GEOLOGICAL, MINERAL AND PROCESS FEATURES OF FRIA BAUXITES (GUINEA)

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Abstract

The Fria group of lateritic tropical bauxite deposits, located in Boke bauxite province, is a raw material base for Alumina Company of Guinea (ACG), the only alumina producer in the African continent. Estimated bauxite reserves at 6 major ore zones are about 600 million tonnes. Investigations of geological features of this group of deposits carried out in 60–70’s of 20th century by several organizations were not comprehensive enough.

The analysis of the region’s geology in light of contemporary knowledge of bauxite provinces of Guinea, obtained in the course of 40-years systematic studies by Russian geologists, has revealed several specific features of Fria bauxite.

Planned ACG expansion called for detailed studies of geological features of Fria bauxites as well as for repeated and more thorough study of their chemical and mineral composition and process properties in alumina production.

On the basis of many parameters, such as average content of available alumina and reactive silica, geological-technological mapping of Fria group was done that gave a new tool of resource estimation considering the bauxite nature specialties. As well it developed of ways of improving bauxite processing technology at ACG that have become a basis for the plant expansion.

Presence of finely dispersed boehmite in the initial bauxite stimulates the formation of secondary boehmite at the digestion stage under specific concentration modes. This particularity forces to limit the process parameters despite the process attractiveness of Fria bauxite processing at as low as possible caustic ratio in the liquid phase of digested slurry.

2 Geological overview

The deposits of Fria group are located on the West coast of Africa (Republic of Guinea) in the area with the tropical, changeable damp climate characterized by alternation of rainy (May–October) and dry (November–April) seasons during an annual cycle. The average annual amount of atmospheric precipitates is 4000–4500 mm, average annual temperature is 28°C.

The plateau of Fouta – Jalon to which the deposits of Fria group bauxites territorially belong is one of the most raised areas of Western Africa and represents itself as a combination of separate flat-topped divide ranges and heights such as mesas separated by deep valleys of the rivers. This region is also named ‘the Water tower of Africa’ since the majority of the rivers of Western Africa originate there.

As a whole, the bauxite-bearing province of the Fouta – Jalon plateau contains more than 30% of known world bauxite reserves. Prevalence of laterite weathering crusts in the region is extremely wide. They cover with practically continuous covering all elements of the relief, except for abrupt (more than 25–30°) sites of slopes and the bottoms of the river valleys with the first above flood-plain terrace. The industrial bauxite bearing are the laterite covers in each concrete area located at the top geomorphologic level. As a rule, these are flat, gentle-wavy or gentle-stepped tops of divide ranges and separate residual mountains (the local name is boval) and flat sections of their slopes (Figure 1). In total there are more than 500 deposits in the province being allocated in 15 major bauxite-bearing areas, one of which is the area of Fria (Sapozhnikov, 1976).
Figure 1: A typical laterite cover at the top of hill (boval)

The territory itself of the considered region for bauxite deposits belonging to Fria group is made of silur sediments separated in Telimele suite and Devonian rocks of Faro suite.

The Fria region bauxite deposits have been estimated by different grids (with different confidence) and have total reserves of more than 600 million tonnes that are divided in 6 major groups (Figure 2).

These bauxites represent typical in-situ laterite bauxite deposits of the Earth tropical zone. According to the experience of studying Cainozoic bauxite deposits, their ore controlling factors, morphology and structure, the following conditions are necessary for the similar laterite deposits formation:
- a favorable parent substratum with the increased contents of silica-alumina rockforming minerals;
- tropical hot, damp climate with periodic change of the rainy and drought periods;
- relatively quiet tectonic continental conditions with insignificant constant and pulsating territory raising providing formation of leveled surfaces (peneplains and pediplains), mesas and deep river valleys.

According to morphology the ore bodies of Fria area are ranged among typical coating deposits, as a rule, with the complex cut up contours in the plan. According to expansion and the cut, the bauxites are changed for the alumo-ferric and kaolin-ferric rocks distinguished from bauxites by a quantitative ratio of minerals as for aluminium to iron and alumina to silica.

