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Technical Note

Removal of limestone from bauxite by magnetic separation

E.Th. Stamboliadis*, G. Kailis

Mineral Resources Engineering Department, Technical University of Crete, 73100 Chania, Greece

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ABSTRACT

Bauxite is the main source for the production of alumina and metal aluminum by the Bayer process. Limestone is an impurity associated to bauxite due to geological and morphological conditions prevailing during its formation. Experimental work has shown that limestone can be easily removed from bauxite using magnetic separation techniques. Three samples of Greek bauxite were used with different $CaCO_3$ content, that assayed between 2.5% and 8.5% CaO. The samples were screened to three size fractions 0-5mm, 5-10mm and 10-20mm. The equipment used for the test work was a belt roll magnetic separator and it was possible to produce more than one magnetic products from each fraction by passing the non-magnetics for second or third time. From one pass to the other the roll speed and hence the feed rate was reduced. The results show that limestone can be removed from bauxite. Depending on the feed CaO assay and the specifications of the product it is possible to produce different product qualities leaving the non magnetic fraction as a residue.

Keywords: Limestone; Bauxite; Magnetic separation

1. INTRODUCTION

Bauxite is the weathering product of ophioliths as well as other protoliths and is usually found in curvatures in the interface between limestone rocks of different geological age (Panagos and Liati, 1995; Manutsoglu, 2002). The main minerals found are hydrated aluminium and iron oxides, which are the weathering products that were transported and deposited.

Depending on the degree of hydration these oxides can form different minerals. For aluminum, these minerals vary from gibbsite $Al_2O_3.3H_2O$ or ($Al(OH)_3$) to diaspore or boehmite (depending on the crystal structure α or γ form) $Al_2O_3.H_2O$ or (AlOOH) and finally to metamorphic corundum Al_2O_3. There are bauxite deposits in which one or the other type of minerals prevails. For iron the corresponding minerals are limonite $Fe_2O_3.3H_2O$ or ($Fe(OH)_3$), goethite (depending on the crystal structure α or γ form) $Fe_2O_3.H_2O$ or (FeOOH) and finally hematite Fe_2O_3 (Panagos and Liati, 1995; Christidis, 2002). In Greek bauxites diaspore, bohemite and goethite are the usual aluminium and iron bearing minerals.

There is some SiO_2 present mainly in the form of quartz, but some alumino-silicates may also be present. Silica content is usually very low in Greek bauxites and fulfills specifications. Some TiO_2 is also present in the form of illmenite $FeTiO_3$ or ($FeO.TiO_2$).

Calcium oxide, CaO, is also present, to a lesser or greater degree, in the form of calcite, $CaCO_3$, the main constituent of limestone. This particular mineral is not a primary product of the weathering and is associated to bauxite due to mixing, during the transportation and deposition stage of bauxite in limestone pockets or during the stage of mining. Due to its differentiation in origin it is, more or less, well liberated from the remaining minerals. The latter are practically impossible to liberate by mechanical means, especially the liberation of iron from aluminium hydroxides, which are very finely inter-grown.

The prevailing process for the recovery of alumina, Al_2O_3, from bauxite and the subsequent production of metal aluminium, Al, by electrolysis is the Bayer process. It is well known that, according to this process, alumina is dissolved in water by sodium hydroxide NaOH, at high temperature and pressure. The aluminium minerals with increased number of water molecules react better in this hydrometallurgical process. The remaining elements form the insoluble residue called red mud, and are separated by filtration.

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* Corresponding author. E-mail: elistach@mred.tuc.gr

Iron and titanium do not create any particular problems in the process except the fact that their presence lowers the content of alumina in the feed and increases the volume of the red mud. On the other hand silica and lime interfere with the chemistry of the process and form insoluble substances with sodium and alumina, which increase the reagent consumption and the loss of alumina in the insoluble residue.

