Element	**Shaking Table**		**Magnetic Separator**	
	Conc. (Heavy)	**Tail. (Light)**	**Magnetic**	**Non-Magnetic**
S	0.71	0.12	0.51	1.01
K	0.55	0.24	0.07	1.01
Ca	0.12	0.41	0.02	1.09
Si	12.41	63.02	14.02	32.30
Ti	19.04	4.12	27.17	7.43
V	0.22	0.10	ND	0.31
Cr	0.01	0.01	0.01	0.04
Mn	1.03	0.18	2.16	1.01
Fe	21.30	6.09	29.13	5.29
Nb	19.55	22.13	22.96	14.01
Cu	0.02	0.32	0.01	0.55
Zn	0.17	0.06	0.28	0.01
Sn	14.08	1.02	1.67	16.08
Zr	10.50	2.17	1.89	18.11
Mo	0.12	0.01	0.01	0.43
Bi	0.11	0.02	0.03	0.92
W	0.06	0.01	0.06	0.32
Pb	0.01	ND	ND	0.08
Total	100	100	100	100

Gravity-Magnetic Separation (Combined Process)

The concentrate of the gravity separation was then charged into dry belt high intensity magnetic separator model 83-375. The magnetic and the non-magnetic constituents were collected as two separate products which were weighed and analyzed separately using XRF (Model Pal-4).

3.0 RESULTS AND DISCUSSION

Table 2 is the Chemical Composition of the Cassiterite Ore at Liberation Sizebefore Concentration

Table 2 reveals that the ore at liberation size before concentration contain 13.30%SnO_2, 17.20%TiO_2, 7.06%ZrO_2, 44.20%SiO_2, and14.49%Fe_2O_3 as the major minerals, with 0.33%CaO, 0.71%V_2O_5, and 0.50%MnO as the minor minerals and 0.10%Yb_2O_3, 0.09%PtO_2 and 0.05%Au as traces. From the results obtained, it is observed that $SnO_2$is one of the major minerals present in the matrix of the ore though in low grade.

Gravity and Magnetic Concentration of Gurum Cassiterite Ore

Table 3 is the chemical analysis of the Gurum cassiterite ore after beneficiation From the XRF result after gravity concentration presented in Table 3 columns 2 and 3.

There was an upgrade in the mineral of interest (Tin) from 10.48%Sn (13.30%SnO_2) before concentration to 14.80%Sn in the concentrate. The Iron (Fe) and the Titanium (Ti) also reported in the concentrate with upgrade. The major gangue Si reported in the gangue. This show that the Gurum cassiterite ore can be upgraded by gravity method using the wifley shaking table.

From the XRF result after magnetic concentration using high intensity magnetic separator presented in Table 3 column 4 and 5. The mineral of interest

(Tin) reported in the non-magnetic fraction showing an upgrade from 10.48%Sn (13.30%SnO_2) before concentration to 16.08%Sn after the magnetic concentration. Si which is a constituent of the major gangue also reported in higher percentage along with the Sn in the non-magnetic fraction. The magnetic components of Fe and Ti appear more in the magnetic fraction as expected. This show that Gurum cassiterite can be upgraded by magnetic beneficiation method using high intensity magnetic separator. Table 4 and 5 show the metallurgical balance of gravity and magnetic concentration process respectively

Table: 4: Metallurgical Balance for Gravity Concentration using Shaking Table

Products	Weight (g)	Assays (%)	Unit	Recovery (%)
Feed	450	10.48	4716	100
Concentrate	251.3	14.08	3538.3	75.03
Tailing	189.0	1.02	192.78	4.08
Loses	9.7	-	-	

Table 5: Metallurgical Balance for Magnetic Concentration using high intensity magnetic

Products	Weight (g)	Assays (%)	Unit	Recovery (%)
Feed	450	10.48	4716	100
Concentrate	211.1	16.08	3394.5	71.98
Tailing	224.2	1.67	374.08	7.94
Loses	14.7	-	-	

From Table 4, total units of 4716 was fed in for gravity concentration and 3538.3 units report in the concentrate containing the mineral of interest with a recovery of 75.03%. While from Table 5, of the 4716 units of fed in for magnetic concentration, 3394.5 units in the concentrate with a recovery of 71.98% with a high percentage of SiO_2. From these analyses it means that more metallic units of Sn is present from the gravity concentration. However the ability of the magnetic concentration to separate the Fe and Ti from Sn is appreciated, therefore the double concentration technique of gravity-magnetic concentration is (preferred) considered.

