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Full Paper

Study on magnetic concentration of Nigerian Itakpe sinter concentrate to a Midrex-grade concentrate

Solomon A. Ola [1], Adewale O. Adeleke [2,*], Garba A. Usman [1], Anthony A. Odunaike [1], Shehu M. Kollere [3] and Paul O. Ajiboye [1]

[1] National Metallurgical Development Centre (NMDC), P.M.B. 2116, Jos, Nigeria

[2] Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

[3] Raw Materials Research and Development Council, Abuja, Nigeria

* Corresponding author, e-mail: aoadeleke2002@yahoo.com

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Abstract: The sinter grade of the Nigerian Itakpe iron ore that assayed 63.63% Fe and 6.62% total acid gangue was subjected to both wet low-intensity magnetic separation (LIMS) and wet high-intensity magnetic separation (WHIMS) to upgrade it to Midrex-grade super-concentrate. Chemical analysis conducted on the super-concentrate samples from LIMS and WHIMS gave Fe content of 67.59% and 68.70%, and lower acid gangue of 1.55% and 3.22% respectively. However, screen distribution analysis results showed that the cumulative fractions passing 45-µm sieve were 0.88% and 0.38% for LIMS and WHIMS super-concentrates respectively. These results indicate that the Fe and acid content determined for both LIMS and WHIMS meets the requirement for a Midrex-grade super-concentrate, while the fractions of the concentrate passing 45-µm sieve are below the 30% upper limit for transportation to the reduction plant.

Key words: Itakpe iron ore, magnetic separation, Midrex-grade concentrate

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Introduction

Itakpe iron ore deposit, with an estimated reserve of about 200 million ton, was found in 1977. The deposit is embedded in the Itakpe Hill near Okene in the north-central Kogi State of Nigeria. The deposit extends approximately 3,000 m in length and includes about 25 layers of ferruginous quartzite. From a tectonic point of view, the Itakpe deposit is confined to the southern limb of a large Itakpe-Ajabanoko anticline with enclosing rocks and conformable ore layers striking sub-latitudinally and slightly bending to the north and dipping southward at angles ranging from 40° to 80° with local minor-fold complications. The deposit contains a mixture of magnetite and hematite with ratio varying throughout the deposit. The ore consists of coarse, medium and fine grained particles. The fine ores are located mainly in the eastern part of the deposit and in thin layers, while the coarse and medium ores are relatively mixed. However, the coarse ore predominates in the north and west of the central layers while the medium one does in the centre of the central layers. The average iron content of the ore deposit was determined to be approximately 35% [1].

The world production of direct reduced iron (DRI) has increased from 1 million ton in 1970 to 40 million ton currently. The Midrex process has accounted for over 60% of the annual worldwide DRI production [2]. Steelmaking slag contains calcium oxide, magnesium oxide, silica, alumina and other compounds in smaller concentrations. Pure silica has a very high viscosity, but the addition of other metal oxides, except alumina, reduces the viscosity. The preferred characteristic for DRI grade pellets is typically 67% (minimum) Fe and 3.0% (maximum) silica + alumina + titanium oxide [3].

A major determining factor in establishing an iron and steel plant is the availability of an iron ore deposit that can be economically upgraded for the intended processing route. The Itakpe iron ore deposit has been earmarked by the Federal Government of Nigeria to supply iron ore concentrate and super-concentrate for the blast furnace process at Ajaokuta and the Midrex-based direct iron reduction plant at Delta steel plant, Ovwian-Aladja respectively. The gravity concentration route currently installed at the National Iron Ore Mining Company (NIOMCO), Okene, was designed to produce iron ore concentrate for the Ajaokuta steel plant while the froth flotation route that requires imported chemical reagents was proposed to produce super-concentrate for Ovwian-Aladja. The aim of this research work is to investigate the possibility of using magnetic separation method to produce a Midrex-grade iron ore super-concentrate for use at the Delta steel plant.

Materials and Methods

Material

The sinter-grade concentrate was supplied for this work by the National Iron Ore Mining Company (NIOMCO), Itakpe, Kogi State of Nigeria. The concentrate was air-dried and representative samples were taken for grain-size distribution analysis and chemical composition analysis.

Grain size distribution analysis

The sinter-grade iron ore, the feed and the magnetic concentrate were subjected to screen distribution analysis by a set of sieves. A stack of sieves with 100 g of the ore charged on the topmost sieve was clamped on the sieve shaker and shaken for 20 minutes. The weight retained on each sieve was then recorded.

