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[1.] Ebenezer Oyedele AJAKA, [2.] Ayotunde Emmanuel ADESINA, [3.] Abiodun I. LAWAL

DETERMINATION OF THE OPTIMUM CONDITIONS FOR BENEFICIATION OF SELECTED NIGERIAN IRON ORES USING SHAKING TABLE

[1-3.] Department of Mining Engineering, School of Engineering and Engineering Technology,
The Federal University of Technology, Akure, Ondo State, NIGERIA

Abstract: The optimum gravity separation conditions for beneficiation of iron ores from Itakpe and Ajabanoko were studied using shaking table. Bulk representative samples were collected from the two locations and their chemical and mineralogical compositions were determined using X-ray fluorescent and microscope respectively. The mineralogical studies of the two deposits shows that hematite is the most dominant iron mineral in the Itakpe iron ore while magnetite is the most dominant iron mineral in the Ajabanoko iron ore. Results of the chemical composition analyses indicated that the grade of Itakpe iron ore is 36.18 % Fe while that of Ajabanoko is 34.14 % Fe. The results of determination of concentration criteria shows the two deposits can also be beneficiated on a large scale with gravity techniques. Beneficiation study with shaking table at feed rate of 0.15 L/sec of the slurry and at inclination of 8^0 and a stroke length of 5 cm gives optimum recovery of iron to be 69.83 % at 20 % solid at +600 µm particle size for Itakpe iron ore while the optimum recovery was found to be 83.13 % at 20 % solid at +900 µm particle size for Ajabanoko iron ore. Similarly, the highest Fe grade of Itakpe iron ore was 70.9 % at 20 % solid and + 300 µm particle size, while the highest Fe grade of Ajabanoko iron ore was recorded at 69.9 % at 20 % solid and + 150 µm particle size with the same condition. The results show particle size and dilution ratio play vital roles on the recovery of the iron minerals.
Keywords: Particle Size, Concentration Criteria, Recovery

1. INTRODUCTION AND GEOLOGY OF THE STUDY AREAS

Gravity concentration process is the oldest beneficiation method known to mankind. This is a physical process that exploits the differences in densities of minerals to bring about a separation. The increasing demand for metals and mineral products, coupled with the critical depletion of known deposits of high grade ore has led to the development and mining of low grade ore deposits and improvement in methods of ore beneficiation. 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 (Egbe *et al.,* 2013). Minerals which can be separated by gravimetric methods must have measurable difference in density. Tabling efficiency is quite high when the specific gravity difference between mineral species in a process feed is high (Samykina *et al.,* 2005).Many factors affect the recovery of valuable minerals from their ores. Some of such factors are the grain size range of the liberated minerals, the percentage of natural fines in the ore and constraints imposed by concentrate end-users (Ajaka, 2009). All of these together relate to the overall cost of concentration.

Gravity techniques separate minerals in fluid media based on the application of two or more forces. Normally one of the forces is the resistance to motion by the viscous fluid e.g. water. So, besides the specific gravity the factors like size, shape and weight of the particles affect the relative movement and hence the separation (Singh *et al.,* 1997). The ease or difficulty of separation depends upon the relative differences in these factors. The 'Concentration Criterion' (CC) which gives an idea of the amenability of two minerals to separation by gravity technique, can be expressed as presented in Equation 1 (Rath and Singh, 2007).

$$CC = \frac{(d_h - d_f)}{(d_l - d_f)} \quad (1)$$

where: d_h is the specific gravity of the heavy mineral; d_l is the specific gravity of the lighter mineral; d_f is the specific gravity of the fluid

In general terms, when the quotient is greater than 2.5, whether positive or negative, then gravity separation is relatively easy, the efficiency of separation decreasing as the value of the quotient decreases.

Most of the iron ore deposit that abounds in Nigeria today has iron composition between the grade of 35% and 54% (Bamalli *et al.*, 2011). On this note, there need to be established an optimum recovery technique for the beneficiation of these iron ores. The process of beneficiation of lean grade ores is dependent on the variation in physical, chemical and mineralogical properties between constituent minerals and their grain sizes (Nayak *et al.,* 2012). Therefore a scientific research approach is required to optimize iron mineral recovery from these lean grade ores. Although the geology of the Itakpe deposit and liberation test suggests that the values are liberated below 1.6mm (Ajaka *et al.,* 2014), but the liberation size that will give optimum iron recovery need to be determined and this will help in the design of Ajabanoko deposit and redesign of Itakpe plant.

