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DIRECT FLOTATION OF ITABIRITIC IRON ORE USING ANIONIC COLLECTORS[1]

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Abstract

The present work has evaluated the hematite direct flotation of an itabiritic ore of low iron content (26.0%) from the iron quadrangle, Minas Gerais, Brazil. The collecting reagents used in the investigation were the oleic acid, two commercial reagents and an industrial vegetable oil. The work considered the investigation of sodium silicate action as a gangue depressant and also a frother and a dispersing agent. After the accomplishment of the preliminary tests that targeted to establish the flotation best conditions, the use of oleic acid without the addition of a frother or a depressant was selected for the results optimization. The rougher concentrates were submitted to various cleaner stages and a Gaudin selectivity index of 31.2 was achieved with two cleaner stages. The silica content in the final cleaner concentrate was 1.67%, the tailings iron content was 3.77% and the iron recovery was 90.85%. With three cleaner stages a Gaudin selectivity index of 40.0 was achieved. The concentrate silica content was 0.95%, the tailings iron content was 4.04% and the iron recovery was 90.09%. These final cleaner stage results clearly demonstrate the viability of producing adequate concentrates for meeting the blast furnace and direct reduction specifications. The high selectivity index obtained in the flotation tests resulted in a superior iron recovery. The results evidenced the technical viability for the direct flotation of low iron content ores occurring in the iron quadrangle region and also indicate a big potential for the operational cost reduction.

Key words: Direct flotation; Hematite flotation; Oleic acid.

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1 INTRODUCTION

The iron ore mineralogical composition and iron content as well as the concentrate specifications demanded by seaborne market are the main technical factors driving the Brazilian iron ore treatment. The current and future scenarios for the mining industry show a progressive decrease of iron content as well as complex ores with different gangue minerals like carbonates, amphibole group minerals and other silicates. The increasing concentrators feed flow rate aiming to compensate the mass recoveries during the mine life, frequently contributes to the declining of iron recovery which is affected by fine particles contaminating the flotation froth. From another point of view, there exists the need for decreasing operational costs, to increase the market share and to reduce health and environmental impacts.

The answer to this intricate scenario has been the combination of different concentration methods, the search for improved or new technologies, the mineralogical aspects identification and reagents affecting the flotation and automated control systems. Regarding this technological and economical context, the cationic reverse flotation, that selectively depress the iron oxides, is currently the only process utilized in all iron ores flotation plants.

From a historical perspective the anionic direct flotation was the first method used to float low grade iron ores, studied before the cationic reverse flotation. The first patent that employed the flotation process for the beneficiation of an iron ore made up of hematite and quartz was applied by Tullis[(1)] in 1923. Hukki and Vartiaine [(2)] studied the effects of several fatty acids on the flotation of oxide minerals. According to Houot[(3)], sulphonates, hydroxamates and fatty acids were tested for the anionic direct flotation and the first industrial plants which used fatty acids for collecting the iron oxides were in the Humbolt and Republic mines in the USA. The silica content in the concentrates used to vary from 6% to 9%.

Another method considered the depression of the iron oxides using different types of starch in a basic pH and the silicates were activated with calcium ions before being collected by a fatty acid. During the seventies the cationic reverse flotation method dominated the industrial plants and today is the only method used.

In 1999 Quast [(4)] investigated the flotation of hematite using oleate as collector. More recently the anionic flotation of a Brazilian itabirite was investigated by Lopes[(5)] through bench scale tests with an ore sample denominated “Serra da Serpentina”. The tests were made in pH 7 with fatty acid and achieved an iron recovery of 90.0% and a concentrate silica content of 14.2%. Santana[(6)] performed bench flotation tests with different types of collectors and achieved the best result with the oleic acid.

A series of bench scale flotation test results with anionic reagents from 1931 to 2012 is presented in T pviana@demin.ufmg.brable 1.

