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REVERSE FROTH FLOTATION OF BAUXITES FROM THE ZONA DA MATA AREA

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ABSTRACT

Bauxite beneficiation is not carried out outside Brazil. In industrial scale the ROM ore is fed directly to the alumina production plant. In Brazil, beneficiation is practiced by MRN, by CBA – in Itamarati de Minas and Poços de Caldas – and by Mineração Rio Pomba – in Mercês, MG.

The Itamarati de Minas plant has a full circuit of scrubbing, desliming, and heavy minerals separation in spiral concentrators, complemented by high intensity magnetic separation, but it still loses values in the fine fraction of the beneficiated ore, which currently consists of a tailing.

Reverse froth flotation of the silica present in this fraction, followed by magnetic separation of the depressed product, allows to recover bauxite from products till then considered as a tailing, and produces silica sand, which can be used in civil construction work and road maintenance, as well as a magnetic concentrate which can be used as charge additive in portland cement production. Therefore, the beneficiation of this fraction is important both economically and for mineral resources conservation.

Through experimentation in bench and in pilot plant scales, this work explores the applicability of that process to the bauxites of the Zona da Mata region, southeast of Minas Gerais. The previous tests have reached available alumina grades of 55% in bench scale and 42% in pilot plant, with 60% and 72% available alumina recovery, showing viability for industrial scale application of the process.

KEYWORDS: bauxite, reverse flotation, tailings recovery.

1. INTRODUCTION

Bauxite occurs as a product of weathered rocks, mainly in the tropical belt, where precipitation and temperature rates are extremely high. While the soluble species are leached, the product is a residue rich in aluminium oxides, although clay minerals, hematite, goethite, titanium oxide and quartz are also present.

About only 5% of the Brazilian production of bauxite is processed in the chemical and refractory industries, so the remaining is processed into alumina by the Bayer process. The alumina that can be extracted by the Bayer process is called available alumina (AA). Silica is present in two forms: quartz is the insoluble silica (Ins SiO_2), and silica found in clay minerals is the reactive silica (Re SiO_2) because it reacts with caustic soda during the digestion step, spends soda and steals aluminium, and forms an insoluble complex that can not be removed from the liquor. The mixture of impurities (iron and titanium oxides) is called red mud of the Bayer process and represents a disposal problem. So, it is imperative to get the lower contaminants grade possible in washed bauxite, otherwise bauxite couldn't be used as raw material for aluminium production.

Companhia Brasileira de Alumínio - CBA runs mines at Itamarati de Minas - MG and Descoberto - MG, and is installing a new complex at Miraí - MG with start-up expected for 2008. This region is inserted in a bauxite occurrence area that stretches from São João Nepomuceno - MG to the south of Espírito Santo.

These deposits, where bauxite occurs at the top and slopes of the so-called "half-orange" hills whose average height is of about 800 m, were originated by laterization of pre-Cambrian age granulites. In accordance to the mother-rock, these bauxites are classified as gnaissic (Itamarati de Minas and Miraí) or amphybolitic (Descoberto). Up to 0.350 mm, they present essentially the same mineralogical assembly; the finer fractions of the gnaissic bauxite are richer in quartz, while the amphybolitic bauxite is richer in titanium oxides and other bearing minerals. Both ores are dressed at CBA's preparation plant at Itamarati de Minas.

Previous investigation work has shown the suitability of the gravity beneficiation in Reichert spirals to remove these heavy minerals (Oba, 2000), and an industrial circuit has been erected at the plant, complemented by a high intensity wet magnetic separator to remove the magnetic fine particles (Bergerman, 2003). It works very well with the amphybolitic ore but poorly with the gnaissic one, so an alternative route had to be found. Considering the size of this fraction, froth flotation was the solution.

There is very little published literature about bauxite beneficiation via froth flotation, and no preparation plants descriptions were found. Only the following publications were found: Xu, Plitt and Liu, 2004; Bittencourt, 1989; and Bittencourt et al., 1990.

The Chinese work is about flotation of diasporic ores, not found in Brazil. The Brazilian publications describe research done at Utah University under Dr. Miller's supervision by Dr. L.R.M. Bittencourt, from Magnesita S.A., Contagem, MG. Aiming to obtain a gibbsite concentrate to be used as raw material for the production of first class alumina refractories, he tried the direct flotation of the bauxite minerals from a Rio Pomba bauxite ore sample, composed basically of gibbsite (50%), kaolinite (15%), and quartz (35%). This flotation had two steps: the first step was the flotation of gibbsite/kaolinite from quartz at pH 2 using alkyl sulfates as promoters, and the second one was the flotation of kaolinite from gibbsite using amines at pH 8.

