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Analysis of the regularity of alumina dissolution parameters: Case of the Rusal/Friguia plant (Republic of Guinea)

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ABSTRACT: Good alumina production using the Bayer process depends on the regularity of the alumina dissolution parameters, as failure to control these factors leads to a drop in alumina yield. This work has enabled us to identify and propose solutions to the anomalies linked to alumina dissolution. An analysis of the dissolution parameters (temperature, liquor concentration, residence time and saturation rate) shows that the alumina yield from January to December was irregular. This fluctuation in alumina yield remains the same for all the parameters studied. Chemical analysis was used to provide results for certain parameters. These included spectral analysis, pH meter analysis and methrom analysis of samples taken from the etching plant. These analyses showed the different behaviours of the concentration of the liquor and the content of the different bauxite constituents. An analysis of the graphs shows that the parameters vary according to the plant's instructions. All the results obtained show the need to regulate the alumina dissolution parameters. Better management of these factors will help to improve alumina yield.

KEYWORDS: Bauxite; Alumina; Dissolution-Attack; Rusal/Friguia; Bayer process; Irregularity.

1 INTRODUCTION

Demand for products made of aluminium or incorporating aluminium in their composition continues to grow year after year. Global demand for aluminium will reach around 65.6 million tonnes in 2019, compared with 65.5 million tonnes in 2018. In addition to global population growth and increased purchasing power in emerging countries, aluminium consumption is increasing as a result of the substitution effect (aluminium gradually replacing other materials) thanks to a unique combination of properties such as lightness, mechanical strength and corrosion resistance, conductivity, ductility, recyclability and many other properties [1]. With an average content of 8%, aluminium is the 3rd most abundant element in the earth's crust, according to Clarke's value. There are various ore carriers, but bauxite is the raw material most commonly used to obtain the alumina needed to produce aluminium as a metal. Bauxite is one of the most abundant natural resources and the growing demand for aluminous materials. Bauxite is an aluminium ore chemically composed of: Al2O3> 40%, SiO_2 (2-20%), Fe_2O_3 (20-35%), TiO_2 (2-44%).

At the Rusal/Friguia plant, the process for converting bauxite into alumina (Al_2O_3) is the Bayer process. This is a wet process. Soda ash is applied to the bauxite in reactors known as attack tanks, under specific pressure and temperature conditions. The process is based on two (2) principles:

- Dissolution of the alumina contained in the bauxite when attacked by concentrated sodium hydroxide solution;
- After dilution and separation of the insoluble residues, partial precipitation of the alumina in solution, made possible by lowering the temperature and diluting the sodium aluminate. This precipitation (decomposition) is very slow and must be encouraged by the addition of a hydrated alumina primer produced previously.

Under these conditions, the natural alumina hydrate is dissolved in the form of aluminate, while the metal oxides (Fe_2O_3, TiO_2, SiO_2, etc.) remain unattached. Furthermore, during the process, some of the silica under the action of soda will lead to the formation of silicate in the presence of aluminate, which gives soda silico-aluminate, which leads to a loss of alumina and soda.

In fact, the Rusal/Friguia plant is faced with a problem of regularity of the alumina production parameters, which is often explained by the poor dissolution of the alumina contained in the bauxite due to the irregularity of the parameters involved in the operation. This work has enabled us to diagnose the dissolution plant circuit, identify the faulty parameters and propose corrective measures to ensure that the plant achieves the predicted alumina production yield.

Studies related to the Bayer process have been the subject of several works, such as [2].

indicate that a low flow rate of the etching liquor causes an increase in the residence time, resulting in a decrease in the production of aluminium hydrate. The quantity of alumina dissolved (g/l) depends on the concentration of the etching liquor, so during etching, only uncombined caustic soda is capable of dissolving the alumina [3]. The authors also indicate that during etching, only uncombined caustic soda is capable of dissolving alumina. Better management of dissolution time improves etching yield [4]. The conditions for dissolving bauxite are also influenced by its mineralogical composition. Ores containing mainly gibbsite can be dissolved at relatively low temperatures (110-150°C), while diaspore and bohemite can require temperatures of up to 260-300°C [5].