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Table 1- Iron ore anionic direct flotation tests modified after Quast

Material	Collector	pH	% Iron feed	% Iron concentrate	% Iron recorery	Reference
Ore	oleic acid	-	17	59	74	Adams,Kobey and Sayers (1931)
Tailings	oleic acid	-	24	63	93	Searles (1938)
Tailings	Na oleate	>8	35	59	92	Cooke and Talbot (1955)
Ore	oleic acid	6 - 7	20	65	90	Cooke,Iwasaki and Choi (1959)
Ore	oleic acid	-	36	62	78	Cooke and Nummela (1959)
Ore	oleic acid	6 - 7	20	62	60	Cooke,Iwasaki and Choi (1960)
Ore	oleic acid	7	-	66	88	Thurston ,Kudo and Cooke (1962)
Tailings	oleic acid	-	49	66	87	Sorensen,Colombo and Frommer (1964)
ore	oleic acid	7.5	35	63	90	Balint and Fleming (1965)
Ore	K oleate	8.5	42	59	82	Fuerstenau,Harper and Miller (1970)
Ore	Na oleate	7	38	60	70	Tripathi, Dey and Jena (1976)
Ore	K oleate	7.8	40	64	56	Kulkarni (1976)
Ore	oleic acid	8	40	65	60	Kulkarni and Somasundaran (1977)
Tailings	oleic acid	6.5 - 7	16	51	83	Meech (1981)
Ore	oleic acid	6.5	16	53	84	Pindred and Meech (1984)
Ore	oleic acid	5.5	41	67	99	Tovar, Navarro and Pastrana (1988)
Tailings	oleic acid	-	32	45	50	Klimpel and Fee (1993)
Ore	Na oleate	7	32	67	91	Vieira and Salum (1994)
Sinthetic mixture	Na oleate	6	15	41	94	Pascoe and Doherty (1997)
Ore	Hidroxamate	7	35	62	78	Lopes (2009)
Ore	oleic acid	7	26	66	90	Santana (2012)

The present work aimed to test the viability of using the anionic direct flotation for the iron quadrangle ores considering the current scenario of the increasing mineralogical complexity and low iron content. The tested ore is not complex from the mineralogical point of view in spite of its very low iron content.

2 MATERIAL AND METHODS

The investigated material was the natural fines fraction minus 0.15 mm of an iron ore from the Minas Gerais iron quadrangle. The chemical analysis of the sample used during the tests showed a low Fe content of 25.78%, 60.33% of SiO_2, 0.26% of Al_2O_3, 0.68% of Mn, 0.010% of P and 1.28% of LOI. Mineralogical studies showed that the material was constituted mostly by hematite-28.52%, quartz-59.72%, goethite-8.93%, magnetite-1.5% and manganese oxides -0.65%. The hematite collecting reagents used in the bench scale tests were the oleic acid, two commercial reagents and an industrial vegetable oil. The work considered the investigation of the sodium silicate action as a gangue depressor, pine oil and a commercial frother reagent and sodium hexametaphosphate for dispersing. The variables considered in the tests were the pH, solids percentage, slurry agitation, conditioning time and reagents dosage. The tests were planned and executed according to the usual bench flotation tests procedures. For the better understanding and interpretation of the results the tests were divided in four phases. Aiming to minimize the time for the execution of the bench flotation tests and numerically validate the results an experiment design testwork was utilized. All the tests were performed in an aleatory order targeting to maximize the experiments robustness. The analyzed results were the modified Gaudin selectivity index, concentrate silica and iron content and iron and mass recoveries.

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3 RESULTS

The results obtained in the first stage tests are depicted in table 2 and figures 1 and 2. The flotation test in the first phase aimed to evaluate the collecting action of the reagents at specific values of pH (3.5, 5.0, 6.0, 7.0, 8.0 and 10.0). For each pH value the reagents were preliminarily tested in the dosages of 100, 200, 300, 400 and 500 g/t_{feed}. The dosage of 300 g/t_{feed} was selected and was utilized in all the first phase tests.