The laterite weathering crust in the cut has enough consistent zoning. A generalised geological section of the laterite crust of weathering and the picture of the cut for the top part of the crust of weathering are shown in Figures 3 and 4. The soil – vegetative layer combined with loams and sandy loams having thickness from 0 up to 2–2.5 meters in average does not exceed 1 meter and covers the bovals surface, being practically completely absent in some places. There is the stony overburden under a soil – vegetative layer, formed with ferrous laterites (‘iron cap’) having thickness of 0.1–3m.
Bauxites in laterite stratum occupy an average part of the cut, their thickness seldom exceeds 10 m and as shown by the data of reserves estimation, thickness of bauxites is rather uniform.

Bauxites are underlayed by thin (0.2-0.4m) layer of strong dense monolitic plate-form and highly ferrous rocks ‘ferriplantites’ (V.I. Mamedov). The rocks of littomarge and saprolite finish the cut of laterite weathering crust, bedded directly on bed-rocks.

The slates and dolerites serve as parent rocks for the given bauxites.

3 Textural and structural features of bauxites

Texture of Fria bauxites is massive, oolitic, cavernous, pseudo debris, often inherited from parent amorphous rocks. (For bauxites formed on sedimentary argilitages and aleurolites – it is inherited thin – layered, for bauxites formed on dolerites – spotty speckled), Structure – from fine-grained up to cryptocrystalline.

The rock is characterized by high porosity – pores occupy from 10 up to 25% of volume. The basis of the rock is gibbsite-alumo-gibbsite or gibbsite – haematite aggregate.

**Gibbsite** composes from 55 up to 80% of the rock. The distinctive feature of Fria bauxite is presence of two gibbsite generations:

(i) fine and medium-grained mass (the scales sizes are from 0.015 × 0.04 mm up to 0.08 × 0.01 nm), frequently consisting of poorly crystallized crystals (Figure 5-a).

(ii) Besides, gibbsite is present as elongated, well faceted, secondary crystals of the size 0.02 × 0.08 mm. These formations are filling interstices and caverns in the rock or observed at their edges. Sometimes similar borders are present on the edges of the areas formed of medium-grained gibbsite. The amount of such secondary material is no more than 10% from all gibbsite mass (Figure 5-b).

This feature affects the efficiency of alumina extraction in conditions of atmospheric pressure digestion, applied at Fria refinery – alumina is easily dissolved from the fine-grained gibbsite, but there are problems of incomplete extraction of Al₂O₃ from coarse crystal formations.

Monohydrate minerals of alumina (boehmite and diaspore) are present in small (boehmite up to 1.0 mass %) and trace (diaspore) quantities and are represented by fine particles. Influence of this feature on the technological properties of Fria bauxite is discussed in Section 5.2.

Of the silica containing minerals, kaolinite contains more than half the silica. There are some grains of quartz. It is irregular-shaped grains of different sizes (the average size of 0.12 × 0.3mm) occur in the bulk gibbsite as well in areas with a wandering texture (Figure 5-c). In some samples, rare for tropical bauxites, siliceous mineral – pyrophyllite is present. There are individual grains of anatase.

As in other Guinean bauxites (for example, Kindia) alumo-goethite associated with gibbsite prevails among minerals of iron. It is also observed the development of alumo-goethite on this type of aggregate. Hematite is presented in the gibbsite- haematite unit, as a kind of dense inclusion and as a bulk (Figure 5-d). Such feature, in view of the high iron oxide content in bauxite, results in formation of a significant amount of red mud “sands” after bauxite digestion.

4 Chemical & mineral composition

The chemical and mineral composition of Fria bauxites was studied on the basis of the analysis of individual and characteristic samples of bauxite selected at Fria mines, as well as representative samples. Investigation of chemical composition was made by various methods: XRF, flame photometry, wet chemistry, mass – spectrometry, etc.

