AKW Apparate + Verfahren GmbH and its expertise in bauxite upgrading

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Abstract

The world production of bauxite was reported to be 258 Mt/year in 2012. With regard to the use of bauxite, metallurgical bauxite for aluminium production accounts for the main share, making up around 90 % of this total. The beneficiation of bauxite is gaining importance not only for effective production of alumina and export of bauxite but also due to decreasing bauxite quality. Even though the beneficiation happens on the red side, it has significant influence on the white side of alumina refineries. In the following the test methods for process determination and the resulting process design are shown. Further on, the implementation and operation of such bauxite beneficiation plants are explained with an example of an operating plant. The scope of supply of AKW A+V starts with the individual test work to determine raw bauxite composition at the company test center, then it is followed by the engineering work for process design and plant construction and is completed by the commissioning of such plant.

Keywords: Decreasing bauxite quality; beneficiation of bauxite; bauxite testing; process design.

1. Introduction

1.1. Background of AKW Apparate + Verfahren GmbH (AKW A+V)

AKW A+V is a medium-sized, privately owned company focused on process engineering and equipment as well as on plant engineering, construction and service for mineral processing plants.

Since the beginning of the 19^{th} century, kaolin, feldspar and silica sand are produced in the area around Hirschau. This is where AKW A+V was founded in 1963 as a research department of a mining company. Since the early beginnings, innovations, new product ideas and technologies have turned the company into a global operating enterprise with the headquarter in Hirschau (Bavaria, Germany), offices in Kiel, Moscow, Shanghai, São Paulo, Dubai and agencies in many other countries. Experience, know-how, motivation, new ideas for products and technologies and a steadily high international standard in quality and service enable AKW A+V to offer tailor made solutions to the different customers and to act as an international provider of mineral processing technology, equipment and plants.

The first contact to the **Bauxite-Alumina-Aluminium** Industry goes back to a development in the early 1970s between VAW, a former German alumina producer (Schwandorf, Lünen, Stade) and AKW A+V. Shortly after the successful introduction of classification equipment (hydrocyclones) in the Bayer process, NABALCO, Gove was the first international refinery which installed AKW A+V hydrocyclones in 1978. In the meantime the hydrocyclone clusters of AKW A+V are used all over the world in the Bayer process.

In order to provide added value to customers, free rein is given to the curiosity of new processes. The strategic focus on interdisciplinary cooperation for the development of customized solutions for even the most complex challenges is the backbone of the long and ongoing success. For the **bauxite-alumina-aluminium** industry the company is interested in an optimization of wet mechanical processes involved with the bauxite mining and the alumina refinery.

1.2. Motivation for upgrading of bauxite

The most important raw material for the production of alumina and aluminium is by far bauxite. In 2012, world production of bauxite was essentially unchanged compared with that of 2011. Total mine production of 258 Mill. t was reported from 26 countries. The leading producers of bauxite were, in decreasing order of tonnage mined: Australia, China, Brazil, Indonesia, India, and Guinea. These countries accounted for 86 % of total world production. The top three producers Australia, China, and Brazil together accounted for 61 % of the world's production. Based on the 2012 production the expected growth up to 2020 is:

- Bauxite: + 134 Mill. t/a of production;
- Alumina: + 52 Mill. t/a of production;
- Primary Aluminium: + 27 Mill. t/a of production.

The growth is dominated by the Chinese primary aluminium industry, followed by the growth of primary aluminium production in the Middle East.
The quality of the bauxite ore, in general, is highly variable between individual deposits. The bauxite deposits differ widely in

- their geological associations,
- content and type of aluminium ore minerals and
- gangue minerals.

Following table shows the typical range in the composition of metallurgical grade bauxite.

Table 1. Typical range in the composition of metallurgical bauxite [1].

Components	Wt.% (as metallic oxide if not indicated otherwise)
Al_2O_3	30 – 60
Fe_2O_3	1 – 30
SiO_2	<0.5 – 10
TiO_2	< 0.5 – 10
Organic Carbon (as C)	0.02 – 0.40
P_2O_5	0.02 – 1.0
CaO	0.1 – 2
V_2O_5	0.01 – 0.10
ZnO	0.002 – 0.10
Ga_2O_3	0.004 – 0.013
Cr_2O_3	0.003 – 0.30
S	0.02 – 0.10
F	0.01 – 0.10
Hg (ppb)	50 - 1000

Bárdossy and Bourke [2] published in 1993 the ideal characteristics for metallurgical-grade bauxite:

- High extractable alumina (+49 %)
- Low "reactive silica" (1.5 – 3 %, kaolinite)
- Low boehmite (< 3 %)
- Iron content (ideally 5 – 15 %)
- Low quartz (ideally < 1 %)