Table 2. Flotation tests results varying the collecting reagents and pH

Collector	pH	Iron recovery (%)	Concentrate SiO_2 (%)	S.I. Gaudin
Oleic acid	3.5	93.54	16.68	10.22
	5	93.81	15.97	10.78
	6	92.61	15.62	10.01
	7	92.66	12.49	11.43
	8	93.84	16.99	10.37
	10	98.22	59.96	1.87
OGVI	3.5	90.94	17.78	8.35
	5	92.58	20.96	8.38
	6	93.08	24.55	7.46
	7	92.45	18.09	9.00
	8	91.22	26.67	6.37
	10	98.08	59.52	1.59
Flotin FS-1	3.5	64.00	18.8	4.12
	5	93.33	37.58	4.98
	6	93.36	36.47	4.92
	7	94.11	32.38	6.24
	8	96.74	53.12	3.64
	10	98.37	59.07	2.49
Flotin FS-2	3.5	88.86	19.51	7.00
	5	96.41	29.19	8.81
	6	95.60	25.73	9.03
	7	94.29	22.87	8.72
	8	92.06	42.52	3.82
	10	94.21	56.99	2.15
Pine oil	3.5	33.06	13.33	3.82
	5	92.58	36.67	4.82
	6	96.47	47.65	4.7
	7	96.45	51.87	3.37
	8	3.33	57.19	1.05
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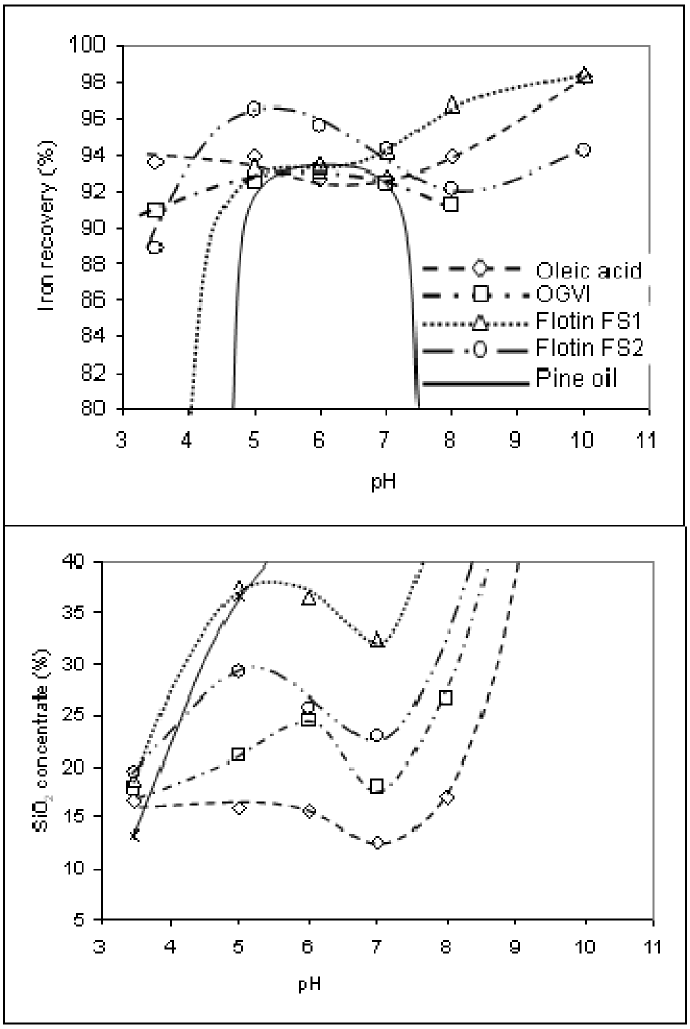

Figure 1. Iron recovery and silica content in the concentrate for different collectors and pH values.

