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BENEFICIATION OF HIGH SILICA BAUXITE ORES OF INDIA AN INNOVATIVE APPROACH

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Abstract

Many bauxite reserves in India have Al_2O_3/SiO_2 ratio of 4 to 6 and hence pose difficulties in production of alumina through the Bayer process. The extraction of alumina from bauxite in low temperature digestion circuit frequently involves a desilication step in which kaolinite dissolves and reprecipitates as sodalite, a caustic insoluble sodium alumino silicate. Thus formed insoluble sodium alumino silicate gets separated from the process into the red mud, thereby entailing the loss of valuable caustic soda and alumina. The more is the silica, higher is the soda consumption which increases the cost of alumina production.

Physical beneficiation techniques are employed to reduce the reactive silica content of bauxite. Based on several investigations it has been made possible to remove ~30% of silica with 92% recovery depending on the characteristics of the ore. The results of detail studies are presented in this paper and it is expected that these findings will lead to improved Alumina Refining practice in the future.

Introduction

The bauxite ore is a hydrated aluminum oxide with associated impurities like iron oxide, titanium dioxide and silicon dioxide. Bauxites are considered to be of two major types known as lateritic bauxite and karst bauxites. Lateritic bauxites are primarily aluminosilicate rocks whereas karst bauxites are from inter bedded carbonate and aluminosilicate rocks. The main minerals associated in lateritic bauxite are trihydrated gibbsite ($Al_2O_3.3H_2O$), monohydrate boehmite ($Al_2O_3.H_2O$) and oxide-hydroxide diaspore (α-AlO(OH). Beside that, it contains hematite and goethite as the iron bearing minerals. In lateritic ore, the main silicate mineral is kaolinite and often associated with goethite. The other common silicate mineral in bauxite ore is quartz. Karst bauxite has a different mineralogical composition than the lateritic ore as it has undergone different weathering conditions during mineralization and contains carbonates in the parent rock. In this bauxite, the silicate minerals are dominated by kaolinite, difficult to process mineral chamosite and quartz. The aluminous minerals are boehmite and diaspore with different in mineralogy compared to lateritic ore. Due to different in mineralogy, the lateritic bauxites are preferred in Bayers process as they are easy to digest than karst bauxites. The conditions in Bayers process, such as concentration of sodium hydroxide, temperature and reaction time are less severe for lateritic bauxite than the karst bauxite. Due to this reason around 90% of alumina in the world is being exploited directly from the lateritic bauxite reserve. In general, the aluminum ore is bauxite and the three aluminium bearing minerals associated in bauxite are gibbsite, boehmite and dispore and essentially contain the major impurities such as iron oxides, silicon dioxide and titanium dioxide which need to be minimized for the cost economic point of view.

The Bayer process involves digestion of bauxite in a caustic soda at temperatures ranging from 100 to 250 °C, depending on the form of alumina in the bauxite, e.g. gibbsitic, boehmitic or diasporic. The digestion of bauxite involves not only dissolution of the majority of the alumina but also silica present as kaolinite and quartz. The reactive silica is present in the ore in two forms. One is due to the presence of colloidal silica, which are highly reactive due to their high surface area and the other silica is present in kaolinite mineral. The loss of soda or high consumption of soda in the Bayers process is thus linearly related with the reactive silica content of the bauxite.

The reactive silica present in bauxite ore is readily attacked by caustic liquor at low temperature and forms desilication product (DSP). Quartz is generally attacked by caustic soda at high temperature digestion. The high percentage of reactive silica consumes more caustic compared to quartz. It is generally considered uneconomic to treat bauxites containing greater than 5% reactive silica due to excessive soda consumption in the Bayers process. It has been estimated that each ton of silica that dissolves from bauxite during digestion consumes approximately 1.2 tons of soda forming DSP. The soda required for processing high silica bauxites accounts for as much as 20% of Alumina production costs. The Alumina and silica content in bauxite ore therefore plays an important role in the Bayers Process and the ratio of Al/Si is also important for economic point of view. It has been observed that, bauxite with Al_2O_3/SiO_2 ratio more than 10 can be directly processed without any difficulty. However many bauxites in India has 4-6 Al_2O_3/SiO_2 ratio found to be difficulties in production of alumina through Bayers process. The modern alumina industries are therefore looking for a suitable process to improve the Al/Si ratio in middle grade bauxite ore.

