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Upgrading a low grade Wasagu – Danko (Nigeria) manganese ore using gravity separation methods

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ABSTRACT

Low grade manganese sourced from Wasagu manganese hill deposit in Kebbi state was characterized to contain 25.36% Manganese, alongside some other associated minerals, with silica and iron as the major impurities. Manganese ore was subjected to sieve analysis toarrive at a liberation size of -125 + 90 μm; a sieve size in which all other of the manganese ore was subjected to, prior to introduction to Spiral concentrator, Wilfley shaking table, Jig and Air flotation separator using a control feeder at flowrate of 50 kg/mins. Analysis of the products (Concentrate and Tailing) realized after weighing used in calculation which led to the drawing of metallurgical balance used in determining mineral's grade, concentration ratio, recovery and enrichment ratio. These shows beyond doubt that Wilfley shaking table gave the highest values of these parameters and it is hereby qualified to be refer to as the best methods to be employed towards value addition to low grade Wasagu manganese ore to obtain quality for Metallurgical purposes.

Key words: Upgrading, Grade, Manganese, Gravity, Separation.

1. INTRODUCTION

Nigeria's intent to become one of the top twenty economies in the world with an overarching growth target of no less than $1000 billion in GDP and a per capita income of no less than $6000 per annum (Olatunji, *et al.,* 2017). These targets are premised upon two key factors that are critical to realizing Nigeria's potential as a leading nation in the immediate future:

1. growth through the diversification of Nigeria's economy by significantly increasing non-oil contribution to GDP; and
2. the empowerment of the Nigerian people to ensure that there is a balance between economic growth and their social welfare.

Nigeria's minerals and metals sector is a key sector which is crucial to the successful execution of Government's economic diversification strategy, alongside the attainment of the growth, wealth creation and poverty reduction goals of this vision. Nigeria is blessed with about 56 different known minerals in industrial quantity and quality, out of which are columbite, Tin oxide, Tantalite, Copper ore, Kaolin, Wolframite, Manganese ore, Lead – Zinc ore, just to mention but a few (Alabi, 2016) Unfortunately, the exploitation and in effective processing technologies of Nigerian solid minerals has become unsustainable for a good result (Olumide *et al.,* 2013). Thus the need to research into development and employ an effective, relatively economical, environmentally friendly and sustainable processing and recovering technique for the minerals is imperative (Alabi *et al.,* 2016). However, this research outlines the path towards the rapid transformation of the minerals and metals sector, its emergence as a strategic catalyst of growth to the Nigerian economy, which will however return to global relevance in the production of minerals and metals in a stable and sustainable manner.
The term manganese ore is used to describe ores assaying more than 35 % Mn. While ores containing 10-35 % Mn are termed Ferruginous manganese ores, and those containing less than 10 % Mn are known as manganiferrous ores (Gupta, 2006). Manganese ores are the source of Manganese metals, that are used in the Ferro alloy industry, where they are used in steel making for de-oxidation and desulphurization with steels containing them in appreciable amounts, having improved hardenability, hardness, tensile strength, high temperature applicability amongst others, therefore, has greater importance from the industrial point of view. The use of Manganese in dyes, paints, battery cell, glass and textiles industries is also of great importance. Other important applications are in the production of Aluminum and cast iron. The metallurgical industries, however account for over 95% of total usage, it is for this reason that manganese is listed amongst the strategic materials by most countries (Jones, 1987). And the reason for the research into processes leading to it's upgrading for industrial purposes.