In some Greek mines, heavy media separation has been used to remove limestone from bauxite due to the difference in specific gravity. However this process requires water for washing the material, otherwise the fines interfere with the specific gravity and, even worse, with the viscosity of the heavy media pulp. Water is not always available and also it requires peripheral installations for dewatering and water recycling.

New developments in magnetic separation have produced high intensity magnetic rolls and drums using Neodymium-Iron-Boron, alloy and have produced magnetic fields that can separate minerals of relatively low magnetic susceptibility (Arvidson and Dille, 1996), such as the iron hydroxides in bauxite. Due to the original intergrowth of alumina and iron minerals and the existing liberation from calcite, as mentioned above, it is easy to separate the low magnetic bauxite from the non-magnetic limestone. This paper presents a case study for the beneficiation of Greek bauxite using a pilot plant machine, the INPROSYS, H-S 10, high intensity belt roll magnetic separator (INPROSYS is now part of Outokumpu Mineral Separation Division).

2. EXPERIMENTAL

Three different samples, 1, 2 and 3, of Greek bauxite, with varying CaO content, were used. The coarse fraction, +20mm is usually within specification, but if not, it is treated by hand sorting and the free limestone, being the minority constituent, is removed. The −20mm fraction, if not within specifications, is stock-piled. All tree samples were the −20mm fraction of the corresponding stockpiles and were further screened to 10mm and 5mm. The size distribution and the chemical analysis of the size fractions produced, for all three samples, are presented in Tables 1, 2 and 3.

Table 1
The size distribution and the chemical analysis for sample 1

Fraction mm	Wt kg	Wt %	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
10-20	11.850	26.1	1.46	20.98	2.39	16.96	8.85	48.85
5-10	9.220	20.3	2.20	20.93	2.24	16.90	8.38	49.32
0-5	24.300	53.6	3.02	21.24	2.45	16.57	7.66	48.54
Total	45.370	100.0	2.44	21.11	2.39	16.74	8.12	48.78

Table 2
The size distribution and the chemical analysis for sample 2

Fraction mm	Wt kg	Wt %	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
10-20	29.810	27.8	5.32	20.65	2.51	13.74	3.32	54.05
5-10	27.070	25.2	5.34	20.72	2.48	14.01	3.78	53.08
0-5	50.410	47.0	5.74	22.10	2.54	14.15	4.10	50.76
Total	107.290	100.0	5.52	21.35	2.52	14.00	3.80	52.26

Table 3
The size distribution and the chemical analysis for sample 3

Fraction mm	Wt kg	Wt %	SiO_2 %	Fe_2O_3 %	CaO %	Al_2O_3 %
10-20	26.190	45.5	3.52	22.88	2.54	54.69
5-10	13.066	22.7	4.06	21.17	2.53	55.92
0-5	18.304	31.8	4.69	22.63	2.57	53.63
Total	57.560	100.0	4.01	22.41	2.55	54.63

Sample 1 has the highest CaO % content, then comes sample 2 and last is sample 3, with the lowest CaO %. On the contrary Al_2O_3 increases as CaO decreases.

The magnetic separator used was the model H-S 10 of INPROSYS. It is a belt roll separator with roll diameter 10cm, length 50cm and belt thickness 0.25mm. Two magnetic rolls were available with magnetic elements configuration 18:6 and 12:4 respectively, which were interchanged depending on sample size fraction . The roll, with 18:6 configuration, was used for the coarse fraction 10-20mm, of all three samples, while the one with 12:4 was used for the two finer fractions of the samples. In order to ensure that the material is evenly distributed on the belt a vibrating feeder was provided.

For the test work each fraction, 10-20mm, 5-10mm and 0-5mm, of the corresponding sample was treated separately. Each fraction was passed twice or three times to the roll of the corresponding configuration, mentioned above. For every pass, a known amount of the material was used, the time was measured and the capacity per meter length of the roll was calculated. The magnetic fraction was collected and the non-magnetic was passed again on the same roll, usually at a lower speed, giving a second magnetic product and a final non-magnetic. In most cases two passes were enough, but if necessary a third pass was performed at even lower speed.