Therefore, the determination of the most applicable techniques and optimum conditions for concentrating values from Itakpe and Ajabanoko deposits (Nigeria) are highly imperative and are the main focus of the research work from which this article is drawn.

The study areas for this research work AreItakpeand Ajabanoko which both are located atOkene, Kogi State, Nigeria. Itakpe is located between latitudes 7°35'00'' N and7°39'00'' N and longitudes 6°17'00'' E and 6°20'00'' E while Ajabanokois located about 4.5 km North West of Itakpe hill, Kogi State and lies between latitude 7°37'22'' N and 7°39'17'' N and longitudes 6°12'55'' E and 6°15'15'' E.Both iron ore deposit are located within the Nigerian Basement complex rocks. Associated rocks in Itakpe area are migmatitic gneiss; schists include quartz-biotite-hornblende-pyroxene gneiss, quartz-biotite garnet gneiss, amphibolites schist, quartzitic schist and muscovite schist. The monzodiorites, granodiorites, granites and pegmatites make up the intrusions. The dominant lithologic units of Ajabanoko deposit area are gneiss of migmatite, biotite and granite, ferruginous quartzites, granites and pegmatite (Amigun and Ako, 2009). The ferruginous quartzite is the source of the iron ore mineralization in the area (Olade, 1978). Figure 1 show iron ore mineralization in Nigeria while Figure 2 presents the regional geology of Itakpe and Ajabanoko areas.

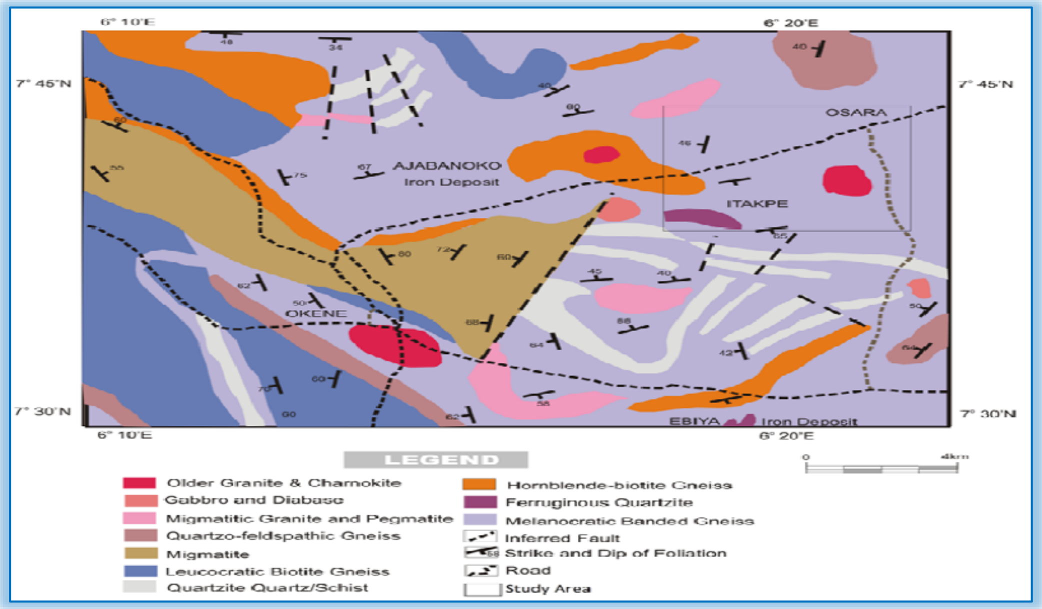

Figure 1: Geological Map of the Study Areas (After Akpah *et al*., 2013)

2. METHODOLOGY

2.1. Sample collection and preparation

Iron Ore samples were collected from National Iron Ore Mining Company (NIOMCO) site at Itakpe and Ajabanoko green field Iron ore deposit both in Kogi State. The samples were then subjected to various analytical tests and beneficiation studies to determine the conditions for optimum recovery.

2.2. Mineralogical analysis of the iron ore samples

Thin section slides of the samples were prepared and studied using a petrography microscope. Modal analysis technique was used to determine the mineralogical composition of the iron ore samples. Four different counts of different spots on a slide were taken and averaged for quantitative assessment of each mineral type identified.