Table 1: Properties of Important Manganese Minerals

Mineral	Formula	Colour	Mn (%)	Hardness	Specific gravity
Pyrolusite	MnO	Steel Grey To Black	63.2	6-7	5
Ramdellite to Black	MnO2	Dark Grey	63	3	4.7
Pollianite Steel grey	Mn2O3	Black to	N.A	6-6.5	5
Manganite steel grey	Mn2O3H2O	Black to	62	4	4.3
Cryptomelane Steel grey	KMn8O16	Black to	45-60	5-6	4.3
Psilomelane dark grey	$BaMn_9O_{16}2H_{2O}$	Black to	N.A	5-6	4.4-4.7
Hausmanite	Mn_2O_4	Brown to black	72	4.8	4.7-5
Braunite	$3Mn_2O_3MnsiO_3$	Brown to black	50-60	6.0-6.5	4.7-4.9
Bixbyite	$(Mn,Fe)_2O_3$	Black	30-40	6	5
Jacobsite	$MnFe_2O_4$	Black	24	6	4.6
Hollandite steel grey	$BaMn_8O_{16}$	Black to	N.A	6	4.5-5.0
Coronadite steel grey	PbM_8O_{16}	Black to	N.A	5.2-5.6	4.5-5.0
Rhodoschrosite to brown	$MnCO_3$	Red-rose	48	3.5-4.5	3.3-3.6
Rhodonite	$MnSiO_3$	pink	42	5.5-6.5	3.4-3.6
Alabandite	MnS	Iron- black	N.A	3.5-4	3.95
Spessartite	$3MnO.A_{l2}O_3$	Brownish-red	33.3	4.1-4.3	7.0-7.5

Source: Binta, 2012.

Majority of Nigeria's manganese bearing minerals deposits are found in the schist belts in the basement complex. Example of the Schist belts are: Birin Gwari, Kushaka, Igarra, Maru and Maska. Available results of geological studies show that in Nigerian, most of the manganese deposits are of metamorphic origin. These deposits includes Tudun kudu and Unguwar Mallam Ayuba in the maska belt, others are Ruwan Dorawa and Maraba Hill in the Maru belt; while others are the supergene enrichment deposit of Igarra formation within the schist belt located in South-Western Nigeria.

However, Mineralogical characteristics of the ore determined using the XRD (X-ray diffraction microscope) and SEM (Scanning Electron Microscope) carried out by Binta, (2012) revealed that ore is predominantly spessartine with quartz and hematite as minor minerals while others are in trace amounts. Hence the need to investigate the best processing method to eliminate impurities such as hematite and silica in form of quartz from manganese ore to upgrade Wasagu Danko Manganese ore to grade needed as a charge for the production of manganese which could be used to impact mechanical properties on produced iron produced to make it an engineering material.

2. MATERIALS AND METHODS

Materials

Materials used at the course of this research work were sourced from Wasagu town, which is located in Wasagu - Danko Local Government Area, Kebbi State (North - Western Nigeria). The mining site lies on latitude 6.001°E and longitude 11.03°N. The town-Wasagu falls within the Sokoto basin. The deposit from where a sample for this research work was obtained is about 18km from Wasagu town. The manganese ore deposit in Wasagu mining site and its environs covers an area of approximately 1637.2Km^2; this is an estimate dimension from artisanal mined out areas. 250Kg of the sample was sourced from five different pits tagged Pit Wa-1, Wa-2, Wa-3, Wa-4 and Wa-5. These five sourced samples were characterized separately before combining and mixing together thoroughly to obtained homogeneity and from which a final sample of 100 Kg was randomly picked; from this mix, sample was prepare towards sieve size analysis to ascertain the ore's liberation size and to determine the energy needed to be applied to give a well ground ore through which manganese mineral will be liberated.

Fractional sieve analysis

One hundred grams (100 gms) of the prepared manganese ore was charged into an array set of sieves arranged in root sieve (√2), ranging from 1000 µm to 63 µm, with a tight fitted pan placed below the bottom sieve to receive the final undersize and lid placed on the topmost sieve that house the most coarse size to prevent escape of samples during operation. This set was sieve shaken on Denver automated sieve shaker model MY-2014at the Mineral research laboratory of the Metallurgical and Materials Engineering Department Federal University of Technology, Akure for 15 minutes; after which product of each size fraction was weighed and the value noted and analyzed using wet instrumentation method at the Sigma Laboratory (Rc 14167080). Number 29, British American Junction, Jos, Plateau State, Nigeria. Results obtained were tabulated in Table 1.