Our initial work tried both routes: the direct flotation of gibbsite and the reverse flotation, floating the contained quartz. The initial studies were done by Freitas, T. G. (2004) in an end-of-course research paper. His work was followed by Kurusu, R.S. (2005) in another end-of-course research, and by Miss Massola-in an ongoing MSc research work. These works have been developed under Prof. Chaves' supervision and with a strong support, material as well as participative, from CBA's Itamarati de Minas Department team.

2. EXPLORATORY AND SYSTEMATIC TESTS

Freitas (Freitas, 2004) has done the first tests with the gnaissic ore from Itamarati de Minas. Two routes have been studied, the anionic (direct) flotation and the cationic (reverse) flotation. The chemicals to be used in the tests, as suggested by Clariant's team, were Flotinor SM-15 and Genapol LRO as promoters for the anionic flotation, and Flotigam EDA as promoter for the cationic one. In the reverse flotation tests, a caustic corn starch solution has been used as gibbsite depressant.

The first step consisted in ten exploratory flotation tests, varying the chemical dosages as well as the flotation pH. It was clear at visual inspection that the best separation between the products was reached in the reverse flotation tests. That was confirmed by the chemical analysis results. The best experimental condition was using 300 g/t of Flotigam EDA and 300 g/t of starch in pH 10, reaching the following grades in the depressed product: 25.5% AA and 1.3% ReSiO_2, with a mass recovery of 63.8%. As the iron and titanium minerals end up in the depressed product, diluting its AA grade, a magnetic separation operation becomes necessary. Thus, the available alumina grade increased to 42.2%.

Those encouraging results suggested that the study be continued. As it had became necessary to make systematic bench tests, samples of the 6" cyclones underflow were taken at Itamarati de Minas plant for 5 hours per day during 5 days, taking increments each hour. One sample was taken while dressing Itamarati de Minas ore, and another while dressing Miraí ore. After being decanted and dewatered in situ, samples were sent to the city of São Paulo, where they were dried, homogenized and quartered in representative aliquots.

Kurusu (Kurusu, 2005) made systematic bench tests, rougher-cleaner-scavenger tests and locked cycle tests trying to represent a continuous circuit using the Itamarati de Minas ore sample. Particles coarser than 0.210 mm, too heavy for flotation, were removed by screening. Also, aliquots had to be deslimed in 1 1/2" (40 mm) cyclones at a d_{95} of about 10 μm. This operation prevents the noxious effect of slimes in flotation: in non-deslimed material flotation tests, the concentrate was enriched in Re SiO_2 and had lower AA recovery when compared with deslimed material flotation tests.

Kurusu checked Freitas' work results, varying promoter addition in a first set, and then varying depressant addition, always keeping pH at 10. The best dosage for those rougher flotation tests was 300 g/t for both chemicals.

Then it went trough a rougher-cleaner-scavenger test. Here, scavenger is defined as the flotation of the rougher depressed product, and cleaner as the flotation of the rougher floated product. To the rougher stage were added 300 g/t of each chemical, plus 150 g/t of promoter to the scavenger one, with magnetic separation of the scavenger depressed product. Finally, a locked cycle was tested with five rougher stages, recycling cleaner depressed plus scavenger floated to the next rougher stage. The grades and recoveries reached in Kurusu's tests are presented in Table I.

Table I – 6" cyclone underflow and Itamarati de Minas ore flotation tests

depressed product	recovery (%)		grade (%)			
	mass	AA	AA	Re SiO_2	Ins SiO_2	Fe_2O_3
rougher	44.8	82.3	21.8	1.2	16.9	34.8
scavenger	46.3	92.9	25.6	0.9	7.0	38.9
non-magnetic scavenger	17.8	68.7	49.3	0.8	11.0	11.9
non-mag. scavenger (locked cycle)	14.1	60.4	52.6	1.9	2.8	9.0

At last, Massola made the bench flotation tests using the Miraí ore. The samples were screened at 0.210 mm and deslimed in microcyclones, using the same procedure Kurusu had followed. The size and chemical analysis per size fraction, for both Itamarati de Minas and Miraí ores, are shown in Table II. The first tests consisted in varying the chemical dosages, i.e., Flotigam EDA and corn starch, to determine the best experimental conditions. That was obtained with 300 g/t of Flotigam EDA and 300 g/t of corn starch at pH 10, recovering 44.1% of mass and 85.9% of available alumina in the rougher concentrate. After magnetic separation, these values were respectively 14.6% and 60.2%, with a final AA grade of 55.2%.