2.3. Chemical composition analysis

Chemical composition analysis was carried out using Energy-dispersive X-ray Fluorescent (XRF). The type of chemical composition analysis required here is the elemental analysis of the ore in order to ascertain the percentage of elements present. The sample to be analysed was ground up to -212µm for effective and quick detection of the desired element. The analysis using the XRF took 25 seconds for the result to be ready.

2.4. Beneficiation studies

Prior to the beneficiation studies, concentration criterion for both ores was calculated using equation (1) to determine the applicability of gravity concentration to the beneficiation of the ores.

The specific gravity of the major minerals is Hematite (5.26), Quartz (2.60) and Magnetite (5.17). The Ore samples were crushed, ground and classified to five different particle size ranges which are +150 µm, +300 µm, +600 µm, +900 µm and +1180 µm for the beneficiation studies. Three (3kg) of each particle size was used in the study. Beneficiation studies of the iron mineral were carried out with a shaking Table. A slurry agitator was used to prepare 3kg of each particle size range into slurry of three dilution ratios (20 %, 30 % and 40 % solid by weight). The objective of the study was to determine the effects of particle size and dilution ratio on recovery of iron mineral. The slurry was then feed into the shaking table at a steady flow rate. Optimum feed rate of 0.15L/sec was used. The composition of the concentrates and tailings were determined using Buck Scientific Model 210 VGP Atomic Absorption Spectrophotometer after adequate digestion of the sample for the test.

3. RESULTS

3.1. Chemical compositional analysis

Table 1 and Table 2 show the results of the chemical compositional analysis of Itakpe and Ajabanoko iron ore respectively, while Table 3 and Table 4 show the results of mineralogical analysis of Itakpe and Ajabanoko iron ore from modal analysis of photomicrograph of thin sections made from the Ore samples.

Table 1: Chemical Composition Analysis of Itakpe Iron Ore Deposit

Chemical Composition	Fe_2O_3/ Fe_3O_4	Al_2O_3	SiO_2	MgO	Na_2O	K_2O
% Composition	36.18	3.20	42.05	0.35	0.22	0.24

Table 2: Chemical Composition Analysis of Ajabanoko Greenfield Iron Ore Deposit

Chemical Composition	Fe_2O_3/ Fe_3O_4	Al_2O_3	SiO_2	MgO	Na_2O	K_2O
% Composition	34.4	2.80	43.05	0.55	0.52	0.64

3.2. Mineralogical analysis

Table 3: Modal Analysis of Itakpe Iron Ore Deposit

Mineral	1st Count	2nd Count	3rd Count	4th Count	Total	Percentage
Hematite	6	7	6	8	27	29.67
Magnetite	5	7	4	6	22	24.18
Quartz	10	9	7	11	37	40.65
Corundum	1	-	-	1	2	2.20
Accessory Mineral	-	1	-	2	3	3.30
Grand Total					91	100.0

Table 4: Modal Analysis of Ajabanoko Iron Ore Deposit

Mineral	1st Count	2nd Count	3rd Count	4th Count	Total	Percentage
Hematite	6	5	4	5	20	20.41
Magnitite	6	9	4	7	26	26.53
Quartz	11	9	10	12	42	42.86
Corundum	1	-	2	1	4	4.08
Accessory Mineral	2	1	1	2	6	6.12
Grand Total					98	100.00