Wilfley shaking Tabling

Sample ground to liberation size of -125 + 90 µm and one (1kg) was weighed, mixed in four (4) litres of water to form slurry at the pulp ratio of 1:4, which was fed into the charging chamber of the machine (1000 rev. per min.) at a feed rate of 50 litres/mins to recover the products as concentrate and tailing.

Spiral Concentrator

One Kilogram sample at -125 + 90 µm was mixed with water to form slurry of pulp ratio 1:4, charge into a spiral concentrator at feed rate of 50 litres per minutes, with the orifice open to 25% through the five (5) stage spiral level. To obtain concentrate and tailing.

Denver Jigging Machine

One kilogram (1 Kg) of manganese ore sample at sieve size of -125 +90 µm was charged into the charging point of the machine where it was diluted with about 45 liters of water and pumped to the pulsation ball jigging machine at a feed rate of 50 liters per minutes which resulted in concentrate and tailing.

Kip Kelly Air Floating Machine

One (1) kilogram of researched material at sieve size -125 + 90µm was charged into a 50 kg per hour capacity Kipp Kelly Airfloating machine, with the deck inclines at 30 degrees, air in let was control to opened at level 2 meaning 20% volume of air passage into the air chamber of the machine vibrating at 1000 revolution per minute (rpm). The concentrate was realized at combined buckets one and two (1 and 2), tailing at combined bucket five and six (5 and 6), while combined Buckets 4 and 5. Contained the middling which was re- run to give a separation which was mixed with either concentrate or tailing receiver.

3. RESULTS AND DISCUSSION

Results

Table 2: Present the Chemical Characterization of the as mined Wasagu Manganese ore from Pit Wa-1 toWa-5 and the homogenized sample.

Sample	Mn	Fe	SiO_2	S
Pit 1(Wa -1)	21.25	5.75	16.68	N.D
Pit 2 (Wa -2)	21.75	5.00	17.10	N.D
Pit 3 (Wa -3)	27.00	3.75	16.30	N.D
Pit 4 (Wa – 4)	22.56	2.89	17.06	ND
Pit 5 (Wa – 5)	21.06	6.12	18.23	ND
Homogenized (Wa - 6)	25.36	3.92	16.74	N.D

Table 2 presents the result obtained from Chemical characterization of Wasagu – Danko manganese ore using ED – XRF. The result revealed that the ore sourced from various pit Wa-1 to Wa-5 contains varying quality of manganese element ranging from 21.25 – 27.36 % Mn and when the ores from five pits were mixed to form homogeneous material it shows 25.36 %, which was used as the grade of the feed in this research. However, the chemical characterization show that crude Wasagu – Danko manganese is a low grade ore of Jacobsite ($MnFe_2O_5$), black in colour, 6.0 hardness and specific gravity of 4.6. (Binta, 2012).The result obtained further showed that the ore cannot be utilized directly in the smelting furnace because of its low grade Mn content unless it is beneficiated to meet metallurgical required grade of not less than 50 % Mn (66%MnO). This shows the ore as a potential source of Manganese metal when extracted can be added to steel as alloying element (Alabi *et al.,* 2016)