- Low titania (ideally < 0,5 %)
- Low carbonates (ideally < 0,1 %)
- Low impurities and trace elements

In general, it can be stated, that following ore characteristics are of major importance for the quality of bauxite ore:

- **Recoverable Al_2O_3**
  Indicates the alumina-content that can be made available by the Bayer-Process with respect to geochemistry and mineralogy of the ore.
- **Reactive silica (R.SiO_2) and TiO_2**
  Strictly influences negatively the consumption of energy and reagents used in the Bayer-Process.
- **Iron content (5 - 15 %)**
  Low iron can lower product quality and high iron dilutes alumina content of bauxite. Especially the mineral goethite slows clarification and increases alumina loss via red mud circuit. It may also decrease alumina quality. Increase of CAPEX and OPEX.
- **Bauxite/Al_2O_3-ratio and Red mud/Al_2O_3-ratio**
  Provides information on the amount of bauxite needed to produce a given amount of aluminium oxide.
- **Quartz**
  A high quartz content increases OPEX (maintenance costs, caustic usage in high temperature plants).
- **Titania**
  Titania can increase caustic usage in high-temperature plants.
- **Organic carbon**
  A high content increases OPEX by reducing plant efficiency and reduces alumina quality.
- **Carbonates:**
  High content can require special design of Bayer Circuit.
- **Impurities and trace elements**
  High content decreases the process efficiency (S, Cl, Ca) and metal quality (Ga, Zn, V, P).
- **Moisture content**
  Has a negative effect on ore processing and transportation.

With respect to the well-known wet-mechanical processes used for different types of metallic ores or industrial minerals and which are subject to different investigations nowadays, as well from AKW Apparate+Verfahren GmbH as from other companies, it can be stated, that a wide range of the above mentioned quality criteria are adjustable by well-known separation processes.

Table 2. Quality criteria of Bauxite which can be optimized by beneficiation.

reactive silica (kaolinit)	**separable**
iron (goethite, magnetite)	**separable**
quartz	**sometimes separable**
organic carbon	**sometimes separable**
titania	**might be separable**
carbonates	**might be separable**
Moisture content	**adjustable**

2. Selected processes of Mineral Processing

To improve the characteristics of the Run Of Mine ore (R.O.M. ore) mineral processing techniques are common in the mining industry of ores and minerals like iron ore, non-ferrous ore, phosphate ore, china clay, coal and so on.

Among the used and tested processes for beneficiation of bauxite ores are:

- Crushing and milling

- Screening
- Elutriation (scrubbing)
- Cycloning (in combination with dewatering screens)
- Dewatering of fine ground ore (for pipeline transportation)

New developments are:

- Gravity separation (spiral)
- Magnetic separation
- Flotation

To have a first idea of a suitable process, the general physical appearance of the ore, including the geometric aspects of, and the mutual relations among component particles, like size, shape and arrangement of the constituent elements (texture) has to be considered.

For the upgrading of bauxite different processes are promising and have been tested with success. Some processes are even of common use in the treatment of R.O.M. bauxite.

2.1. State of the art – common processes

Generally the R.O.M. bauxite is processed by,

- Crushing and milling
- Screening

And for some mines these process steps are supplemented by,

- Elutriation (scrubbing);
- Cycloning (in combination with dewatering screens).

The elutriation in combination with classification by cyclones is carried out to decrease the amount of reactive silica (kaolinite). Mine sites which are using these processes are: Juruti, Trombetas (Brazil), Awaso (Ghana), Weipa (Australia), Coermotibo (Suriname). [3]

2.2. State of the art – special processes

Just in a few places a more advanced processing of the R.O.M. bauxite are already used. There are examples for the use of different gravity separation processes for the upgrading of R.O.M. bauxite.

In [4] Papoutes reported the results of a dense media separation for greek bauxite from S&B Industrial Minerals S.A. – this gravity separation process is used to remove liberated limestone, which is found in a range of 2-4 % expressed as CaO.

The separation is carried out in a rotating dense media by using TriFlow separators. Alternatively a heavy media cyclone could be used.

In [5] Chaves discussed the process results of a gravity separation with spiral separators of an ore from Companhia Brasileira de Alumínio (CBA).

The unit operations used at the CBA plant are:

- Scrubbing of the feed in drum scrubbers,
- Screening of the scrubbed bauxite in high frequency screens (0.355 mm) - the +0.355 mm product is a final concentrate
- Desliming of the -0.355 mm fraction in a two stage cyclone plant
- Gravity concentration with spirals complemented by magnetic separation of the light product from the spirals.