Since the magnetic field intensity is constant at all passes, it is the roll speed that differentiates between particles with different magnetic susceptibility. Highly magnetic particles are attracted during the first pass when the roll speed is high. Less magnetic particles are attracted during the second pass at lower roll speed and finally, if necessary, the very low magnetic particles are attracted at the third pass at even lower speed. The final rejected product is the non-magnetic particles of the material. For every test all the products were weighted and assayed for different elements.

3. RESULTS AND DISCUSSION

The results obtained are presented in Tables 4 to 9 and in Figures 1 to 6.

Table 4 presents the results of magnetic separation for all three fractions of sample 1. Two passes were used for all size fractions. One can see the wt% distribution and the chemical analysis of the products obtained for each size product separately. However in practice, one is usually interested for the combined products that can be obtained from all fractions and are of the same quality. The combined products obtained from all fractions are calculated in Table 5. Combined product A is made of partial products with CaO% < 2 , combined product B is made of partial products with 2 < CaO% < 8 and combined product C is the remaining material which is rejected.

Table 6 presents the results of magnetic separation of all three size fractions of sample 2. The two coarser fractions were passed twice while an extra pass was performed for the finer fraction. The combined products are presented in the corresponding Table 7 and the criteria of sample combination are more ore less the same as above.

Table 8 presents the results of magnetic separation of all three size fractions of sample 3. The two coarser fractions were passed twice while an extra pass was also performed for the finer fraction. The combined products are presented in the corresponding Table 9 and the criteria of sample combination are different from above since sample C was originally a better quality feed. Combined product Super A contains partial products of CaO% < 1, combined product A contains the partial products with 1< CaO% < 2 and the remaining is combined product C.

Table 4
Magnetic separation of sample 1

Fraction mm	Configuration	TpH/m	Rpm	Product	Wt g	Wt% of the Fraction	Wt% of the Initial	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
10-20				Feed	11,850	100.0	26.1	1.46	20.98	2.39	16.96	8.85	48.85
	18:6	7.76	110	Mags 1	6,200	52.3	13.7	2.11	26.96	2.61	12.04	1.24	54.51
	18:6	4.07	70	Mags 2	450	3.8	1.0	2.45	29.05	2.70	12.76	1.61	50.92
				Nmags 2	5,200	43.9	11.5	0.59	13.15	2.10	23.20	18.54	41.93
5-10				Feed	9,220	100.0	20.3	2.20	20.93	2.24	16.90	8.38	49.32
	12:4	8.30	70	Mags 1	4,650	50.4	10.2	2.41	26.98	2.62	12.52	1.25	54.69
	12:4	2.74	50	Mags 2	3,550	38.5	7.8	2.35	17.91	2.20	16.65	7.34	53.02
				Nmags 2	1,020	11.1	2.2	0.70	3.90	0.65	37.71	44.52	12.00

continued (Table 1)

Fraction mm	Configuration	TpH/m	Rpm	Product	Wt g	Wt% of the Fraction	Wt% of the Initial	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
0-5				Feed	24,300	100.0	53.6	3.02	21.24	2.62	16.57	7.66	48.54
	12:4	11.66	80	Mags 1	20,000	82.3	44.1	3.19	23.11	2.81	15.31	5.57	49.67
	12:4	2.14	10	Mags 2	3,300	13.6	7.3	2.67	14.52	2.00	19.33	11.73	49.42
				Nmags 2	1,000	4.1	2.2	0.85	5.91	0.80	32.69	36.09	23.15
				Total			100.0	2.44	21.11	2.39	16.74	8.12	48.78