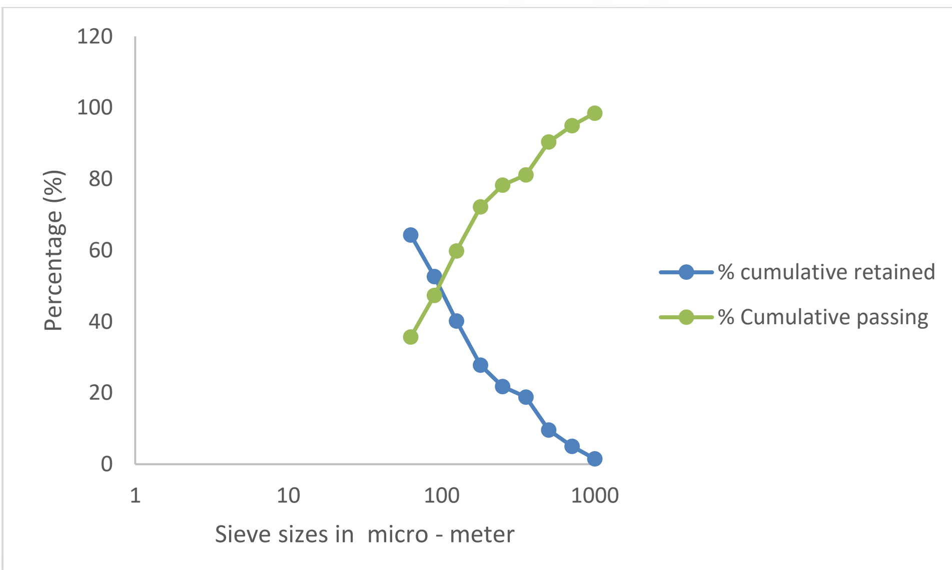

Figure 1: Graph of % Cumulative Retained and % Cumulative Passing against Sieve Size (μm) of Wasagu - Danko Manganese ore.

Table 3: Sieve Analysis of Homogenizedas mine Wasagu– Danko Manganese Ore

Sieve Range (μm)	Nominal Sieve Size (μm)	Weight (g)	Weight (%)	Cumulative Weight Retained (%)	Cumulative Weight Passing (%)	Manganese (%Mn)
+1000	1000	1.50	1.50	1.52	98.48	18.23
-1000+710	710	3.48	3.48	5.00	95.00	18.29
-710+500	500	4.60	4.60	9.60	90.40	18.31

-500+355	355	9.20	9.21	18.81	81.19	18.37
-355+250	250	2.95	2.95	21.76	78.24	18.67
-250+180	180	6.03	6.04	27.80	72.20	19.97
-180+125	125	12.35	12.36	40.16	59.84	12.69
-125+90	90	12.45	12.46	52.62	47.38	25.83
-90+63	63	11.67	11.68	64.29	35.71	24.35
-63	-63	35.67	35.71	100.00	0.00	24.76
Total		99.90	100.00			

Table 3 and Figure 1 present results obtained for the fractional sieve size analysis of Manganese ore and the graph revealing the 50% intersection indicating the economic liberation size at -125 + 90 µm at an actual liberation size indicated at this point with highest grade of 25.87 % Mn. Thus, taken -125 + 90 µm as the liberation size in which the ore was comminuted to in order to obtain high efficiency in the chosen processing mechanism as revealed in the literature, Alabi, *et al*., (2018) and revealed that both iron ore and its silica content can be processed out at this particle size (Kudrin *et al,* 1985).

Table 4 Metallurgical Balance of Gravity Processed Wasagu – Danko Manganese ore at Liberation Sieve Size of -125 + 90µm.

SAMPLE	FEED			CONCENTRATE			RECOVERY
Processes	WEIGHT (g) F	% Mn ASSAY	Mn Unit Ff	WEIGHT (g) C	% Mn ASSAY c	Mn UNIT Cc	RECOVERY Cc/Ff x 100
Wilfley Shaking Table	1000.0	25.36	25360	428.35	56.13	24043	95.18
Spiral Concentration	1000.0	25.36	25360	546.78	38.89	21264	83.88
Jig Concentration	1000.0	25.36	25360	632.06	33.71	20675	81.53
Kip Kelly Air float	1000.0	25.36	25360	503.89	45.50	22926	90.40