It is reported the mass recovery of the process is about 60 % with a metallurgical recovery of up to 90 % of Al_2O_3.

2.3. Future Trends

In the near and medium future the beneficiation of R.O.M. Bauxite will increase. This is expected to be supported mainly by three different subject areas.

- Improvement of the sustainability of mining operations:
  As already practiced in mining operations for different kind of ores, the tailor made process technology of advanced mineral processing plants is able to improve the life time of a mining project, which leads to a lower overall environmental impact of the mining process by providing the opportunity of mining of lower quality ore and which may reduce mining costs. Examples for this idea of beneficiation of bauxite are presented in [6] and [3].
- Improvement of the efficiency of the Bayer process:
  As already mentioned, there are several minerals which have a negative impact on the process efficiency of an alumina plant. Among these minerals are iron oxides like goethite, which can be separated by gravity separation or magnetic separation. For iron-rich bauxites, with iron contents above 25% and even for medium iron-rich bauxites, with an iron content above 15%, a separation of the iron minerals can improve the process efficiency and last but not least lower the amount of residue (red mud).
  A separation of organic carbon is not reported up to now, but there are simple and cost-effective processes, like teeter bed separators (up-stream separators) which are used for this task for the beneficiation of different industrial minerals.
- Improvement of infrastructure cost:
  The successful implementation of the first long-distance bauxite slurry pipeline (245km) from Paragominas mine to Alunorte Alumina refinery (Norsk Hydro) in Brazil has proofed that the hydraulic transport of fine bauxite is a cost effective way for the transportation of ore to the refinery, especially in rugged terrain where rail and conveyor construction can become expensive and time consuming. What has to be recognized is, that on one side of the pipe, a mineral processing plant for comminution and classification of the bauxite has to be implemented and on the other side the slurry has to be dewatered before the Bayer plant.

In the past AKW A+V already reported at different occasions about the most promising mineral processing methods for the upgrading of R.O.M. Bauxite [7, 8, 9]
In the following chapter the focus is given to successful conducted test-work in the technical laboratory in Hirschau/Germany, which always has been the point of origin for successful design of industrial scale plants or semi-industrial pilot-plants.

3. Examples from AKW Apparate+Verfahren GmbH

3.1. Improvement of sustainability in mining operations

AKW Apparate+Verfahren GmbH was involved in different investigations for the beneficiation of R.O.M. bauxite to improve the life time of existing mining operations and therefore the environmental impact of mining.

Example for the reduction of reactive silica:
At a South American bauxite area it was the target of the mine operator to increase the remaining lifetime of the established mine areas by extracting those parts of the deposit that had not been mined in the past owing to an excessive content of reactive silica.
The high content of reactive silica of up to 15 wt. % is caused mainly by the kaolinite contained in the rock. Thanks to its small particle size, this can be fully removed by classification after a reasonable elutriation. Following a successful test program conducted at the AKW A+V test center, this plant was put into operation in 2007. [3]
The material with a particle size of up to 1,000 mm is fed to a roller grizzly with a variable cut-point. Depending on the composition of the raw material, material in the size range from <100 - 150 mm is fed to the downstream Washing and Elutriation Drum (Wasch- und Läuter Trommel - WLT). The separated material >100 - 150 mm is already product. The WLT completely dissolves any kaolinite contained. At the end of the WLT, a strainer basket removes the fraction >16 mm.

The underflow from the strainer basket is sized at around 2 mm on a vibrating screen. The screen overflow is discharged together with the material >16 mm on to a belt conveyor at the side. The screen underflow is collected in a pump sump and fed to a hydrocyclone with a centrifugal pump. Its overflow has a high content of kaolinite, the underflow is dewatered on a dewatering screen and fed to the product belt conveyor. In the plant – installed next to the independent feed unit in three (3) containers – a hydrosizer can be added in future if the bauxite quality requires this. The flow sheet and some pictures of the plant on site are shown in figure 1.