The saturation rate during etching is a function of the charge ratio and the suspension residence time [6]. Etching is an important stage in the Bayer process. Its main role is to dissolve the alumina trihydrate in the caustic liquor [7]. The aim of this work is to improve the alumina dissolution rate in order to optimize its yield. To achieve this, we will compare production data from the Friguia plant with the parameters predicted by the Bayer process.

2 MATERIALS

The first material used in this study is bauxite, from which we took a bauxite sample from the Rusal/Friguia plateau3. This bauxite ore is red in color with a density ranging from 2 to 2.2 g/cm3. The main minerals that make up this bauxite are: bohemite, diaspore and gibbsite, which are described in Fig.1.

Fig. 1. A sample of bauxite from Rusal/Friguia's plateau 3

From a facies point of view, there are small hollows that can be assimilated to skeletal bauxites resulting from the alteration of dolerites. Macroscopic observation also shows:

- Grey to dark grey grains corresponding to pyroxene minerals, part of the main minerals.
- Black grains superimposed like relics of magnetite, part of the accessory minerals.

The second material was the attack reagent, i.e. the caustic soda used to dissolve the alumina contained in the bauxite. This soda liqueur is subdivided into three categories:

- Strong liquor: whose concentration varies from 150 to 200 g/l, makes up the etching liquors, evaporation liquors and those in the last etching tanks.
- Medium liqueur: with a concentration of between 75 and 150 g/l, concerns the liqueurs in the Dessilicateur vats.
- Weak liquor: with a concentration of between 25 and 75 g/l, this is the adjuvant liquor.

3 METHODS

The approach consists of carrying out mechanical and chemical tests, using certain laboratory equipment. These different methods of analysis provide an interpretation of the production samples. These analysis results give an idea of the etching yield.

3.1 MECHANICAL TESTING

CThese tests were carried out using a sieve column, which is used to determine the particle size in order to get an idea of the different particle size ranges. The second sequence was used to determine the weights of the various samples: sieve rejects and samples entering the mechanical laboratory. These different tests are shown in Fig.2 and 3.

Fig. 2. Sieve column

Fig. 3. Electronic scale column

3.2 CHEMICAL TESTS

These tests determine the concentration of the liquor, the weight ratio (Rp) and the content of the various components of the bauxite (Al2O3, Fe2O3, SiO2, etc.). They were carried out on the three types of liquor (strong, medium and weak). The analyses were carried out using the following equipment:

- pH meter: used to determine the pH of the solution, the concentration of the solution and the weight ratio.
- Methrom: used to confirm or refute the results of the pH meter for comparison purposes.
- Reactor: used to simulate the behaviour of the attack in relation to its parameters on a laboratory scale.
- Spectrometer: used for qualitative and quantitative analysis of bauxite samples with respect to the various oxides of which they are composed.

These various devices are shown in the fig. 4; 5 6; 7:

Fig. 4. The pH meter

Fig. 5. Methrom

Fig. 6. Spectrometer

Fig. 7. Reactor

4 RESULTS AND DISCUSSION

The results are based on the bauxite etching parameters, which can help to better understand the mechanism that controls the transformation of bauxite into alumina. These parameters are: temperature, concentration of the liquor after etching, residence time and alumina saturation rate. These parameters were analyzed by acquiring and processing data from the various stages of the bauxite etching process. The etching parameters for the month of January 2019 are taken as starting data Table1. At the Rusal/Friguia plant, alumina is produced on two parallel production lines.