Chemical composition analysis

The ore was subjected to chemical analysis. The iron (%Fe), alumina (%Al_2O_3) and silica (%SiO_2) content of the ore were determined by classical wet analysis as outlined by the National Metallurgical Development Centre [4].

Magnetic separation

The sinter-grade concentrate was first run through a wet low-intensity magnetic separator of 250 kg/hr capacity (manufactured by Boxmag-Rapid) to remove the ferro-magnetic material leaving a combination of gangue and para-magnetic material, which were directed to a wet high-intensity magnetic separator P40 of 250 kg/hr capacity (manufactured by Humboldt-Wedag, Germany) operating at 10,250 gauss for the separation of the para-magnetic material from the tailings. The concentrates of the wet low-intensity magnetic separation (LIMS) and the wet high-intensity magnetic separation (WHIMS) were combined to form the magnetic super-concentrate. The mass balance was done by taking samples with pulp-density cans at some points in the process line (Figure 3) and working out the corresponding weight % at each point.

Results and Discussion

The results obtained on the grain-size distribution and chemical composition analyses are presented in Tables 1-2 and 3-4 respectively, while the curves for the particle size distribution and the mass balance for the process are presented in Figures 1, 2 and 3.

From Tables 1-2, particle size distribution analyses gave, for sinter grade concentrate, LIMS super-concentrate and WHIMS super-concentrate: 62.67%, 63.22% and 57.43% passing 355-µm sieve size; 27.38%, 26.83% and 22.86% passing 180-µm sieve size; 2.12%, 2.79% and 1.54% passing 63-µm sieve size; and 0.65%, 0.88% and 0.38 passing 45-µm sieve size respectively. The highest undersizes of 63.22%, 2.79% and 0.88% (a total of 66.89% in the lower sieve range) on 355-µm, 63-µm and 45-µm sieves respectively were determined for LIMS as against 57.43%, 0.65% and 0.38% (a total of 58.46% in the lower sieve range) for WHIMS. The screen distribution results suggest that the LIMS super-concentrate consists generally of finer grain in comparison with the WHIMS super-concentrate.

Table 2 shows the sieve analyses for the super-concentrate produced from LIMS and WHIMS. It can be seen from the table that the 45-µm size materials consist of 0.88% and 0.38% of LIMS and

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WHIMS super-concentrates respectively. The results therefore show that the magnetic separation process is very effective for the production of super-concentrates from Itakpe iron ore. The fractions of the concentrates that passed the 45-µm sieve for both LIMS and WHIMS were very much lower than the upper limit of 30% required for the Middrex-grade super-concentrate used to produce pellets for direct reduction [5]. The plots of log % cumulative undersize against log sieve aperture size for LIMS and WHIMS in Figures 1 and 2 respectively are almost linear. The pattern of the curves obtained conforms to expectation [6].

Table 1. Grain-size distribution of Itakpe iron ore sinter grade concentrate

Sieve size (µm)	Weight % retained on sieve	Cumulative% undersize	Cumulative% oversize
-710	11.13	88.87	11.13
-500+355	11.81	77.06	22.94
-355+250	14.39	62.67	37.33
-250+180	18.50	44.17	55.83
-180+125	16.79	27.38	72.62
-125+90	13.00	14.38	85.62
-90+63	8.04	6.34	93.66
-63+45	4.22	2.12	97.88
-45	2.00	0.65	99.35

Note : - indicates sieve aperture undersize; + indicates sieve aperture oversize.

Table 2. Grain size distribution of Itakpe iron ore sinter and magnetic concentrates

Sieve size (µm)	Log sieve aperture	LIMS super-concentrate cumulative undersize (%)	Log % LIMS super-concentrate cumulative undersize	WHIMS super-concentrate cumulative undersize (%)	Log % WHIMS super-concentrate cumulative undersize
-500+355	2.70	78.53	1.90	nd	-
-355+250	2.55	63.22	1.80	57.43	1.76
-250+180	2.40	44.18	1.65	38.76	1.59
-180+125	2.26	26.83	1.43	22.86	1.36
-125+90	2.10	15.01	1.18	11.88	1.08
-90+63	1.95	7.37	0.87	5.19	0.72
-63+45	1.80	2.79	0.45	1.54	0.19
-45	1.65	0.88	-0.06	0.38	-0.42

Note : nd = not determined

- indicates sieve aperture undersize; + indicates sieve aperture oversize.