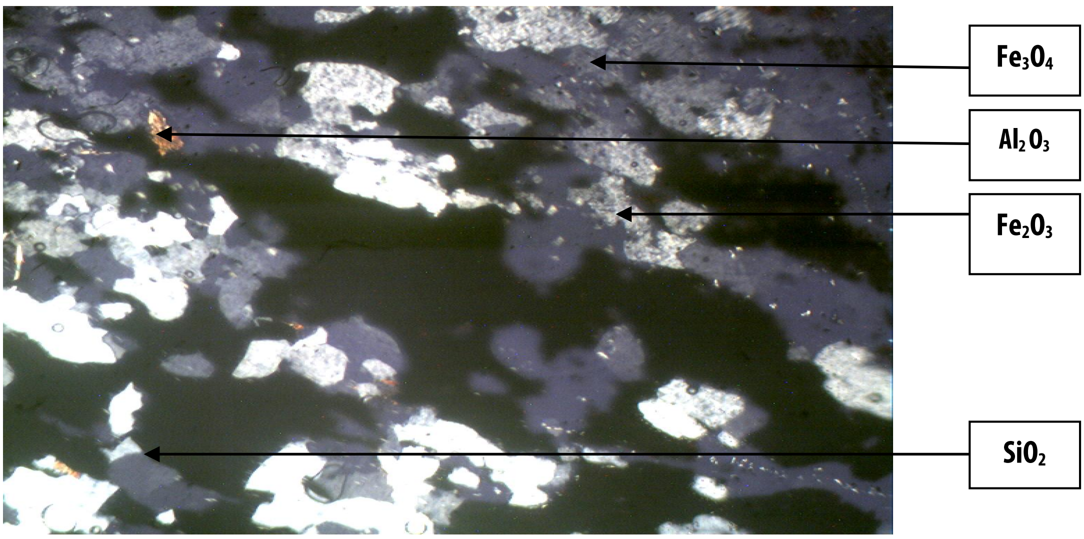

Plate 1: Microstructure image of Itakpe Iron Ore under the Microscope

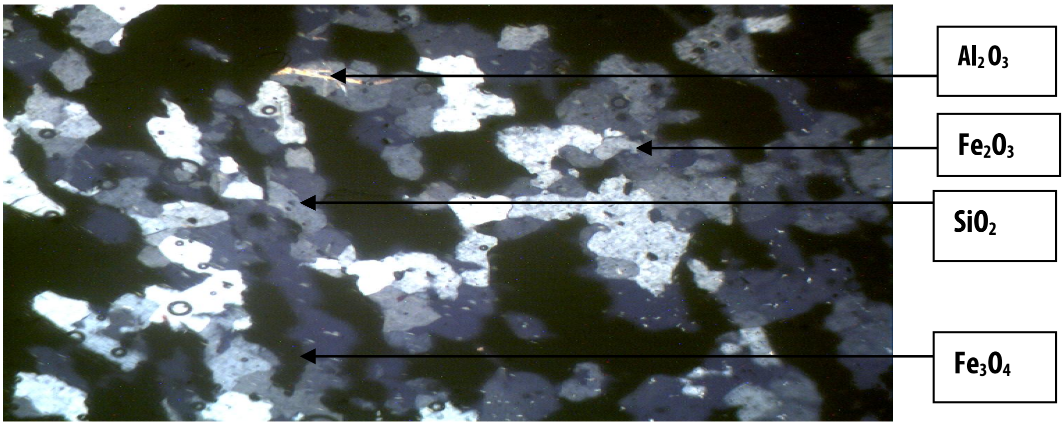

Plate 2: Microstructure image of Ajabanoko Iron Ore under the Microscope

3.3. Particle size analysis

Table 5 and Table 6 show the result of Particle size analysis after grinding of Itakpe and Ajabanoko iron ore respectively.

Table 5: Particle Size Analysis of Itakpe Iron Ore after Grinding

		RETAINED				PASSING
Sieve size range (mm)	Nominal Aperture sizes (μm) N	Wgt (g)	Cum Wgt (g)	% Wgt	% Cum Wgt (M)	% Cum Wgt (P)
+2350	2350	850.40	850.40	28.34	28.34	100.00
-2350+1700	1700	265.06	1115.46	8.84	37.18	71.66
-1700+1180	1180	127.06	1242.52	4.24	41.42	62.82
-1180+900	900	160.16	1402.68	5.34	46.76	58.58
-900+450	450	204.90	1607.58	6.83	53.59	53.24
-450+300	300	210.84	1818.42	7.03	60.62	46.41
-300+212	212	189.44	2007.86	6.32	66.94	39.38
-212+150	150	308.54	2316.40	10.29	77.23	33.06
-150+105	105	384.84	2701.24	12.83	90.06	22.77
-105	-105	298.24	2999.48	9.94	100	9.94

Table 6: Particle Size Analysis of Ajabanoko Iron Ore after Grinding

		RETAINED				PASSING
Sieve size range (mm)	Nominal Aperture sizes (μm) N	Wgt (g)	Cum Wgt (g)	% Wgt	% Cum Wgt (M)	% Cum Wgt (P)
+2350	2350	878.34	878.34	29.28	29.28	100.00
-2350+1700	1700	218.12	1096.46	7.27	36.55	70.71
-1700+1180	1180	119.10	1215.56	3.97	40.52	63.44
-1180+900	900	165.10	1380.66	5.50	46.02	59.47
-900+450	450	213.98	1594.64	7.13	53.15	53.97
-450+300	300	216.78	1811.42	7.23	60.38	46.84
-300+212	212	228.40	2039.82	7.61	67.99	39.61
-212+150	150	190.58	2230.40	6.35	74.34	32.00
-150+105	105	376.90	2607.30	12.56	86.90	25.65
-105	-105	392.58	2999.88	13.09	99.99	13.09