Bauxites of Fria deposit can be classified as medium, non-export quality bauxites with content of Al₂O₃ ranging from 39 to 45 mass %, SiO₂ up to 2.0 mass %. In the refinery practice the bauxite is mined and supplied for production on the basis of the values for the available alumina and reactive silica (mae) at the industrial temperature of digestion at Fria refinery (107°C). The values vary within the following range – Al₂O₃mae from 35 to 42 mass %, SiO₂mae from 0.7 to 1.0 mass %. The content of harmful impurities and organic matters (Ceq = 0.14 – 0.22 mass %) is at a usual level for tropical bauxites.

Typical chemical composition of bauxite samples is presented in Table 1. The silica ratio of bauxite and theoretically possible extraction of alumina (ηAl₂O₃) are calculated according to the total content of alumina and silica in bauxite.
The basic minerals of the rock are gibbsite (containing more than 90 % of alumina), hematite and allo-goethite. Bauxites are characterized by the low content of impurity minerals – kaolinite, boehmite, anatase, rutile. Essentially bauxite does not differ from Guinean bauxites from Debele deposit (Kindlia), but contains more of allo-goethite α-(Al,Fe)OOH×nH₂O.

### Table 1: Typical chemical composition of Fria bauxite, mass %

<table>
<thead>
<tr>
<th>Mineral</th>
<th>LOI</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>P₂O₅</th>
<th>Cr₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>SiO₂</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>SO₂</th>
<th>Cr</th>
<th>Mn</th>
<th>FeO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.5</td>
<td>44</td>
<td>2.6</td>
<td>0.16</td>
<td>0.09</td>
<td>0.7</td>
<td>0.02</td>
<td>1.55</td>
<td>0.09</td>
<td>0.03</td>
<td>0.12</td>
<td>0.85</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows the quantitative mineral composition calculated on the basis of the data for the X-ray diffraction and chemical analysis, and also selective dissolution of certain minerals.

### Table 2: Typical mineral composition of Fria bauxites, mass. %

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Gibbsite, 8,5 Å</th>
<th>Boehmite, 6,11 Å</th>
<th>Diaspore, 4,0 Å</th>
<th>Quartz, 3,25 Å</th>
<th>Kaolinite, 7,20 Å</th>
<th>Al-goethite, 4,18 Å</th>
<th>Hematite, 2,70 Å</th>
<th>Anatase, 3,02 Å</th>
<th>Rutile, 3,24 Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral content</td>
<td>62.7</td>
<td>0.8</td>
<td>traces</td>
<td>0.7</td>
<td>1.8</td>
<td>21.1*</td>
<td>10.4</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Al₂O₃ content in mineral</td>
<td>41</td>
<td>0.7</td>
<td>&lt;0.1</td>
<td>-</td>
<td>0.7</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* degree of isomorphous substitution of alumina in allo-goethite (Al → Fe) is up to 20 molar %.

5 Selection of optimal technological parameters

In the course of elaboration of technological parameters for expansion of ACG refinery the optimum technological modes at stages of preliminary desilication, digestion, post-desilication, red mud thickening have been simulated and selected in laboratory conditions.

#### 5.1 Predesilication

The operation of preliminary desilication is carried with the purpose to reduce aluminosilicate scales at heating surfaces and decrease of content of the dissolved silica in the pregnant solution. The modes of preliminary desilication have been simulated in laboratory at the temperature of 105°C. The experiments were made on a dense (L:S = 2:1 according to mass) and a standard slurry dosage for a target caustic ratio αₑ=1.35 (Rp = 1.22) during 5, 8 and 10 hours using various spent liquors.

As it is expected from the low content of reactive silica in bauxite, the higher desilication level (Na₂O/SiO₂ ratio 0.38) is achieved after 10 hours retention of dense slurry (L:S = 2:1 by mass).

#### 5.2 Digestion

Fria refinery was constructed according to Pechiney design and commissioned in 1960. In order to reduce the industrial risks and due to the low raw material cost the major equipment and process concept includes atmospheric-pressure digestion: temperature 107°C, concentration of spent liquor for digestion (Na₂O,OC) = 200 g/dm³ and target caustic ratio in liquid part of digested slurry αₑ = 1.56 (Rp=1,086).