Considering all the collectors the oleic acid and the industrial vegetable oil OGVI achieved the best results when observing the variables iron recovery and the concentrate silica grade. The best results for the silica grade in the concentrates were obtained in pH 7. The test with oleic acid produced a concentrate with a silica content of 12.49% and an iron recovery of 92.66%. The industrial vegetable oil OGVI test had the second best result and achieved a silica content in the concentrate of 18.09% and an iron recovery of 92.45. The data in the figure 2 shows the oleic acid with the greater selectivity index followed by the industrial vegetable oil OGVI and the commercial reagent Flotin FS2. Despite the fact that the acid oleic showed the best results among the tested collectors in this work further investigation demonstrated that the industrial vegetable oil and Flotin FS2 could also be used for floating the iron oxides and attend the concentrate chemical specifications. Based on the results of the first stage tests the oleic acid and the pH 7 were selected for the second phase tests. The oleic acid dosage remained 300 g/t_{feed}.

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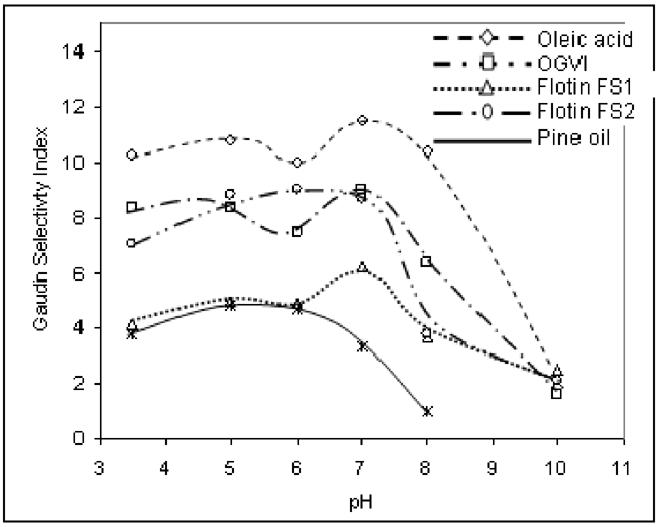

Figure 2. Gaudin selectivity index for different collectors and pH values.

The second phase tests consisted of varying the following test parameters: slurry agitation intensity, solids percentage during conditioning, conditioning time, frother dosage, dispersant dosage and depressant dosage. The results are shown in the table 3.

Table 3- Second phase test results

Collector	pH	Parameter		Iron recovery	Concentrate SiO_2 (%)	S.I. Gaudin
Oleic acid	7	Rotation (rpm)	900	92.66	12.49	11.43
			1800	93.32	56.59	1.90
			2500	73.81	43.92	2.16
		Conditioning solids (%)	42	93.37	14.04	11.31
			50	92.66	12.49	11.43
			55	93.88	21.52	8.80
		Conditioning time (min)	3	92.66	12.49	11.43
			10	91.73	14.93	9.75
			20	91.03	18.78	8.09
		Frothing reagent (g/ton)	0	92.66	12.49	11.43
			40	91.73	16.41	9.29
			80	94.90	30.32	7.18
		Dispersing reagent g/t	0	92.66	12.49	11.43
			40	93.39	27.46	6.91
			80	93.37	26.57	7.07
		Depressant (g/t)	0	92.66	12.49	11.43
			500	93.32	23.69	8.12
			1000	92.07	22.99	7.28

Table 3 data demonstrates that the best agitation condition was achieved with 900 rpm with a Gaudin selectivity index of 11.43, the lowest concentrate silica content and a high iron recovery. The best result for the conditioning solids percentage was obtained with 50% solids. Three minutes of conditioning was the best conditioning time. All the three reagents tested for verifying the best dosage showed the same result with 0.0 g/t_{feed} as the best flotation condition. The best results achieved in the

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second phase were established as fixed parameters during the tests of the third stage. The third stage tests were performed for detailing the influence of the oleic acid dosage in the flotation results. The results can be seen in the figure 3 and table 4.