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Table 3. Chemical analysis results for Itakpe sinter concentrates at various size fractions

Parameter (%)	Itakpe sinter grade	Sieve fraction		
		- 180µm	- 500µm+180µm	+500µm
Fe	63.63	56.27	64.23	66.88
SiO_2	5.90	10.36	5.03	1.98
Al_2O_3	0.72	0.61	0.76	1.00
SiO_2+Al_2O_3	6.62	10.97	5.79	2.98

Table 4. Chemical analysis results for super-concentrates produced by magnetic separation

Parameter (%)	Itakpe sinter grade	LIMS super-concentrate	WHIMS super-concentrate
Fe	63.63	67.59	68.70
SiO_2	5.90	0.90	2.44
Al_2O_3	0.72	0.65	0.78
SiO_2+Al_2O_3	6.62	1.55	3.22

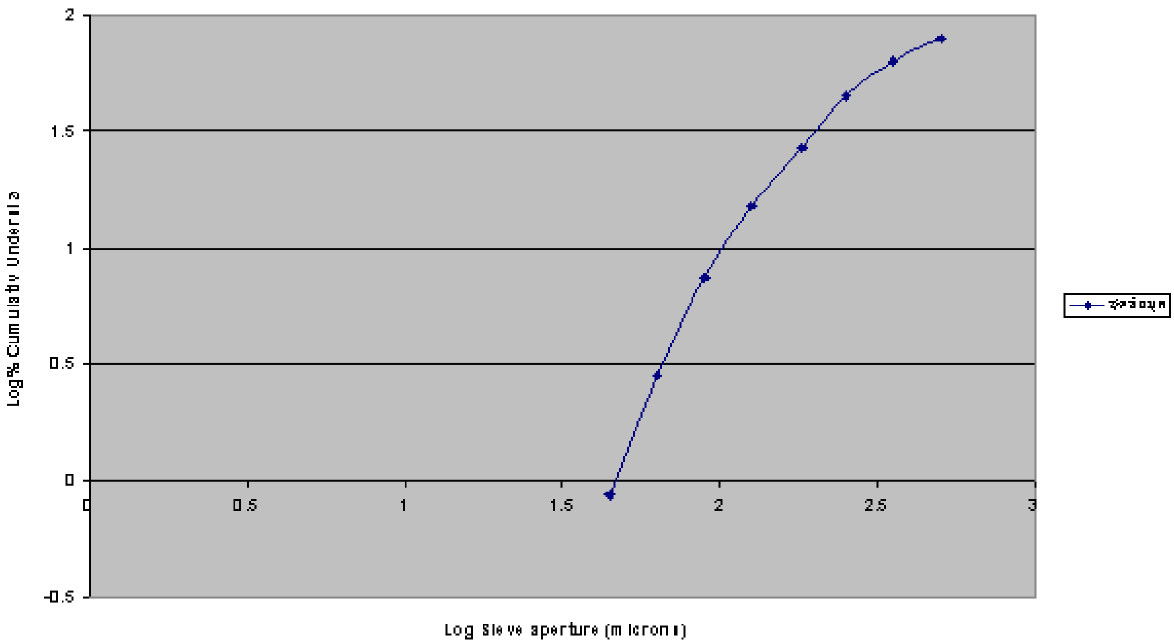

Figure 1. Plot of log % cumulative undersize against log sieve aperture size for LIMS