Table 5
Combined products of sample 1

Product	Wt %	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
A	24.9	2.25	27.05	2.62	12.27	1.26	54.44
B	51.9	3.06	22.33	2.72	15.51	5.84	50.17
C	23.2	1.28	11.99	1.80	24.29	20.59	39.59
Feed	100.0	2.44	21.11	2.39	16.74	8.12	48.78

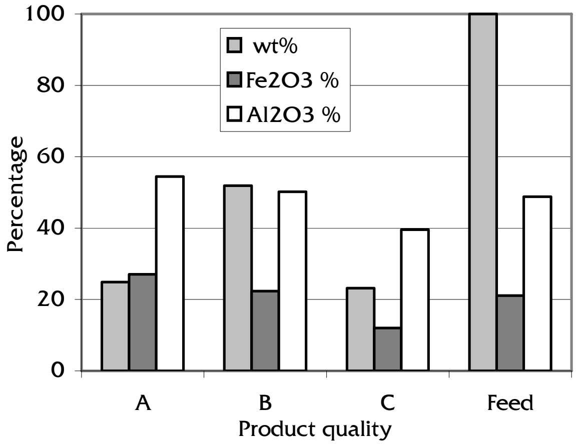

Figure 1. Wt%, and Fe_2O_3, Al_2O_3 assay for products obtained from sample 1

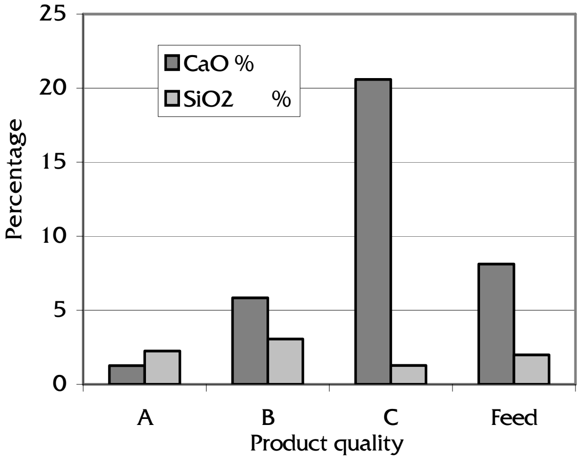

Figure 2. CaO and SiO_2 assay for products obtained from sample 1

Table 6
Magnetic separation of sample 2

Fraction mm	Confi guration	TpH/m	Rpm	Product	Wt g	Wt% of the Fraction	Wt% of the Initial	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
10-20				Feed	29,810	100.0	27.8	5.32	20.45	2.50	13.74	3.32	54.05
	18:6	3.46	120	Mags 1	11,570	38.8	10.8	3.76	23.68	2.60	12.41	0.85	56.17
	18:6	2.35	80	Mags 2	9,780	32.8	9.1	6.47	20.78	2.30	12.81	1.59	55.11
				N mags 2	8,460	28.4	7.9	6.13	15.64	2.59	16.65	8.71	49.94
5-10				Feed	27,070	100.0	25.2	5.34	20.74	2.40	14.00	3.78	53.08
	12:4	3.90	180	Mags 1	10,780	39.8	10.0	4.27	24.76	2.59	12.64	1.33	53.90
	12:4	2.06	100	Mags 2	10,370	38.3	9.7	5.81	20.97	2.37	12.81	1.78	55.45
				N mags 2	5,920	21.9	5.5	6.46	13.03	2.11	18.58	11.73	47.42
0-5				Feed	59,410	100.0	47.0	2.68	23.49	2.60	14.80	5.18	50.67
	12:4	5.70	210	Mags 1	30,820	51.9	24.4	3.07	23.04	2.62	13.95	4.57	49.59
	12:4	3.55	150	Mags 2	26,430	44.5	20.9	2.32	24.55	2.60	15.46	5.37	52.17
	12:4	0.21	60	Mags 3	1,000	1.7	0.8	1.99	21.70	2.70	14.56	4.00	54.57
				N mags 3	1,160	2.0	0.9	1.25	12.87	2.10	22.73	18.31	41.84
total				total			100.0	5.52	21.35	2.52	14.00	3.80	52.26