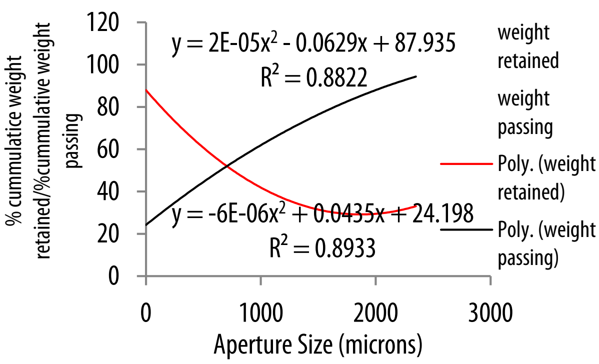

Figure 1: Particle Size Analysis of Itakpe Iron Ore after Grinding

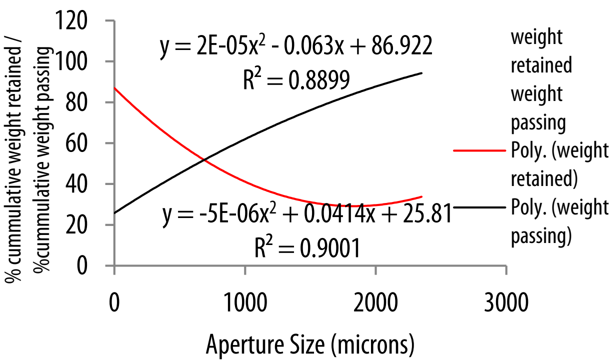

Figure 2: Particle Size Analysis of Ajabanoko Iron Ore after Grinding

3.4. BENEFICIATION STUDIES

Table 9 to Table 12 show the result of Beneficiation Studies of Itakpe and Ajabanoko iron ore using shaking table.

Table 7: Beneficiation of Itakpe Iron Ore using Shaking Table at 30 % Solid

Sieve Size (µm)	Feed (g)	Concentrate			Middlings			Tailings			Recovery (%)
		Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	
1180	3000	1000	62.9	14.8	1500	41.4	36.2	500	14.3	62.7	57.95
900	3000	1100	63.5	14.6	1300	42.3	35.8	600	13.2	63.2	64.35
600	3000	1000	64.1	13.5	1200	44.6	33.2	700	13.1	64.1	59.07
300	3000	900	67.9	12.65	1100	46.1	30.3	900	10.8	66.1	56.3
150	3000	800	60.2	18.2	1200	43.2	35.1	1000	11.6	65.8	44.37

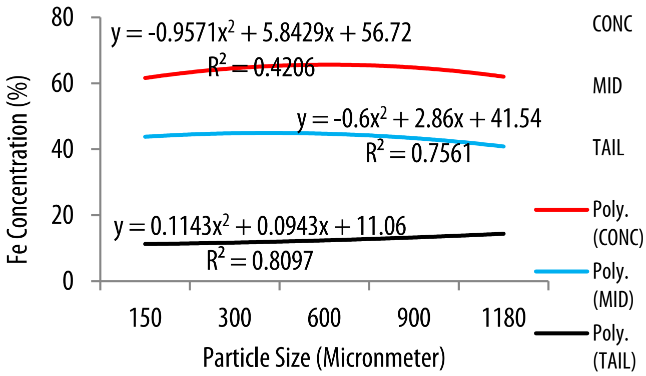

Figure 3: Iron Concentration Variation with Particle Size of Itakpe iron ore after Beneficiation using Shaking Table at 30% Solid

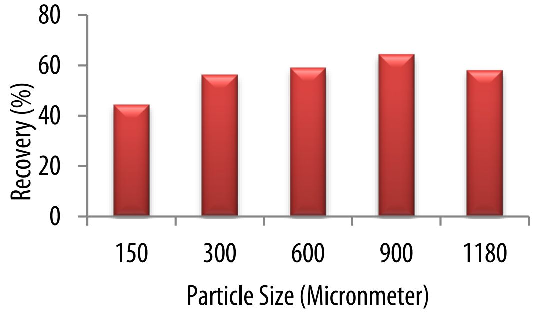

Figure 4: Iron Recovery Variation with Particle Size of Itakpe iron ore after Beneficiation using Shaking Table at 30% Solid