A worldwide trend of declining bauxite grades underlines the importance of research into practical ways of processing high silica bauxites. The major cost penalty associated with processing high silica bauxites is the loss of caustic soda from the recirculating Bayer liquor. To address these issues, Vedanta Aluminim Limited, Lanjigarh tied up with CSIR-IMMT, Bhubaneswar to utilize expertise and R&D facilities to develop the process flow sheet of beneficiation of high silica bauxites present in India. Five number of bauxite samples from various regions are tested in pilot plant scale at IMMT Bhubaneswar and findings are summarized, in which one representative sample was prepared by mixing the five samples and applying coning and quartering method. Experimental test works as well as findings are presented as follows.

Characterization studies

The representative bauxite sample was subjected to detail characterization studies to derive some information with regard to the removal of silica, reactive silica and iron values from the given sample. The physical and chemical properties of the sample as carried out by the standard method are shown in Table-1. The bulk density and specific gravity of the sample was found to be 1.69 g/cm^3 and 2.54 respectively. The chemical constituents of the sample indicates that it contains 42.54% Al_2O_3 21.33% Fe_2O_3, 6.19% SiO_2, 4.73% TiO_2 and 23.1% LOI. The reactive silica content in the sample was found to be 4.52%. It was observed that both the silica and reactive silica content in the sample is well within the specified limit. However looking into the long term cost reduction objectives and to reduce the overall soda consumption, it is worthwhile to pursue investigations for the reduction of reactive silica in particular. Beside that higher iron content in the feed generates higher amount of residue and deposited in redmud pond.

However the removal of either of these components has to be looked into without sacrificing loss of any alumina value into the rejected tailings. The size and chemical analysis of the different constituents present in the bulk bauxite sample is shown in Table-2. The data indicates that better quality of alumina is concentrated in coarser size particle compared to the finer sizes. However the iron values are slightly more in the finer fractions but almost uniformly distributed in all the size ranges. The silica, reactive silica and loss on ignition have a unique relation with the particle size. It is observed that better is the alumina content lower is the loss on ignition which may be attributed due to the presence of surrounding water molecules present in bauxite ore. The size vs. cumulative weight% passing is shown in Figure-1. The 80% passing size of the sample is found to be 25 mm. It has been observed that both silica and reactive silica increases with decrease in particle size. This indicates that both the components are associated with finer sizes and probably associated with the kaolinite mineral phase which is basically a clay mineral. It is observed that highest value of silica and reactive silica has been found in the size fraction of below 45-micron and most of the silica are also concentrated in this finer fraction. TiO_2 and Fe_2O_3 are equally distributed in all the sizes, there is decrease trend of alumina and LOI with decrease in particle size.

The Bonds grindability index of the bauxite sample as carried out by the standard method is found to be 12.5 kwh/sh.ton which is 13.8 kwh/ton, which is slightly higher than the iron ores of India. In bauxite, the iron particles may preferentially ground in comparison to alumina particles present in the bauxite ore.

Table-1

Constituents	%	Physical Properties	
Al_2O_3	42.54	Bulk Density (g/cm^3)	1.69
Fe_2O_3	21.33	Specific Gravity	2.54
SiO_2	6.19	Avg. Particle size(d_{80})	25 mm
R- SiO_2	4.52		
LOI	23.1		
TiO_2	4.73		

Table-2

Size and Chemical Analysis of bauxite ore

Size mm	Wt %	Cum. Wt %	Fe_2O_3 %	Al_2O_3 %	SiO_2 %	R-SiO_2 %	TiO_2 %	LOI %
+40	13.1		20.0	45.7	4.76	3.95	5.24	23.9
-40+30	30.4	86.9	17.6	48.5	2.74	2.49	5.06	25.8
-30+20	14.9	56.5	15.9	50.1	3.35	2.18	5.57	25.3
-20+10	19.3	41.6	20.7	46.	4.43	3.72	3.60	24.7
+10+5.6	7.3	22.3	21.4	45.2	4.73	3.91	4.12	24.0
-5.6+3.35	2.8	15.0	23.2	43.5	5.69	4.68	4.26	22.9
-3.35+2	1.5	12.2	23.9	42.8	6.05	4.82	4.36	22.3
-2+1	1.8	10.7	24.3	43.6	6.86	5.41	4.54	20.2
-1+0.5	1.4	8.9	22.3	41.9	8.73	6.24	4.28	22.1
-0.5+0.25	1.3	7.5	22.2	39.5	12.69	8.90	4.30	20.7
-0.25+0.15	0.9	6.2	22.0	39.5	13.01	9.10	4.60	20.5
-0.15+0.1	0.4	5.3	23.4	39.4	11.90	7.80	4.59	20.3
-0.1+0.075	0.4	4.9	23.5	39.7	11.25	7.50	4.50	20.4
-0.075+0.045	0.5	4.5	23.7	39.4	11.50	7.60	4.38	20.6
-0.045	0.4	4.0	20.3	35.9	17.65	13.10	4.29	17.6