Table 7
Combined products of sample 2

Product	Wt %	SiO_2 %	Fe_2O_3 %	TiO_2 %	LOI %	CaO %	Al_2O_3 %
A	39.6	5.01	22.63	2.47	12.66	1.37	55.17
B	46.1	2.71	23.70	2.61	14.65	4.92	50.85
C	14.3	5.94	14.46	2.37	17.78	10.49	48.45
Feed	100.0	5.52	21.35	2.52	14.00	3.80	52.26

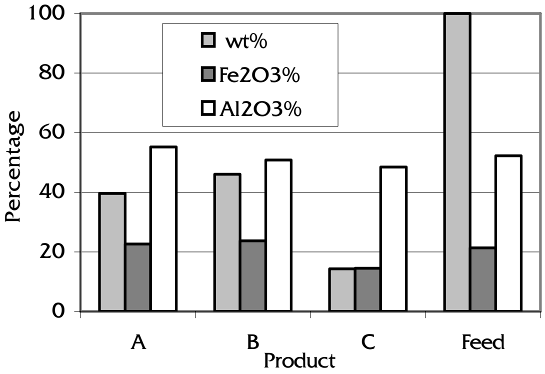

Figure 3. Wt%, and Fe_2O_3, Al_2O_3 assay for products obtained from sample 2

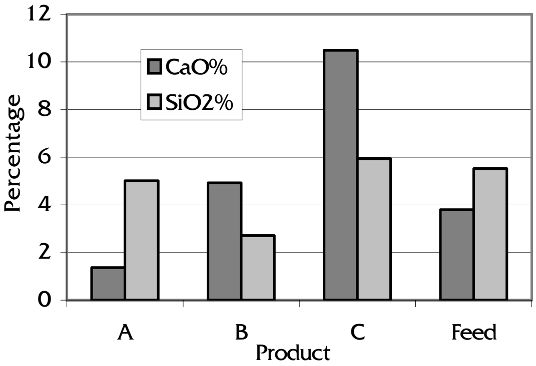

Figure 4. CaO and SiO_2 assay for products obtained from sample 2

Table 8
Magnetic separation of sample 3

Fraction mm	Confi guration	TpH/m	Rpm	Product	Wt g	Wt% of the Fraction	Wt% of the Initial	SiO_2 %	Fe_2O_3 %	CaO %	Al_2O_3 %
10-20				Feed	26,190	100.0	45.5	3.52	22.88	2.54	54.69
	18:6	12.20	90	Mags 1	10,554	40.3	18.3	2.93	25.70	0.31	55.72
	18:6	,	80	Mags 2	10,382	39.6	18.0	3.69	24.51	1.32	54.55
				N mags 2	5,254	20.1	9.1	4.36	14.01	9.44	52.90
5-10				Feed	13,066	100.0	22.7	4.06	21.17	2.53	55.92
	18:6	8.70	110	Mags 1	4,816	36.9	8.4	3.66	26.13	0.56	54.60
	18:6		90	Mags 2	4,832	37.0	8.4	4.76	21.65	0.58	57.50
				N mags 2	3,418	26.2	5.9	3.64	13.52	8.06	55.56
0-5				Feed	18,304	100.0	31.8	4.69	22.63	2.57	53.63
	12:4	4.00	140	Mags 1	8,056	44.0	14.0	4.76	28.10	1.64	49.62
	12:4		120	Mags 2	4,014	21.9	7.0	5.24	22.96	1.25	54.89
	12:4		100	Mags 3	2,859	15.6	5.0	4.55	18.90	1.37	58.80
				N mags 3	3,375	18.4	5.9	3.97	12.32	7.36	57.31
Total				Total	57,560		100.0	4.01	22.41	2.55	54.63