Table 8: Beneficiation of Itakpe Iron Ore using Shaking Table at 20 % Solid

Sieve Size (µm)	Feed (g)	Concentrate			Middlings			Tailings			Recovery (%)
		Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	
1180	3000	1100	63.8	14.8	1200	46.4	32.1	700	13.3	64.8	64.66
900	3000	1150	64.9	14.2	1000	45.8	33.3	800	15.9	63.2	68.76
600	3000	1100	68.9	13.8	1200	44.9	33.1	700	13.4	65.4	69.83
300	3000	1020	70.9	10.2	1350	46.8	31.8	500	10.1	66.9	65.32
150	3000	1000	65.5	18.9	1400	50.2	28.2	600	12.6	67.1	63.36

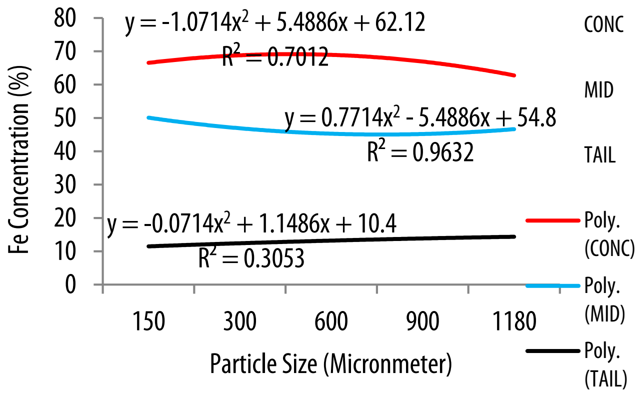

Figure 5: Iron Concentration Variation with Particle Size of Itakpe iron ore after Beneficiation using Shaking Table at 20% Solid

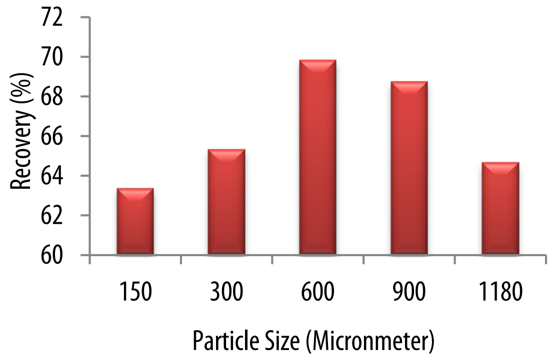

Figure 6: Iron Recovery Variation with Particle Size of Itakpe iron ore after Beneficiation using Shaking Table at 20% Solid

Table 9: Beneficiation of Ajabanoko Iron Ore using Shaking Table at 30 % Solid

Sieve Size (µm)	Feed (g)	Concentrate			Middlings			Tailings			Recovery (%)
		Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	
1180	3000	1200	63.1	15.8	1000	43.4	35.2	600	12.3	64.8	73.59
900	3000	1200	64.9	14.6	950	45.7	33.8	700	15.3	62.1	75.68
600	3000	1000	62.35	12.5	1150	49.2	29.4	800	13.5	65.1	60.59
300	3000	900	65.5	11.65	1200	46.3	32.2	900	11.2	65.9	57.29
150	3000	900	67.9	10.3	1100	51.6	27.2	1000	10.6	67.8	59.38

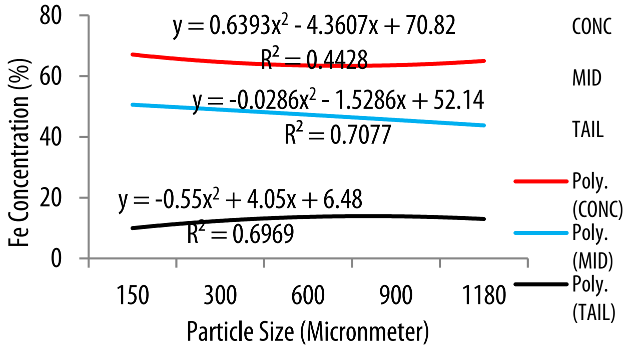

Figure 7: Iron Concentration Variation with Particle Size of Ajabanoko iron ore after Beneficiation using Shaking Table at 30% Solid