Following Technologies has been tested in the laboratory scale to reduce the reactive silica content present in the bauxite.

a) Screening and Washing
b) Gravity Separation
c) Jigging
d) Flotation
e) Bioleaching
f) Mechano-Chemical treatment
g) Magnetic Seperation Techniques

Though the various techniques are available for reduction of silica content present in the bauxite, the applicability of the same varies depending upon the Characteristics of the bauxite. Based on several investigations. It was successfully proven in the pilot scale by adopting physical beneficiation techniques can reduce the reactive silica content of bauxite. Summary of the findings are presented as below.

Scrubbing Studies

Looking into the chemical analysis and size analysis of the sample, it was felt that representative bauxite sample does not require any complex processing system but perhaps can be improved by a relatively simple and inexpensive process by removing the clay particles mostly associated in sub micron size. In this context, bauxite sample was taken in a batch scrubbing unit with required water to remove the contaminated fine clay particles. The scrubbed product was taken out and treated in 1 mm vibratory screen.

The results of scrubbing study at different time intervals are shown in Table-3. The result of the study indicates that due to larger area, better attrition between the particles is possible. It was observed that the fine fraction in Silica has gone up to 15-16% with increase in scrubbing time. Careful analysis of the scrubbing data indicates that the alumina content in the +1 mm fraction has gone up to 45.3% with decrease in both silica and reactive silica. The scrubbing action could also decrease the iron content from 23% to ~22% in the coarser fraction of the product. From the table-3, it clearly indicates that increasing the residence time of the scrubber will reduce the R-SiO_2 content in the bauxite with the improvement in the Al_2O_3 content also. It is decided to go with 3 min residence time in scrubber to avoid increase in project cost due to large volume of the scrubber. As Vedanta Lanjigarh is operating the plant with outsourced bauxite having a cost of 40-45 $ per Tonn of bauxite, % weight Recovery of bauxite plays an important role to determine the process conditions. Process simulation studies were done to determine the optimum recovery of bauxite to sustain the operations with reduction of silica content in the bauxite by implementation of Beneficiation Project. It was observed that with 93% recovery of bauxite and 30% reduction in R-Silica content in the processed bauxite, there will be 3-4 $/T of alumina savings in cost of production.

Table-3
Effect of scrubbing time, solid liquid ratio 1:1

Time min	Pro duct mm	Wt %	Al_2O_3 %	Fe_2O_3 %	SiO_2 %	TiO_2 %	R.SiO_2 %
3	+1	81.8	43.76	23.24	4.47	4.40	3.51
	-1	18.2	36.14	22.35	15.50	4.43	9.42
6	+1	80.6	45.28	21.17	3.66	4.52	3.07
	-1	19.4	35.47	22.86	17.49	4.52	10.71
9	+1	80.6	44.31	22.87	3.53	4.84	3.04
	-1	19.4	36.92	22.71	14.51	4.47	9.40
12	+1	78.8	44.76	22.31	3.90	4.70	3.26
	-1	21.2	37.24	22.41	13.70	4.43	9.30

As the bauxite recovery from Scrubber followed by 1 mm screen is found to be 81.8%, to increase the recovery further, screen underflow which contains -1 mm particles is treated in 45 microns cyclones to recover the bauxite. Scrubber overflow containing +1mm particles are dewatered and treated as a product material.

Hydrocyclone studies

The material balance as depicted in table-3 indicates that ~81.8% material of +1 mm fraction with 4.47% silica and 3.51% of reactive silica can be achieved by simple scrubbing. The results of the studies also indicate that the -1 mm material contains high amount of silica with enriched alumina values which cannot be discarded from the economic point of view. The size analysis of the -1 mm material is shown in Table-4. The data indicates that both silica and reactive silica are rich in -45 micron size material. The -1 mm material as it is contains around 15.5 and 9.42% of silica and reactive silica respectively. So a technique to remove -45 micron size will certainly give an advantage for further removal of these two elements. In the same time, additional material enriched with alumina can also be recovered will be an added advantages. With this objective, hydro cyclone studies were undertaken and the results are shown in Table-5. The results of the hydrocyclone studies indicate that, it was possible to get 66.8% by weight in the underflow fractions. The Reactive silica content in the underflow fraction could be brought down to 7.5% while it was as high as 13.4% in the overflow fraction. The overflow fraction is rich in both silica and reactive silica. It was also observed that the alumina content in the underflow fraction has gone up to 38.4% which is quite suitable for Bayer process.