Table 9
Combined products of sample 3

Product	Wt %	SiO_2 %	Fe_2O_3 %	CaO %	Al_2O_3 %
Super A	35.1	3.54	24.83	0.43	55.88
A	44.0	4.37	24.77	1.42	53.51
C	20.9	4.05	13.40	8.47	54.89
Feed	100.0	4.01	22.41	2.55	54.63

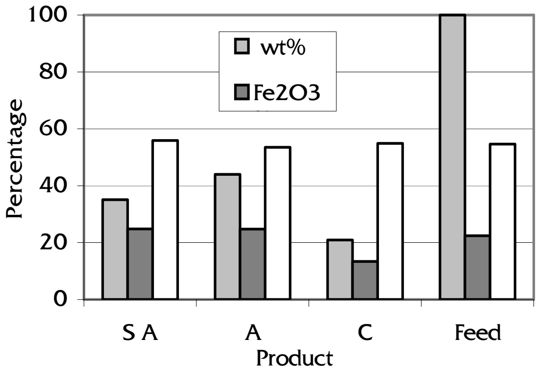

Figure 5. Wt%, and Fe_2O_3, Al_2O_3 assay for products obtained from sample 3

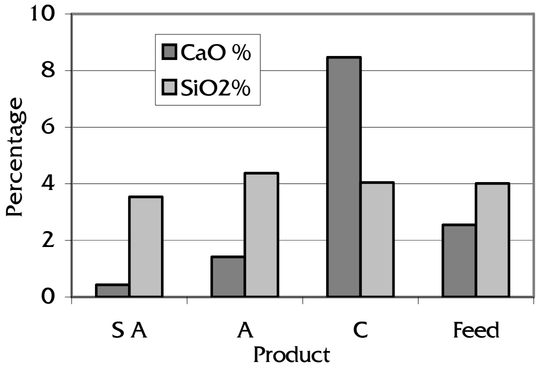

Figure 6. CaO and SiO_2 assay for products obtained from sample 3

It is obvious that the magnetic force acts on the iron bearing particles and one is expecting a differentiation in iron content between the magnetic products at different passes. Actually the magnetic products of the first pass contain more Fe_2O_3 than those of the second or third pass and, even more, than the non-magnetic. However liberation seems to be a very important factor that affects magnetic separation. Alumina bearing minerals are very finely inter-grown with iron oxides and although they are non-magnetics, it appears that, more or less, they follow the iron oxides, see Figures 1, 3, and 5. In a lesser degree, this happens also with the silicates.

The only non-magnetic mineral, which actually is not attracted by the magnet, is calcite. It exists in the form of liberated limestone and is represented by the CaO content. From Figures 2, 4 and 6 it is apparent that CaO differentiates drastically between the different products compared to all other elements shown in Figures 1, 3 and 5. Consequently, it is possible to remove the unwanted CaO and recover Al_2O_3 although both are equally non magnetic. The quality of the products obtained is very good and the rejects are usually stock piled for future use.

Magnetic separation is a simple process with very small operating cost, compared to heavy media separation, which can be also used. The main advantage is not only the cost but also the fact that magnetic separation can handle dry material without the need to wash it with water, which in some cases may not be available and it also requires peripheral dewatering equipment with additional cost (Arvidson, 2001). Dry screening required for magnetic separation, especially at finer fractions like 5mm, as mentioned above, is usually not a problem for dry climates where bauxite is found. Even more new developments in dry screening (Papageorgiou and Zuber, 2001) can afford some amount of moisture and eliminate wet screening.

4. CONCLUSIONS

From the results obtained above one can conclude that magnetic separation can be used to remove unwanted lime stone from bauxite. This process can upgrade existing stock-piles of –20mm or -30mm fractions and also encourage mining of lower grade bauxite deposits.

Although the magnetic force acts on the iron minerals the products obtained are also upgraded in terms of alumina, due to the mineralogical structure of the ore.

The advantage of using magnetic separation compared with heavy media separation is the low capital investment and operating cost.

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