Double (Gravity-Magnetic) Concentration of Gurum Cassiterite Ore

The concentrate of the gravity concentration was subjected to magnetic concentration process and the XRF result is presented in Table 6. The metallurgical balance of the double concentration is presented in Table 7.

From Table 6, after the combined concentration process, the mineral of interest (cassiterite) report in the non-magnetic portion with an upgrade to 30.02%Sn which is higher than the value obtained for single process of gravity concentration 14.08%Sn and single process of magnetic concentration 16.08%Sn. Si also report in the non-magnetic fraction to the tune of 12.30%Si which is far less than the 19.73%Si (42.20%SiO_2) present in the head sample at liberation size before concentration. The magnetic portion which is the tailing from our concentration contains 26.64%Ti and 29.98%Fe among others.

Table 6: Double (Gravity-Magnetic) Concentration of Gurum cassiterite Ore.

Element	**Combined Process**	
	Concentrate (Gravity and magnetic)	**Tailing (Gravity and Magnetic)**
S	ND	0.38
K	0.48	0.27
Ca	0.42	0.99
Si	12.30	8.98
Ti	4.39	26.64
V	0.50	0.94
Cr	0.45	0.76
Mn	0.53	2.75
Fe	3.72	29.98
Nb	20.37	17.93
Cu	0.66	1.60
Zn	0.52	0.97
Sn	30.02	0.24
Zr	21.79	2.49
Mo	0.93	0.64
Cd	ND	0.61
Bi	0.72	0.89
W	0.57	0.95
Pb	1.62	1.99
Total	100	100

Table 7 show that of the total 3538.3 unit of the feed, 3512.34 units reported in the concentrate with 99.26% recovery which is higher than that obtained from the individual concentration processes considered. This shows that the Gurum cassiterite can be optimally upgraded by gravity-magnetic (double) concentration method, because the mineral of interest cassiterite has been upgraded from13.30%SnO_2(10.48%Sn) before concentration to 30.02%Sn after the combined process and also the major gangue mineral silica is reduced from 19.73%Si (42.20%SiO_2) to 12.30%Si.

Table 7: Metallurgical Balance for combine process (Gravity-Magnetic Beneficiation)

Products	Weight (g)	Assays (%)	Unit	Recovery (%)
Feed	251.3	14.08	3538.3	100
Concentrate	117	30.02	3512.34	99.26
Tailing	109	0.24	26.16	0.74
Loses	25.3	-	-	

Therefore, the double concentration technique is recommended for a better upgrade of Gurum cassiteriteore.

CONCLUSION

1. The gravity concentration technique using shaking table report an upgradein the mineral of interest (Cassiterite) from 10.48%Sn (13.30%SnO_2)before concentrationto 14.08%Sn after gravity concentration and also gives concentrate unit 3538.3 with a recovery of 75.03%.
2. The magnetic concentration technique using high intensity magnetic separator machine report an upgrade of the mineral of interest (Cassiterite) from 10.48%Sn (13.30%SnO_2) before concentration to 16.08%Sn after magnetic concentration with aconcentrate unit 3394.50 and recovery of 71.98%.
3. The double concentration technique (Gravity-Magnetic) report an upgrade in the mineral of interest (Cassiterite) from 10.48%Sn (13.30%SnO_2)before concentration to 30.02%Sn after double stage concentration (Gravity-Magnetic) and also gives concentrate unit of 3507.8 and recovery of 99.26% respectively.
4. TheGurum cassiterite ore responds to gravity, magnetic and gravity-magnetic (combined process) concentration techniques. However, the combined process (gravity-magnetic) concentration method gave the optimal result. Therefore the double concentration technique is recommended for a better upgrade of Gurum cassiteriteore.

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