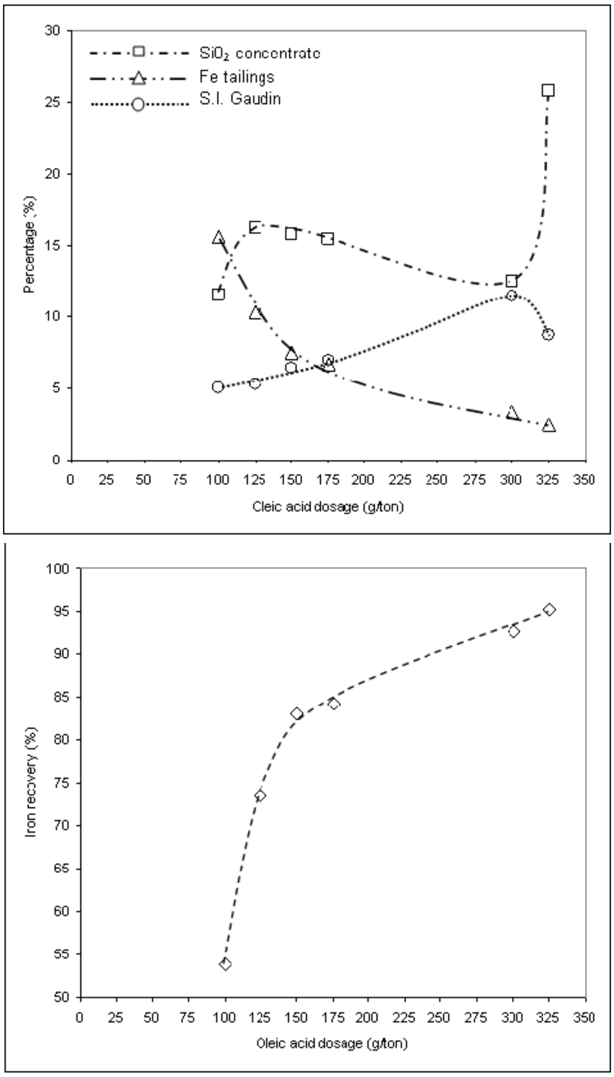

Figure 3- Influence of oleic acid dosage in the flotation results.

Table 4- Flotation tests results varying the collector dosage.

Collector	pH	Dosage g/t	Iron recovery	Concentrate SiO_2 (%)	Tailings Fe (%)	S.I. Gaudin
Oleic acid	7	100	53.82	11.52	15.54	4.99
		125	73.55	16.15	10.29	5.27
		150	83.07	15.78	7.45	6.46
		175	84.20	15.40	6.65	6.98
		300	92.66	12.49	3.32	11.43
		325	95.30	25.78	2.42	8.70

The second graph of figure 3 shows a continuous iron recovery increase as the oleic acid dosage increases. The optimal dosage was established as 300 g/t_{feed} based on the results presented in the first graph of the figure 3. The silica content decreases

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until reaching 300 g/t_{feed} and shows a sharp raising when attains 325 $g/_{tfeed}$. The selectivity index achieves a maximum value at 300 g/t_{feed}.

The fourth phase of tests was carried out aiming at the production of a concentrate to meet the silica content required by the seaborne market specifications. Four concentrate cleaner steps were added after the rougher step until reaching the adequate specifications. The results are shown in figure 4 and table 5.