Table II – size distribution and chemical analysis (%) of 6" cyclone underflow samples, Miraí and ITM ores

mm	mass		AA		Re SiO_2		Ins. SiO_2		Fe_2O_3	
	ITM*	Miraí	ITM*	Miraí	ITM*	Miraí	ITM*	Miraí	ITM*	Miraí
0.420	4.0	4.1	30.6	22.9	7.0	1.26	20.0	48.1	14.8	12.0
0.210	29.6	18.9	11.9	11.6	2.5	0.76	63.5	65.6	11.8	11.7
0.149	20.7	26.1	11	21.2	3.9	1.52	59.5	54.1	12.4	17.3
0.105	18.1	11.9	12.7	13.6	3.5	1.15	50.7	44.7	15.9	22.1
0.074	10.3	15.2	17.8	14.9	4.6	1.20	37.6	36.0	21.3	25.4
-0.074	17.3	23.8	17.3	14.0	5.9	3.65	17.6	15.0	25.2	36.4
calculated head			14.2	15.9	4.0	1.8	48.0	42.9	16.1	22.4

*ITM: Itamarati de Minas ore

As the slimes were an actual problem, a di-amine was tested as an alternative promoter, which has a coagulant in its formulation and is able to deal with the amount of slimes present in the samples. So, after repeating the tests routine, the result was that 400 g/t of di-amine and 300 g/t of starch were the best conditions. Those dosages yielded a concentrate with 26.3% of mass recovery, 35.0% of AA recovery at a grade of 71.7%. Unfortunately, the di-amine consumption is higher than the Flotigam EDA one, and this chemical, more expensive, so it was decided to continue this work using Flotigam EDA as the promoter. Table III sums up the results obtained in the Miraí ore bench flotation tests.

Table III – Bench flotation tests using the Miraí ore

depressed product	promoter	recovery (%)		grade (%)			
		mass	AA	AA	Re SiO_2	Ins SiO_2	Fe_2O_3
rougher	Flotigam EDA	44.1	85.9	26.1	0.7	8.9	38.1
non-magnetic rougher	Flotigam EDA	14.6	60.2	55.2	1.0	3.4	12.0
scavenger	di-amine	26.3	71.7	35.0	1.1	0.8	31.7

The next step was to study the kinetics of the Miraí ore flotation, using the already determined chemicals dosage. The recoveries and grades of the rougher floated product were accumulated with the flotation time, and are presented in Table IV.

Table IV- Kinetics study of the Miraí ore

	recovery (%)		grades (%)			
	mass	AA	AA	Re SiO_2	Ins SiO_2	Fe_2O_3
30 s floated	24.40	3.12	1.69	1.85	80.50	11.10
60 s floated	35.93	4.74	1.74	1.86	79.34	11.31
90 s floated	48.13	6.69	1.84	1.68	78.63	11.83
120 s floated	50.58	7.32	1.91	1.67	77.57	11.78
180 s floated	51.50	8.14	2.09	1.68	77.00	12.00
240 s floated	52.04	8.65	2.20	1.68	76.49	12.22
360 s floated	52.92	9.74	2.44	1.68	75.40	12.72
498 s floated	53.57	10.69	2.64	1.68	74.59	13.06
feed	100.0	100.0	13.23	0.93	41.94	24.73

The graph in Figure 1 shows the best residence time for the Miraí ore is 100 seconds. Starting from this point, there is almost no gain in AA recovery that can justify the increase in mass recovery.

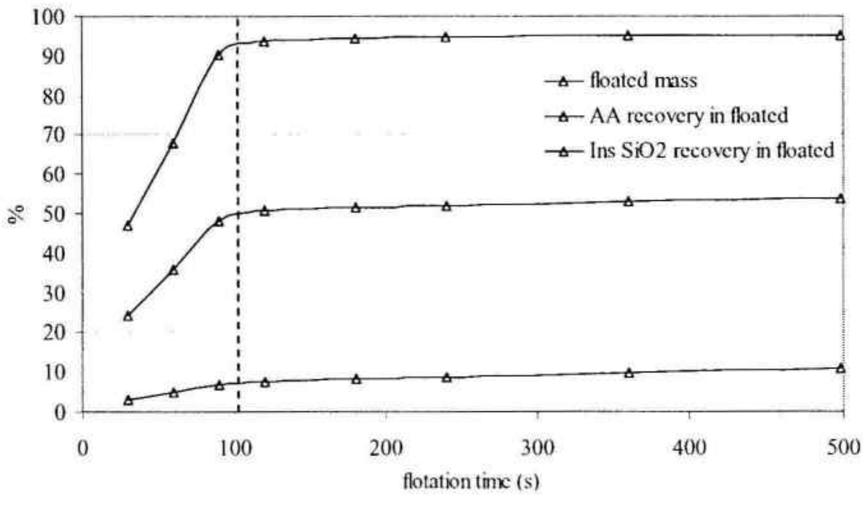

Figure 1 – residence time for the Miraí ore

After that, tests in an attrition machine were performed varying the attrition time. These tests aimed at removing the slime particles from the coarse ones, since it seemed that those slimes came from the goethite coatings, which are removed by attrition in the flotation cell. The optimum attrition time was about 1 minute. Then, some samples were screened in 48 #, deslimed in 10 μm, attritioned during 1 min, and deslimed in 10 μm again. These attritioned samples were used in new flotation tests, using Flotigam EDA as promoter and corn starch as depressant, at pH 10. The best results were reached when using 250 g/t of promoter and 300 g/t of depressant; the depressed product was 41.3 % in mass, recovering 79.3 % of AA at a 25.8 % AA grade. Compared to the test using the same chemical dosages, but with non-attritioned feed, this test got an increase of 2% in AA recovery. Thus, since slimes were efficiently removed, the promoter consumption is reduced.