Table-4
Size Analysis of -1mm scrubbed bauxite material

Size, microns	Wt %	Al_2O_3 %	Fe_2O_3 %	SiO_2 %	TiO_2 %	R.SiO_2 %
-1000+710	20.5	41.01	22.85	7.44	4.31	3.9
-710+500	11.4	40.0	22.62	9.84	4.27	5.5
-500+300	7.4	39.24	21.96	11.16	4.34	6.95
-300+210	5.7	39.03	22.87	11.29	4.38	7.26
-210+150	3.6	38.9	23.91	10.21	4.34	7
-150+100	4.4	38.4	23.48	10.68	4.38	7.32
-100+75	3.7	37.9	24.74	11.22	4.36	7.93
-75+45	4.7	37.1	23.33	11.82	4.59	8.36
-45	38.6	30.6	21.32	23.67	4.56	15.04

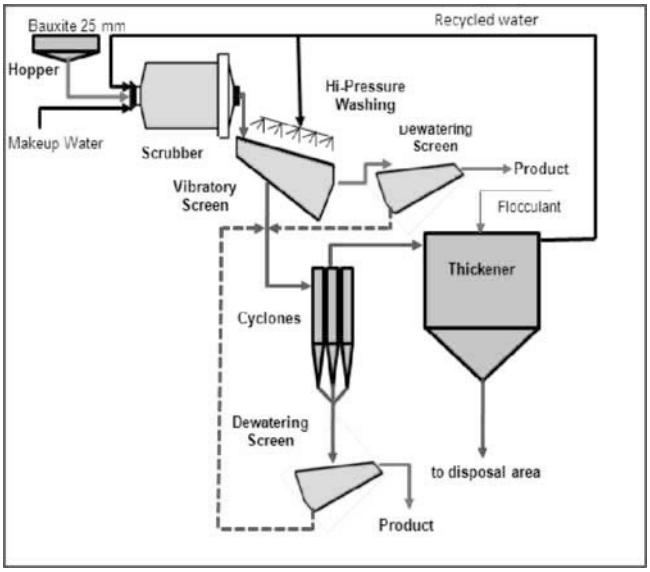
Table-5
Results of Cyclone studies

Products	Wt %	Al_2O_3 %	Fe_2O_3 %	SiO_2 %	TiO_2 %	R.SiO_2 %
Underflow	66.8	38.4	21.9	10.5	4.41	7.5
Overflow	33.2	31.9	24.1	25.1	4.80	13.4

Results and Discussions

Investigations were carried out on five different low grade ore samples of Indian bauxite to reduce reactive silica content to minimize the caustic soda consumption. Detailed characterization studies involving physical, chemical and mineralogical were carried out to evaluate the major and minor minerals present and their liberation size. These studies indicated that these samples consist of clay, gibbsite, and quartz as major minerals. Detailed beneficiation studies were carried out on representative sample involving scrubbing and screening followed by hydrocyclone to remove reactive silica. The results of experiments conducted in the pilot plant scale, indicated that it is possible it can be possible to remove silica of 38.4% and R-SiO_2 of 34% with a bauxite recovery of 94% by using the scrubbing, screening and cycloning techniques. Further investigations were carried out using different types of bauxite samples with varying contents of silica and reactive silica to ascertain the results obtained on representative sample. All these results indicate that more or less similar performance can be achieved by the process flow sheet-1 as given below. It may be noted here that in certain cases, desired results could not be achieved due to the nature of occurrence of silica and reactive silica in bauxite ores. The extent of removal is restricted in case of bauxites with low amount of these impurities. If the reactive silica is more than 5%, then the process flow sheet is more effective in reducing the same.

Bauxite Beneficiation process flow sheet-1



Conclusion

Bauxite quality is impacted by the content of alumina and alumina containing minerals, like gibbsite, boehmite and diaspore and the amount of reactive silica, goethite, haematite and other impurities. The wide range in the composition of the different bauxite ores derives from the differences in the origin and geologic history of the individual deposits. In the Bayer plant, bauxite mineralogy affects process efficiency by driving the chemical reactions that occur in the process. If the Run of Mine bauxite is of lower quality, in some cases the beneficiation by means of physical separation process is economical feasible. These generally low cost processes can extend the lifetimes of existing bauxite mines considerably, and substantially improve the technical and economic basis of the Bayer process itself.

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