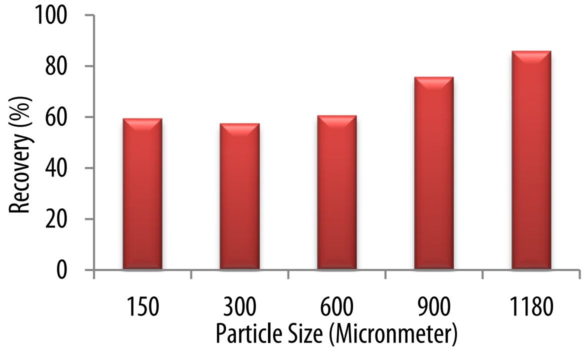

Figure 8: Iron Recovery Variation with Particle Size of Ajabanoko iron ore after Beneficiation using Shaking Table at 30% Solid

Table 10: Beneficiation of Ajabanoko Iron Ore using Shaking Table at 20 % Solid

Sieve Size (μm)	Feed (g)	Concentrate			Middlings			Tailings			Recovery (%)
		Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	Wt (g)	% Fe	% Si	
1180	3000	1300	60.9	15.8	1000	41.1	37.8	700	11.9	67.9	76.93
900	3000	1400	61.1	14.6	1000	43.8	35.2	600	13.7	66.2	83.13
600	3000	1200	64.5	13.5	1100	45.6	32.8	700	12.1	67.9	75.0
300	3000	1100	66.35	11.65	1150	47.9	31.0	750	10.3	69.0	70.92
150	3000	900	69.90	10.3	1100	49.2	28.0	1000	9.8	69.9	61.13

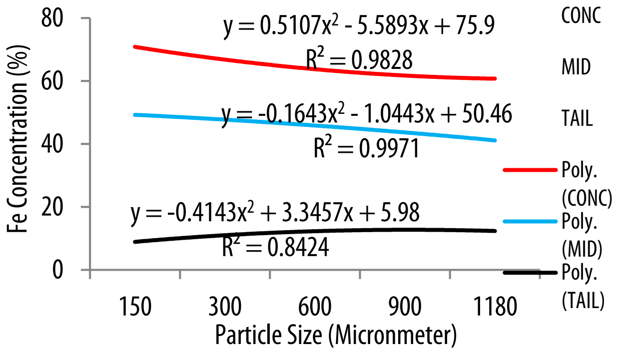

Figure 9: Iron Concentration Variation with Particle Size of Ajabanoko iron ore after Beneficiation using Shaking Table at 20% Solid

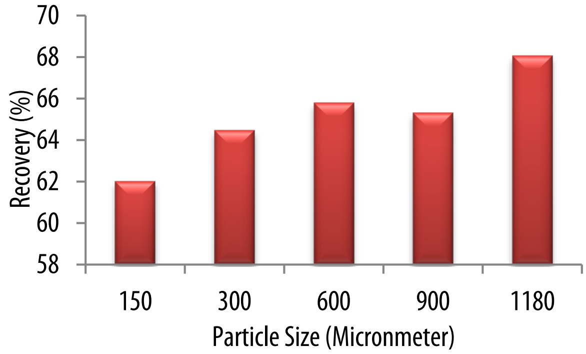

Figure 10: Iron Recovery Variation with Particle Size of Ajabanoko iron ore after Beneficiation using Shaking Table at 20% Solid

4. DISCUSSION

4.1. Chemical Composition Analysis

The chemical composition analysis of Itakpe iron ore as represented in Table 1 show that Itakpe contains iron, silicate, aluminium, magnesium, potassium and sodium elements, while Table 2 represents the Ajabanoko deposit which is composed of iron, silicate, aluminium, magnesium, potassium and sodium as well. It should be noted that potassium, aluminium, magnesium and sodium occurs in a very small amount for the two deposits. The chemical composition also confirmed that Itakpe iron ore has average iron concentration of 36.18 % before carrying out any beneficiation on it, while the Ajabanoko iron ore has average iron concentration of 34.4 % before processing as presented in Table 2.

4.2. Mineralogical Analysis

Table 3 and Table 4 show the mineralogical analysis of Itakpe and Ajabanoko iron ore respectively. Table 3 shows that Itakpe has higher composition of hematite mineral (29.67 %) than magnetite mineral (24.18 %). Table 4 which represent the Ajabanoko mineralogical analysis which has higher composition of magnetite mineral (26.54%) compare to hematite mineral (20.41 %). Although, both ore has higher composition of quartz mineral which can be consider as the dominant gangue mineral present in the ores.

4.3. Beneficiation studies

The general observations in the study shows that separating fluid plays a vital role in the separation of concentrates from the tailings and that the particle sizes also aid the recovery. Although, there is appreciable recovery at higher particle sizes, but the recovery was decreased at smaller particle sizes.