Table 1. Basic production parameter data for Lines 1 and 2 (Rusal/Friguia, 2019)

Parameters	Lines		
	I	II	Units
Bauxite tonnages	120	118	t/h
Alumina content (Al_2O_3)	41,4	41,4	%
Moisture	7,3	7,3	%
Etching yield	89,0	89,0	%
Production factor (Kf)	95	95	%
Etching liquor flow rate	503	500	m^3/h
Etching liquor caustic	183,3	183,3	g/l
Attacking liquor input weight ratio	0,644	0,644	_

Using the data received on lines 1 and 2 of the attack workshop, the parameter calculations carried out for the month of January enabled us to summarize all the attack parameters for the other months of 2019, which are grouped together in Table 2. It is these values that will enable us to present the results and then interpret them.

Table 2. Summary of attack parameters and their values at the Rusal/Friguia plant from January to December 2019

Month	Concentration; g/l (200-220) *	Saturation rate % (38) *	Length of stay; h, mn (2 h-2 h -30) *	Performance; % (80-90) *
January	183,3	40,03	2,36	89
February	200,9	38,43	2,06	91
March	201,3	37,18	2,25	89,7
April	202,2	39,04	2,59	89,8
May	202,5	39,90	3,04	89,5
June	199,6	42,85	3,23	89,3
July	199,5	36,13	2,12	87,7
August	195	36,79	2,16	87,5
September	190,5	39,25	2,38	92,7
October	197,3	36,36	2,16	91,3
November	196,9	40,39	2,16	90,5
December	200	40	2,15	90,7
Average	197,42	38,86	2,39	89,89

(*): value used at the Rusal/Friguia plant

4.1 ANALYSIS OF YIELD AS A FUNCTION OF ETCHING TEMPERATURE

The temperature at which the soda ash attacks the bauxite is a very important parameter, as it favours the other alumina dissolution conditions. The alumina dissolution temperature depends on the mineralogical composition of the bauxite. For gibbsite, the temperature is low and ranges from 110°C to 150°C, while for diaspores and bohemite, temperatures are high and vary from 260 to 300°C [5]. At the Rusal/Friguia plant, the extraction method used is the Bayer process, where the ore is heated to 108°C in the etching tanks. The temperature trend over the production period is shown in Fig.8.

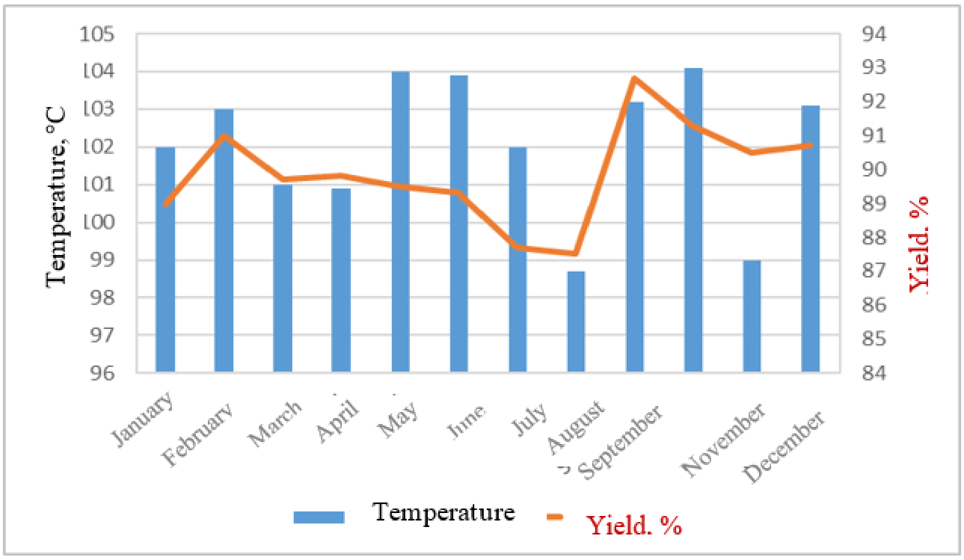

Fig. 8. Changes in alumina yield as a function of etching temperature

Analysis of the results shows that all the temperatures recorded during the period studied were both irregular and below the temperature set by the plant (108°C).