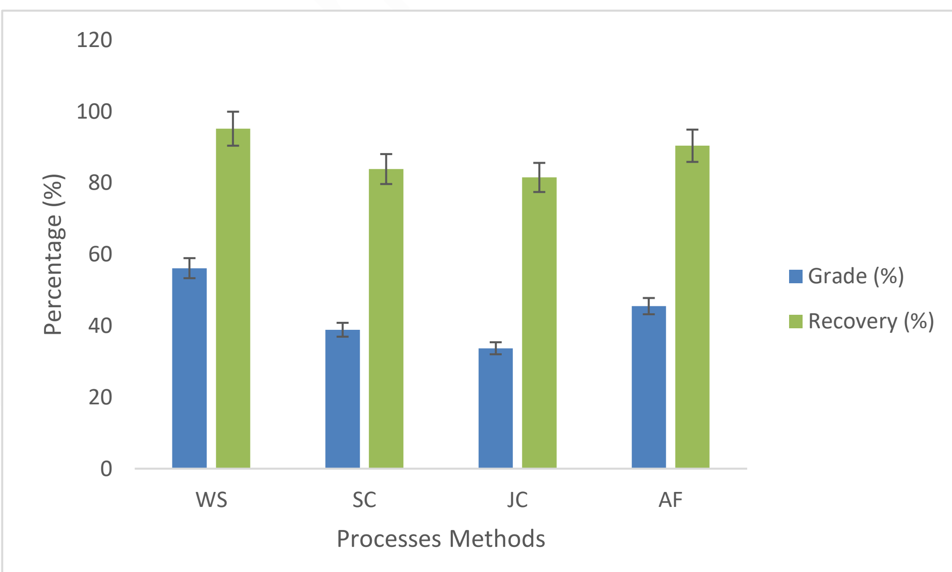

Figure 2: The graph of percentage grade and recovery plotted against processing method.

Table 4 shows the metallurgical balance of gravity separation process of Wasagu – Danko Manganese ore using varying gravity beneficiation methods at feed of 1000 gms of crude each and constant grade of 25.36 % Mn, to obtained concentrate weight, assay and computed recovery. Willey Shaking table gave concentrate of weight 428.35 gms at 56.13 % Mn at recovery of 95.18%, Spiral Concentration resulted into concentrate weight of 546.78 gms at 38.89% Mn at recovery of 83.88%, while Jig concentration gave concentrate of weight 632.06 gms at 33.71 % Mn at recovery of 81.53%, and Kip Kelly Air float gave concentrate of weight 503.09 gms at 45.5% Mn and at recovery of 90.4%. Going by the literature the manganese percentage required as charge into in a pyrometallurgical extraction process towards ferromanganese production is 50 % Mn (66% MnO) minimum (Binta, 2012). Thus, only the grade obtained at the use of wilfley shaking table; met the required stated standard. While, the grade of manganese obtained for Spiral Concentrator, Jig concentration and Kip Kelly air float do not meet the stated literature value of 50% Mn required for ferromanganese alloys production. This implies that much of the manganese bearing minerals are liberated at -125+90 µm fraction using Wilfley shaking table and thus chosen most appropriate for the beneficiation. The graph of percentage grade and recovery was plotted against processing method as shown in Figure 2.

4. CONCLUSION

The upgrading of low Wasagu – Danko manganese ore to a metallurgical grade concentrate using various gravity separation method was investigated in this research; the following conclusions were however drawn:

1. the chemical characterization of the ore revealed that the head sample of the ore assays 25.36% Mn (33.48 % MnO) on the average, which revealed that the ore is within the class of Black Jacobsite with hematite and silica in form of Quartz as associated impurities.
2. the Fractional sieve analysis carried out on the as mined Wasagu - Danko manganese ore revealed that the liberation sieve of the ore is at -125 + 90 µm with analyzed 25.86 % Mn
3. separation tests on the ore were carried out using gravity separation techniques. Only the grade of manganese concentrate obtained from wilfley shaking separation testmet the required literature value of 50.0 % Mn for the production of ferromanganese. Based on these results, the Wilfley separation technique gave the best grade manganese concentrate and hence, recommended for the upgrading of the ore.

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Conflicts of Interest: The authors declare no conflict of interest.

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