For modernization and expansion of the plant the VAMI process laboratory conducted the investigation of Fria bauxites under different caustic ratios of liquors – 1.36, 1.4, 1.44 (Rp = 1.21, 1.18, 1.14 respectively) with digestion temperature 155°C and 175°C and retention under reaction temperature of 30, 45 and 60 minutes with liquor concentrations 140, 180 and 200 g/dm³ Na₂O,OC.

Occurrence of a large part of alumina in the form of fine gibbsite permits to conduct bauxite digestion for low caustic ratio with low caustic concentration. This concept will allow to increase the alumina recovery from bauxite and extend alumina yield at the precipitation area, however the need to increase the temperature up to 155–175°C will require autoclaves for digestion. The decrease of overall caustic concentration will permit to reduce evaporation load.

Despite the favorable gibbsite form and traces of Al₂O₃ monohydrate minerals there is a process risk of boehmite reversion, connected with the trace quantities of finely dispersed boehmite.

Based on our experience (Suss, 1992) and research works of western experts (Authier-Martin, 2002), in the case of boehmite occurrence in the initial bauxite and the process conducted on the low, close to the equilibrium caustic ratio with temperature higher than 130°C, at the stages of preliminary desilication, digestion or thickening the generation of the secondary boehmite γ-Al₂O₃(OH) is possible. The intensity of this process only insignificantly depends on the boehmite concentration in the initial bauxite. More significantly this intensity is defined by the size and morphology of initial boehmite crystals, acting as the seed for crystallization process – dispersed discrete polysize crystallites with developed surface contribute to formation of the large amount of secondary boehmite.

This assumption was confirmed by the results of experiments – with decrease of caustic concentration up to 143 g/dm³ the alumina recovery is reduced up to 70% (point A on Figure 7). Due to the above the goal of experiment was to select the minimum possible caustic ratio and liquors concentration outside of boehmite crystallization zone (line 2 on Figure 7). The boehmite crystallization zone depends on the activity of boehmite crystals acting as seed and for each specific case is established individually. It differs from the boehmite solubility zone, established from reference data (curve 1 on Figure 7). The graph shows that recovery of alumina from recrystallized boehmite is not possible at the given temperature and concentration conditions.

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The secondary boehmite formation process is as follows: during the preliminary desilication (temperature 105°C, retention 8–10 hours, standard slurry for caustic ratio ≤1.35 or dense slurry L:S = 2:1) practically all gibbsite is dissolved. The following conditions occur: the liquor is significantly saturated by alumina, in the initial bauxite the crystallization centers are formed by primary boehmite crystals, further the liquor is digested under the temperature 155°C – where the low caustic concentrations and saturation of liquor by alumina gives conditions for boehmite reversion. It results in underrecovery of alumina at the level of 5–15 % or higher.

Figure 6: Alumina recovery under different temperature and concentration digestion modes

In order to avoid the secondary boehmite formation it was suggested to increase the caustic concentration in the liquor up to 180 g/dm³. In the series of experiments under those conditions with desilication using standard slurry, the certain amount of secondary boehmite has also been produced and the recovery was at the level 87.3 of mass % (Figure 6). The investigation of the digestion process and demonstrated that the variations of the processing parameters with wide enough range practically do not influence recovery, and the easy reactivity of fine and cryptocrystalline gibbsite can explain it.

5.3 Continuous testing and consumption factors

For more complete assessment of this bauxite process properties and for additional benchmarking of two digestion temperatures the continuous testing has been conducted as follows: preliminary desilication of dense slurry during 10 hours under temperature 105°C and digestion under 155 and 175°C with 45 min retention, then desilication and thickening.

It should be noted that the liquor caustic ratio after desilication is close to the target one, and this is an index of the practically complete alumina recovery. The extraction of Al₂O₃ obtained after digestion at 155°C (88.8%) is slightly higher than at a temperature of 175°C (87.6%) with the same other conditions and it can be caused by higher quartz dissolution and increased formation of pseudo-boehmite at 175°C.

Table 3 reflects the outputs of the continuous experiment with preliminary desilication, digestion and dilution.