Temperatures varied between 98.7 and 104.1°C, a difference of 9.7 and 3.9°C respectively. The transformation of bauxite into alumina below the set optimum etching temperature can lead to poor dissolution on etching. Processing bauxite at 108°C contributes significantly to the separation of the various oxides that make up the bauxite ore [8]. Alumina yields as a function of temperature range from 87.5 to 92.7% Fig.8. The lowest alumina yield was obtained in August, when the lowest attack temperature (98.7°C) was also recorded. The highest yield was obtained in September, with an attack temperature of 103.2°C.

4.2 Analysis of alumina yield as a function of residence time

Residence time is an important factor in the Bayer process. This residence time is generally within a range. A residence time below this range would make it difficult to dissolve the alumina, and beyond that, the alumina already dissolved would partially precipitate. The residence time therefore makes it possible to regulate the dissolution process and assess the yield. The residence time characterizes the rate of dissolution of the soda liquor, and defines the yield of the etching [9]. The evolution of residence time over the course of 2019 (January to December) is shown in Fig. 9.

The residence time recorded at the Rusal/Friguia plant is between 2 h and 2 h 30.

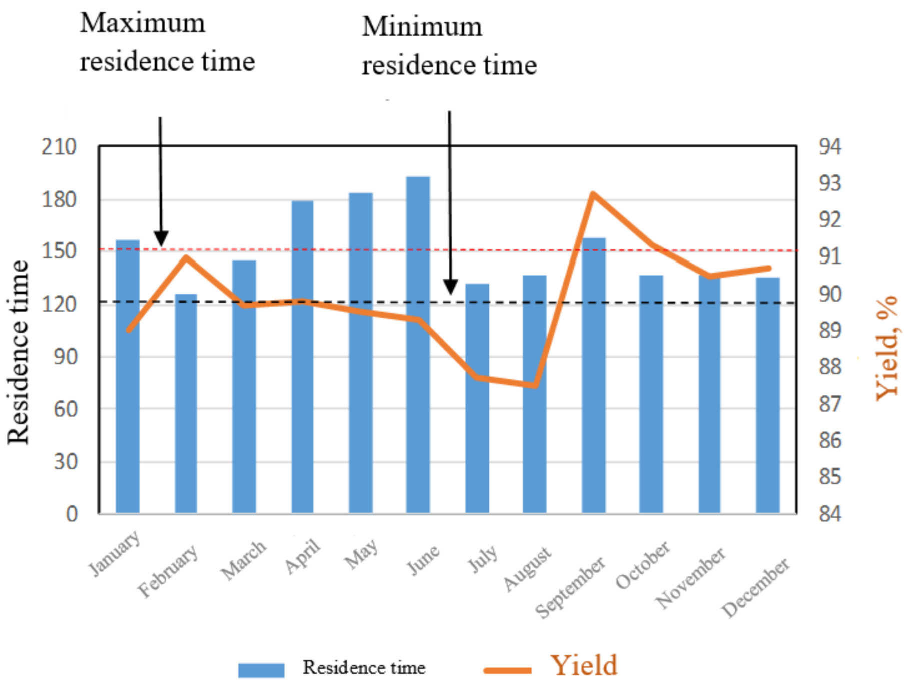

Fig. 9. Changes in alumina yield as a function of residence time

The curve shows an irregular pattern, with residence times in January, April, May, June and September exceeding the maximum recommended duration. During etching, exceeding the set residence time would lead to alumina precipitation at this stage, reducing the etching yield.

Alumina yields as a function of residence time ranged from 87.5 to 92.7% Fig.10. The lowest alumina yield was recorded in August. The highest yield was obtained in September.

The analysis of yield as a function of residence time can be explained in two ways:

- **Residence times in excess of the interval:** these residence times were observed in the months of January, April, May and June. They have yields between 89 and 92.7%, despite these high residence times, yields are appreciable according to those set by the plant (80-90%).
- **Residence times within the range:** residence times obtained in the months of February, March, July, August, October, November and December, which oscillate between 2 h 06 min and 2 h 16 min, with yields varying between 87.5 and 91%. These residence times, within the range indicated, comply with the yields defined by the plant (80-90%), which validly verifies the condition**.**

This analysis shows that changes in alumina yield do not necessarily depend on compliance with the recorded residence time.