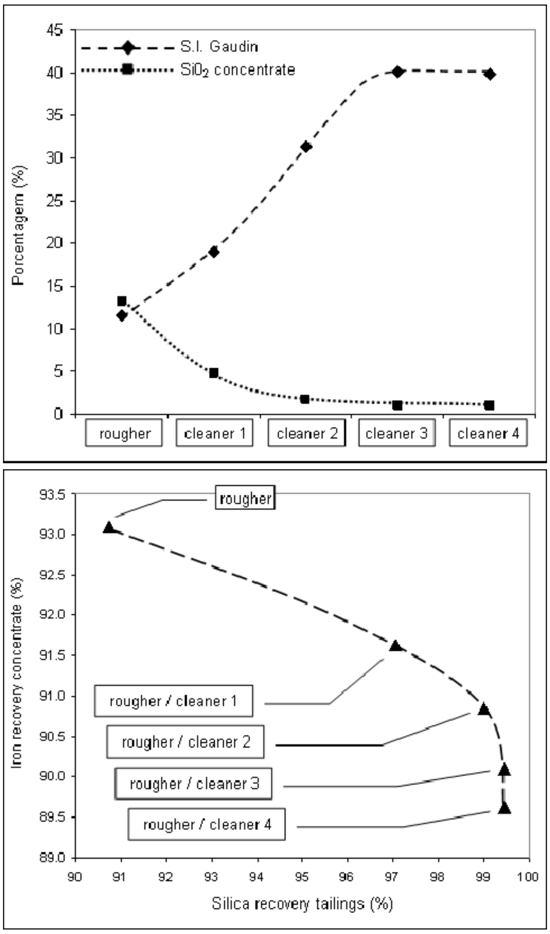

Figure 4- Concentrate rougher and cleaner stages.

Table 5- Bench flotation tests – concentrate rougher and cleaner stages

Collector	pH	Dosage g/t	Stage	Iron recovery	Concentrate SiO_2 (%)	Tailings Fe (%)	S.I. Gaudin
Oleic acid	7	300	rougher	93.10	13.24	3.13	11.48
			cleaner 1	91.64	4.72	3.53	18.91
			cleaner 2	90.85	1.67	3.77	31.22
			cleaner 3	90.09	0.95	4.04	40.05
			cleaner 4	89.62	0.92	4.22	39.75

It can be observed in table 5 that after two cleaner stages the concentrate silica content reaches 1.67%. This silica content would meet the blast furnace specification. The third cleaner stage generates a concentrate silica content of 0.95% that would meet the specifications for direct reduction furnaces. The figure 4 graphs show that the fourth cleaner stage is not necessary. The iron recovery and the

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Gaudin selectivity index have a small decrease and the concentrate silica content is almost the same of the third cleaner stage.

4 CONCLUDING REMARKS

The main result achieved in the present investigation was the possibility of producing an iron ore concentrate from an itabiritic Brazilian ore with extremely low iron content utilizing the anionic direct flotation method. The final concentrate silica content achieved values that meet the blast furnace and direct reduction specifications. The high selectivity index obtained in the flotation tests resulted in a superior iron recovery. The results evidenced the technical viability for the direct flotation of low iron content ores occurring in the iron quadrangle region and also indicate a big potential for the operational costs reduction.

REFERENCES

1 TULLIS W. Improvements in or Relating to the Concentration and Preparation for Smelting of Iron Ores, Bristsh Patent 206, 565, 1923.
2 HUKKI R. T. and VARTIAINEN O. An Investigation of the Collecting Effects of Fatty Acids in Tall Oil on Oxide Minerals, Particularly on Ilmenite. Transactions AIME 818-mining engineering, august 1953.
3 HOUOT R. Beneficiation of Iron Ore by Flotation – Review of Industrial and Potential Applications. International Journal of Mineral Processing, v. 10, n. 3, p. 183-204, 1983.
4 QUAST K. B. Flotation of hematite using oleate as collectors. The AusIMM proceedings, n.1, p. 7-13, 1999.
5 LOPES G. M. Flotação direta de minério de ferro. Ouro Preto: Departamento de Engenharia de Minas, Universidade Federal de Ouro Preto, 2009. 175p. (Dissertação de Mestrado).
6 SANTANA P. P. Flotação direta de minério de ferro itabirítico. Belo Horizonte, Programa de Pós-Graduação em Engenharia Metalúrgica, Materiais e de Minas (PPGEM), Universidade Federal de Minas Gerais, 2012.163p. (Dissertação de Mestrado).