Table 3: Continuous experiment. Liquid phase, mud and alumina recovery parameters

<table>
<thead>
<tr>
<th>T°C digest</th>
<th>Liquid phase characteristics</th>
<th>Red mud characteristics</th>
<th>Na₂O</th>
<th>Recovery of Al₂O₃, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Content, g/dm³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Na₂O total</td>
<td>Na₂O carb</td>
<td>Na₂O₂</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>155</td>
<td>199.9</td>
<td>25.2</td>
<td>174.2</td>
<td>203.0</td>
</tr>
<tr>
<td>175</td>
<td>200.7</td>
<td>24.0</td>
<td>176.7</td>
<td>206.4</td>
</tr>
</tbody>
</table>
Table 4: Designed and investigated digestion parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>T°C</th>
<th>(\text{Na}_2\text{Oc}) concentration in spent liquor, g/dm³</th>
<th>Retention time, min</th>
<th>(\alpha_c) target</th>
<th>Rp target</th>
<th>Recovery of (\text{Al}_2\text{O}_3) at digestion</th>
<th>Consumption of raw bauxite (moisture 11%), t/t of (\text{Al}_2\text{O}_3)</th>
<th>Consumption of caustic soda (as 100% NaOH), kg/t (\text{Al}_2\text{O}_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current situation</td>
<td>107</td>
<td>200</td>
<td>120-150</td>
<td>1.56</td>
<td>1.09</td>
<td>87.0</td>
<td>3.2</td>
<td>75.0</td>
</tr>
<tr>
<td>Optimal parameters</td>
<td>155</td>
<td>180</td>
<td>45</td>
<td>1.38-1.40</td>
<td>1.21-1.18</td>
<td>88.8</td>
<td>3.0</td>
<td>41.0</td>
</tr>
</tbody>
</table>

The produced data confirm in whole the significant efficiency of the adopted technology. The following consumption factors have been achieved (Table 4).

Thereby the optimum process modes for modernization and expansion of ACG plant have been established.

6 Geology technological mapping and reserve assessment

During the work execution the new approaches to the bauxite reserve assessment for this region have been elaborated in view of raw material nature.

The analytical processing of the technological analysis for individual samples of all survey drillings has been conducted to establish only \(\text{Al}_2\text{O}_3\text{mae}\) and \(\text{SiO}_2\text{mae}\), \(\text{Al}_2\text{O}_3\), \(\text{SiO}_2\) and other compulsory components have not been chemically studied.

The application of computer software allowed to identify the nature of the major components \(\text{Al}_2\text{O}_3\text{mae}\) and \(\text{SiO}_2\text{mae}\) in bauxite group, justify the selection of quality requirements and execute the reserve calculation of bauxite deposit, meeting by quality the requirements of process concept for refinery expansion.

The results of the final audit of the ACG raw material basis once again confirmed the sufficient reliability and efficiency of the adopted reserve and bauxite quality assessment method and this approach permits to classify according state-of-the-art method as category B + C1 + C2 or ‘proven + probable’ about 500 M tons of bauxite in the raw material stock feed of ACG as of 01/01/2005.

According to the result of expert audit the raw material basis of bauxite alumina complex ACG-Fria has today the sufficient quantity of bauxite reserves to schedule the further increase of alumina production up to 1.4 M tons of alumina per year with total bauxite reserves 638,816 kt with average content of \(\text{Al}_2\text{O}_3\text{mae}\) – 41.1% and \(\text{SiO}_2\text{mae}\) – 0.85%.

7 Conclusions

1. The executed scope of geo-technological works confirmed the reserve of bauxite to satisfy the expansion of Fria refinery up to 1.4 mtpy.
2. The process modes to refine the above bauxites with high technical and cost efficient parameters have been selected.
3. Presence of finely dispersed boehmite in the initial bauxite stimulates the formation of secondary boehmite at the digestion stage under specific concentration modes. This particularity forces to limit the process parameters despite the process attractiveness of Fria bauxite processing at as low as possible caustic ratio in the liquid phase of the digested slurry.

References