4.3 Analysis of yield as a function of etching liquor concentration

The dissolution of aluminium hydroxides in bauxite ores is a key parameter in the aluminium industry. In general, the aluminium-bearing minerals in bauxite are in the form of gibbsite, bohemite and diaspore [10]. The rapid dissolution of alumina depends considerably on the concentration of the etching liquor. The liquor improves etching efficiency and regulates suspension residence time. The monthly values for concentration trends in 2019 are shown in Fig. 10.

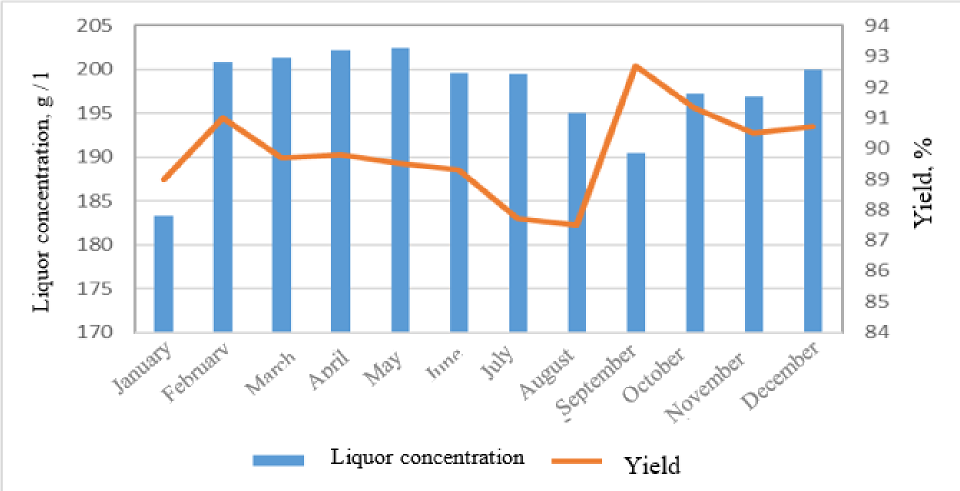

Fig. 10. Changes in alumina yield as a function of etching liquor concentration

The concentration of the etching liquor should be between 200-220 g/l. At this concentration it will dissolve the oxides contained in the bauxite in the reaction medium and increase the yield.

The curve of alumina yield as a function of liquor concentration is irregular according to the results obtained. Analysis of the data Fig. 10. shows that the liquor concentrations in January, August, September, October and November are below the minimum value of 200 g/l indicated at the plant. Concentrations varied between 183.3 and 199.6 g/l. Concentrations below 200 g/l can lead to a drop in attack yield.

Yields as a function of concentration ranged from 87.5 to 92.7% (Figure 10). The lowest yield was recorded in August with a concentration of 195 g/l. The highest yield was recorded in September with a concentration of 190.5 g/l. These results show that the variation in yield is not necessarily linked to the higher concentration of liqueur.

4.4 Analysis of yield as a function of alumina saturation rate

The saturation rate is a parameter that takes into account the limit of alumina dissolution in a given quantity of liquor. This factor is used to assess the maximum extractable alumina (MAE). The alumina saturation rate set at the Rusal/Friguia plant is 38%.

The alumina saturation rates recorded during 2019 are shown in Fig. 11.