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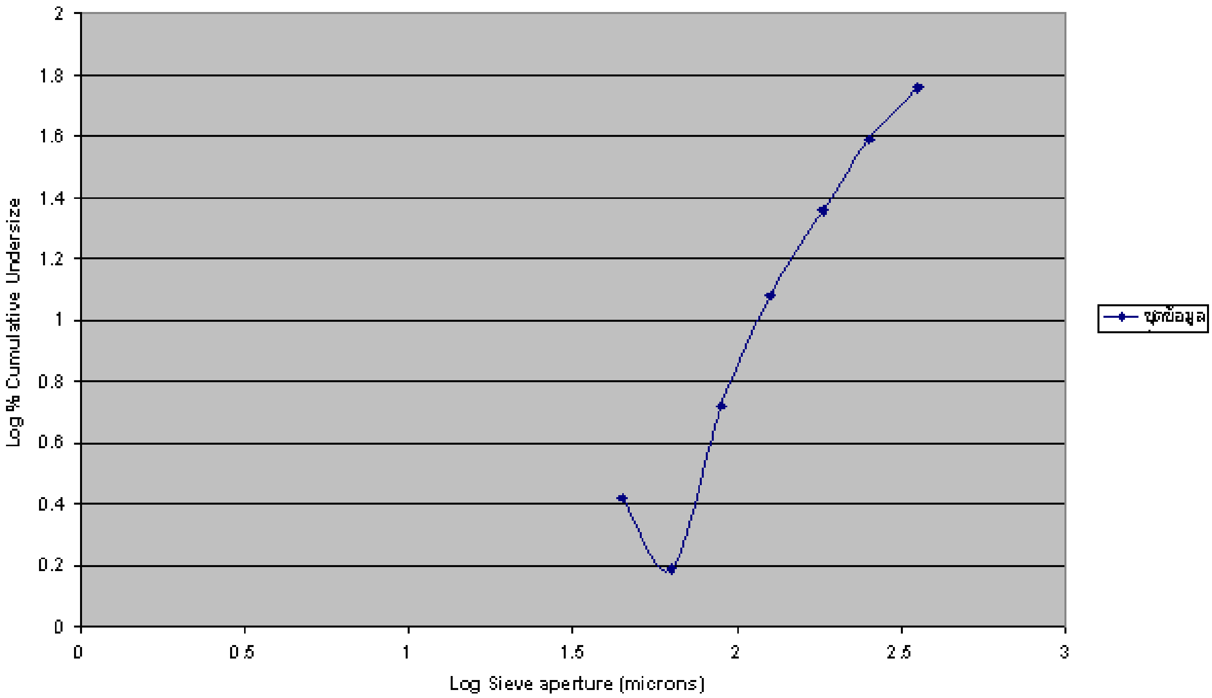

Figure 2. Plot of log % cumulative undersize against log sieve aperture size for WHIMS

The mass balance chart in Figure 3 shows that Itakpe sinter feed with 77% fractions passing through the 500-µm sieve was fed to the wet low intensity magnetic separator, which produced a ferromagnetic super-concentrate and a second product consisting of paramagnetics and gangue. The super-concentrate assayed 67.59% with the weight and iron recovery of 13.20% and 14.40% respectively, while the paramagnetic assayed 62.83% with the weight and iron recovery of 86.80% and 85.60% respectively. The WHIMS super-concentrate obtained from the paramagnetic assayed 68.70% with the weight and iron recovery of 78.73% and 84.91% respectively. These results show that the WHIMS concentrate had the highest iron content and recovery, while the paramagnetic yield of the Boxmag-Rapid wet low-intensity magnetic separation gave the lowest iron content. In general, the results indicate that the magnetic method successfully upgraded Itakpe iron ore to a super-concentrate grade [6].

Chemical analysis revealed iron content of 66.88%, 64.23% and 56.27% for +500µm, -500 µm+180µm and -180µm sieve fractions of sinter-grade iron ore respectively (Table 3). The average iron content determined for the sinter-grade ore was 63.63% (Table 4). The iron content of 66.88% and 64.23% for the coarse-size fractions of +500µm and -500µm+180µm exceeded the average iron content of 63.63%. However, the 56.27% iron content determined for the -180 µm fraction was lower than the average iron content. This suggests that the coarse fractions of the Itakpe sinter-grade ore were richer in iron than the fine-size fractions, and that such concentration method as gravity separation may be more economical in upgrading the Itakpe sinter-grade concentrate to a super-concentrate. The iron content determined for all the size fractions, except the -180µm one, was higher than the 63.22%

present in the concentrate in use at the China Anshan iron and steel company. In addition, it exceeded the standard specification of 63% for use at the Ajaokuta steel plant blast furnace.

The determined acid oxides in term of silica and alumina were 2.98%, 5.79% and 10.97% for +500µm, -500µm+180µm and -180µm sinter-grade iron ore fractions respectively (Table 3), the average acid oxide content being 6.62% (Table 4). The acid content thus seemed to increase with decreasing sieve size, the coarser fraction of the sinter-grade concentrate containing less acid gangue than the finer fraction. The acid gangue content determined for all the size fractions as well as the representative sample was observed to exceed the upper limit of 3.0% for Midrex direct reduction process [6]. For some other standards, the total acid oxides include titanium oxide [3]. These analysis results indicate that Itakpe concentrate needs to be further upgraded to be useable in the Midrex direct reduction process.