» **Effects of Dilution Ratio**

The influence of dilution on the recovery of iron ore using Shaking Table is as revealed in Tables 9, 10, 11 and 12. The volume of water in the agitator provides the necessary dilution required for particles separation for efficient separation. The highest grade was achieved with 20% solid with tabling gravity technique. The 30 % solid which is the low dilution (higher percent solids) led to decrease in the falling rate of particles leading to overcrowding of the particles in the course of separation which will make the separation not to be effective. The beneficiation of both deposit using shaking table shows best grade were achieved at 20 % dilution as presented in Tables 10 and 12.

» **Effects of Particle Size on Separation**

The effect of the particle size on the recovery of iron ore is also shown in Tables 9, 10, 11 and 12. Lower separation efficiency in finer particles was observed and believed to be caused by the negligible mass associated with these size particles. Particles so small that settle in accordance with Stroke's law are unsuitable for concentration (Wills and Napier-Munn, 2006). The coarser particle size was the size at which both deposit recorded the highest recovery using the Shaking Table. The tables also revealed that there is increasing uniform trend of grade from higher particle sizes (+ 1180 μm) to smallest particle size (+150 μm) used in this study.

» **Separation Effectiveness**

The results, as shown in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8 Figure 9 and Figures 10 revealed that iron ore concentrate was effectively separated from the tailings, which are dominated with quartz minerals. Theoretically, effective separation was possible because the quotient of the difference in their specific gravities is greater than 2.5. From the same results, it was observed that the overflow, i.e. the tailings still have a higher percentage of Fe. This Fe in the gangue may come frommagnetite in the ore, which was not effectively separated. The result of the concentration criteria reveals that the 2.79 concentration criteria for the beneficiation of these iron ores in a large scale is possible and will be effective. Recall that hematite has higher specific gravity compare to magnetite which could hinder the effectiveness of separation. The specificgravity of magnetite is between 4.6 and 5.2, indicating that the quotient varies is between2.6 and 2.62. Recall from equation (1), as the quotient reduces, the effectiveness of the separation reduces. Also, from the mineralogical studies, it could be recalled that the Itakpe ore has higher percentage of hematite and lower percentage of magnetite, while the Ajabanoko ore has higher percentage of magnetite and lower percentage of hematite. This can be observed from the results of processing of the two deposits using shaking table study as presented in Table 9, Table 10, Table 11, and Table 12, it was observed that more quantity of water was collected at the tailings compartment and the rate at which the water move towards the tailings compartment made the requirement for water in separation process to increase which almost nullify the effects of dilution ratio compare to how the effects of dilution ratio remains the basis for separation.

5. CONCLUSION

The quartz mineral present in the iron ore was seen as the major gangue mineral and appears in form of coarse grains under the microscope during the mineralogical analysis. The iron ore reserves at Itakpe and Ajabanoko in Kogi state are mostly of lean grade. The results from mineralogical analysis revealed that the concentration criteria are fulfilled for the effective separation of the valuable minerals from the gangues using gravity separation techniques. These results shows that gravity separation can as well be carried out in a large scale on the two deposits which will be economical and profit driven if invested on.

The results of this study have clearly shown that optimum separation of iron ore concentrate from Itakpe and Ajabanoko iron ore by tabling operations is possible. It is clearly revealed that the optimum separation was greatly influenced by the dilution ratio and the particle size of the ores. The result of the work has also shown that the optimum Fe recovery could be achieved when the particle size is at coarser particle size and 20% dilution for both deposits using shaking table at 8° deck angle of inclination and 5 cm stroke length. As a result of the reasonable difference in specific gravity between the iron mineral and the main associated gangue minerals. Gravity separation was a possible solution for concentrating such ore. With respect to the particle sizedistribution, it was found that the recovery at coarser particle size is better than fine particle size. The outcome of the shaking table studies shows more water is needed for optimum processing of iron ore as this will give optimum beneficiation. The result of both deposits show little or no difference in terms of their recovery, which interprets to both deposit having the same physicochemical properties. The result of beneficiation using shaking table shows particle size and dilution ratio plays vital roles on the recovery of the iron mineral from its ores. Increase in dilution ratio gives increase in recovery and grade of iron. Also, the smaller the particle size the better the result of grade, but there is a limit at which gravity concentration will be efficient when the dilution ratio is too high or the particle size is too fine.

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