3. PILOT PLANT TESTS

The pilot plant tests used a sample of the 6" cyclone underflow dressing a mixture of the Itamarati de Minas and Descoberto ores, taken during 12 days at the Itamarati de Minas plant. The sample was sent to São Paulo, where it was dewatered and screened in 0.297 mm screen. Both undersize and oversize were dried and homogenized in piles. At that point, it was clear that the undersize fraction had an enormous amount of slimes, so it was dislimed in a 2" cyclone at a d_{95} of about 15 μm. After the disliming process, the product was dried and homogenized in piles again. The mass balances before and after the disliming are presented in Table V.

Table V – Screening and desliming of mixtured ores

size fraction	head	flotation feed
+ 0.297 mm	28.3	0
-0.297 mm dislimed	66.8	93.2
slimes	4.9	6.8
- 0.297 mm	71.7	100.0

As the ore sample was different from those already tested, it was necessary to make new bench scale tests, in order to determine which chemicals dosage it would be best for this sample. So, tests varying those dosages were carried out, obtaining 500 g/t of promoter and 200 g/t of depressant as the best conditions, which allowed for the obtention of a 39.5% mass recovery in the concentrate, with 80.0% AA recovery at a 28.4% AA grade, which increased to 43.3% after magnetic separation.

After these tests, in October 2006 it was finally possible to start the pilot plant testing by adopting the circuit shown in Figure 2. The pilot plant was tested for two days, 6 hours per day without interruption, making mass and flow measurements of each pulp, chemicals and water flows. The chemical analysis of the flows and mass balance is presented in Table VI.

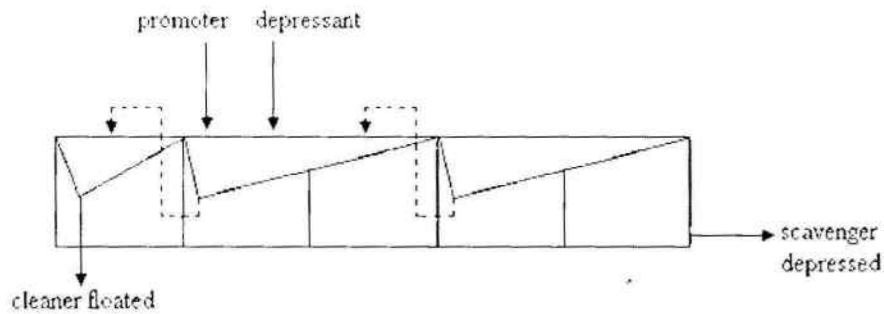

Figure 2 – pilot flotation plant circuit

Table VI – Pilot plant tests

	product	mass recovery (%)	grades (%) AA	Re SiO_2	Ins SiO_2	Fe_2O_3	Rec (%) AA	Ins SiO_2
1st day	scavenger depressed	48.6	24.2	5.1	12.5	32.2	89.9	11.9
	magnetic svavenger depressed	25.2	9.5	1.8	9.3	53.0	17.6	3.7
	non-mag. scavenger depressed	23.4	42.3	1.3	22.2	10.5	72.3	8.2
	cleaner floated	51.4	2.6	0.8	87.0	7.8	10.1	88.1
	rougher floated		5.1	1.0	71.6	20.2		
	scavenger floated		13.1	3.0	38.0	25.2		
	calculated feed		*13.0*	*2.9*	*50.8*	*19.6*		
2nd day	scavenger depressed	75.8	20.6	1.5	15.5	34.7	98.2	35.4
	magnetic svavenger depressed	45.1	10.6	2.0	10.6	50.9	28.1	13.6
	non-mag. scavenger depressed	30.7	38.7	1.7	25.0	13.4	70.1	21.8
	cleaner floated	24.2	1.2	1.2	88.5	8.5	1.8	64.6
	rougher floated		3.1	1.6	81.1	10.1		
	scavenger floated		5.6	3.2	70.6	10.8		
	calculated feed		*15.9*	*1.4*	*33.2*	*28.3*		

So, the best results were reached in the first test day, obtaining a non-magnetic concentrate with 42.3% of AA, recovering 72.3% of the AA in the feed.

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