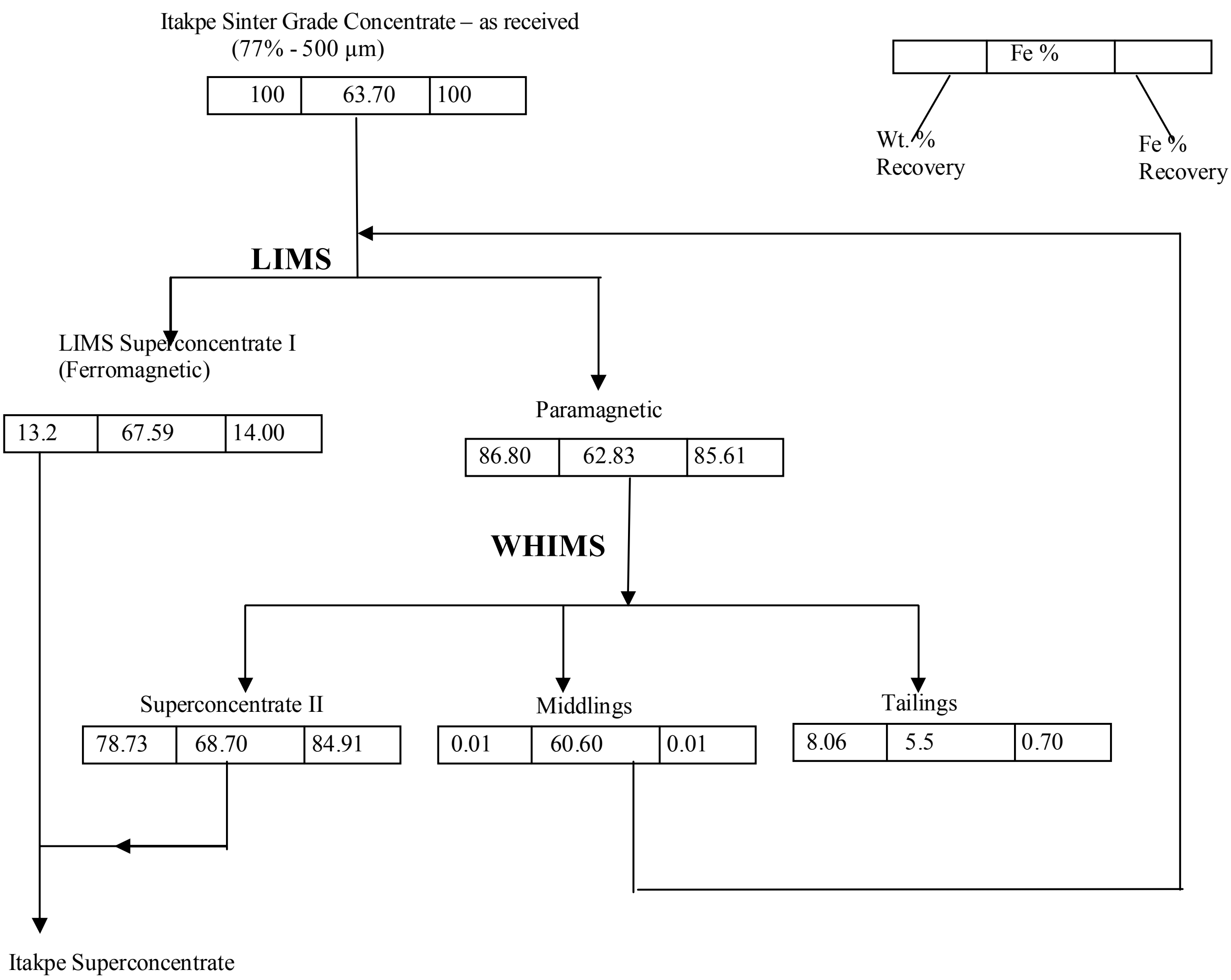

Figure 3. Mass balance for the production of Itakpe super-concentrates by magnetic separation.

The chemical analysis result also indicated the content of iron and acid oxide at 67.59% and 1.55% respectively for LIMS super-concentrate, and at 68.70%, 3.22% respectively for WHIMS super-concentrate. This indicates that the magnetic concentrates satisfied the iron content (66-66.8%) required for the Midrex process while the acid oxide content (1.55-3.22%) fell below the upper limit of 3.5% for the Midrex process. Thus, LIMS and WHIMS Itakpe iron ore super-concentrates obtained met the chemical composition requirements for Midrex direct reduction.

Conclusions

The sinter grade of the Nigerian Itakpe iron ore that assayed 63.63% iron and 6.62% total acid gangue was successfully upgraded to super-concentrates by low intensity magnetic separation and wet high intensity magnetic separation with higher iron content of 67.59% and 68.70%, and lower acid gangue of 1.55% and 3.22% respectively. These figures meet the requirements for a Midrex-grade super-concentrate while the percentage of fractions of the concentrates passing through the 45-μm sieve fell below the upper limit of 30%. This should minimise dust loss during transport to the direct reduction plant.

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