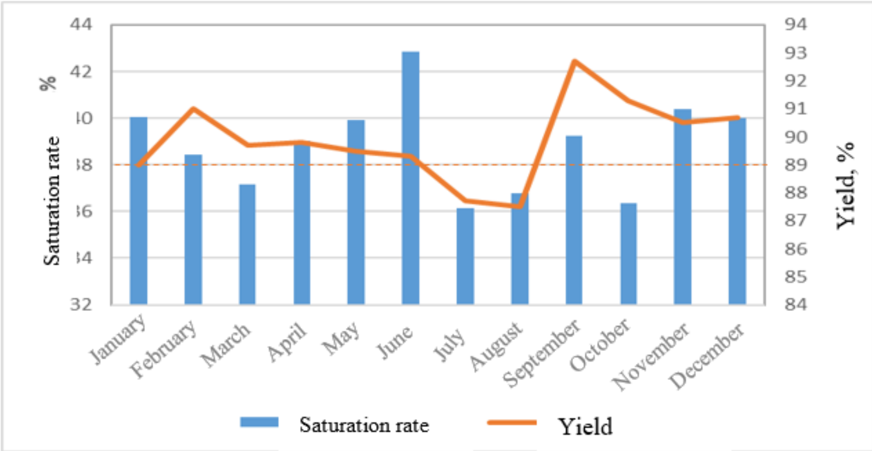

Fig. 11. Evolution of alumina yield as a function of saturation rate

Analysis of the yield as a function of the alumina saturation rate shows irregularity during the attack, which leads to poor alumina dissolution. These saturation rates can be divided into two areas in relation to the alumina saturation rate set at the Rusal/Friguia plant:

- **Alumina saturation rate below 38% (under saturation):** the saturation rates recorded are between 36.13 and 37.18%, i.e. a difference of 0.82 and 1.87%, with alumina yields varying between 87.5 and 91.3%. This under-saturation leads to a drop in the rate of alumina dissolution**.**
- **Saturation rate above 38% (oversaturation):** the saturation rates obtained vary between 38.43 and 40.39%, i.e. a difference of 0.43 and 2.39%, with alumina yields varying between 89.3 and 92.7%. Alumina supersaturation leads to overconsumption of the aluminate liquor, which would increase the quantity of new soda to be injected into the circuit and the loss of alumina in the residues.

Supersaturation creates conditions where there is a risk of alumina retrogradation [8]. Retrogradation is a phenomenon to be avoided because it results in the premature precipitation of part of the alumina on attack, which mixes with the insoluble residues and is dumped with them.

The values of certain yields in these two areas are sometimes higher than the set yield (80-90%). In short, the analysis of the various graphs shows an irregularity in the instructions given by the factory. The trends in the various parameters according to output show a significant failure on the production line. The findings reveal that compliance with the instructions given by the plant sometimes does not justify obtaining a better yield. It is clear that certain parameter values, which do not comply with the plant's requirements, sometimes give good results. These irregularities therefore need to be brought to our attention with a view to better management of the attack parameters.

5 Conclusion

Bauxite is the main ore for aluminium, of which Guinea has 2/3 of the world's reserves.

The aim of our research is to understand the evolution of the dissolution parameters of the alumina contained in bauxite, namely: temperature, saturation rate, residence time and soda liquor concentration.

However, this study enabled us to detect various irregularities in the attack parameters.

The results showed that the regularity of certain parameters does not necessarily define a good yield for our case study. These irregularities are not without consequences during alumina production, often leading to poor alumina dissolution.

In this work, the approach consisted of analyzing the values of the various production parameters at the bauxite etching stage as a function of their yields, then comparing them with the values set by the Rusal/Friguia plant. Analysis of the dense liquor concentrations shows that the concentrations in January, June, July, August, September, October and November were below the minimum value set at 200 g/l. No concentration exceeded the maximum value.

With regard to the dwell time set by the plant, which must be between 2 h and 2 h 30 min, analysis shows that dwell times in January, April, May, June and September 2019 exceed the maximum duration set. The values recorded are between 1h30mn-2h05mn.

The saturation rates recorded in March, July, August and October were below the minimum rate set by the plant, which is equal to 38%. These lower saturation rates were recorded in January, February, April, May, June, September, November and December 2019. This shows poor liquor productivity during these months.

Analysis of the various production data shows that the alumina etching parameters (temperature, concentration, residence time and saturation rate) are not regular. This irregularity reduces the alumina etching yield.

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CONFLICTS OF INTEREST

The authors approve the publication of this article in this journal.

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