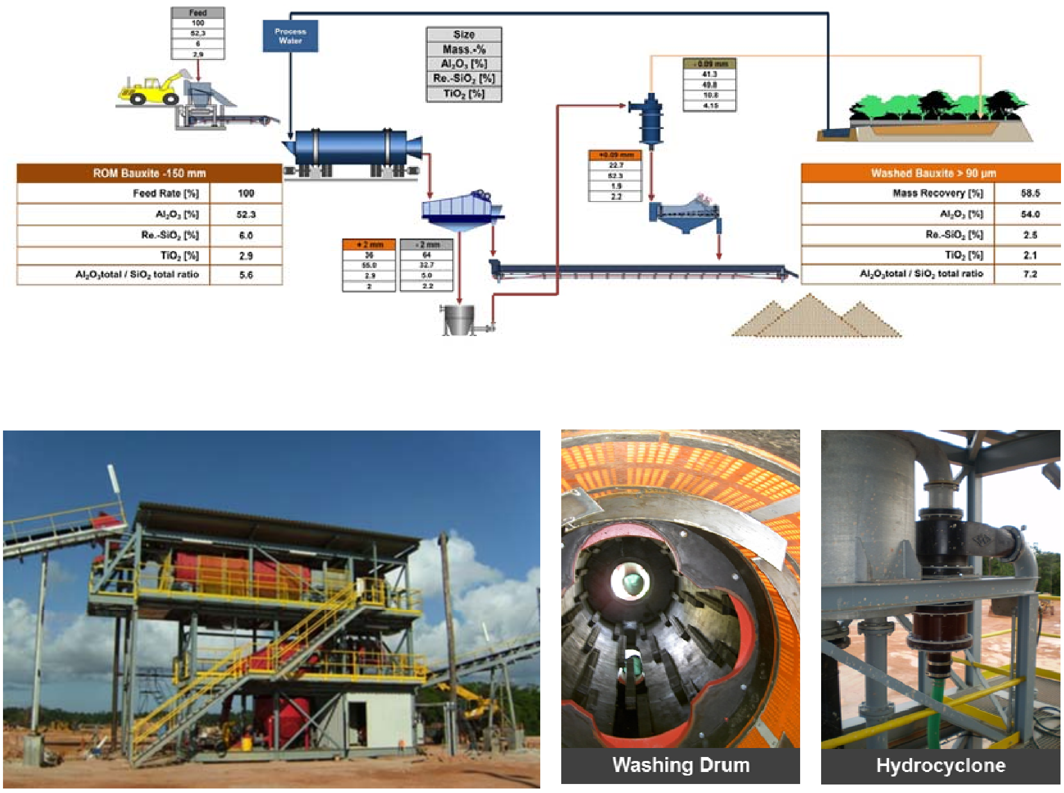

Figure 1. Flow-sheet and pictures of Bauxite processing plant for the removal of reactive silica, planned and delivered from AKW A+V.

<u>Example for the reduction of quartz:</u>

At Los Pijiguaos (Venezuela) the economic bauxite horizon attains an average thickness of 7.6 m. Below this layer, bauxite containing high quartz (HQ Bauxite) can be found.

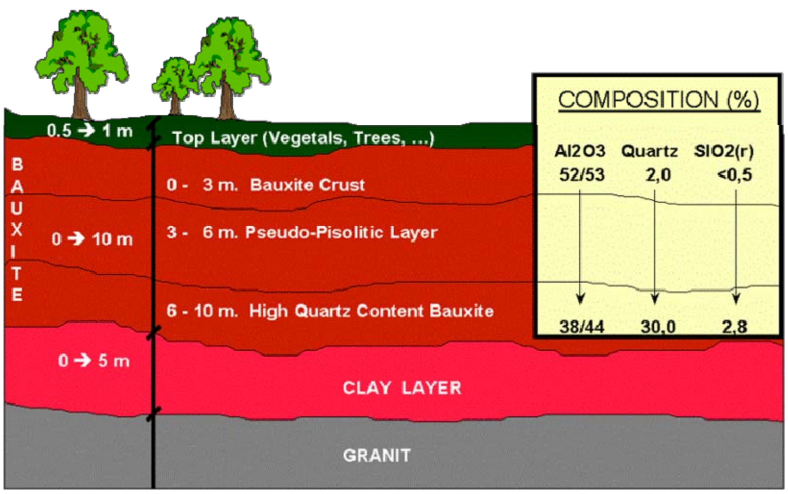

Figure 2. Sketch of the different bauxite horizons of Las Pijiguaos mine, Venezuela.

The aim of a study conducted in co-operation with ALCAN Bauxite and Alumina and CVG Bauxilum was to investigate the possibility to extract quartz from HQ Bauxite of Los Pijiguaos, with a minimum of Al_2O_3 losses.

The beneficiation process studied in this work was carried out in several steps. The first step was an elutriation, operated in a washing drum, aiming at liberating quartz particles. The second step was a classification process, aiming at obtaining different grain sizes according to the quartz content. Part of the study was to investigate if the finest fractions could further be beneficiated using such technologies as cyclones and shaking tables. The results of this study have been reported in [6].

All samples used for the characterization and beneficiation tests showed accumulated quartz content in intermediate fractions (0.063 mm – 2 mm). A cut size of 2 mm for the screen placed after the Washing Drum was found to be optimal. This simple process (wet screening at 2mm) delivers a recovery of 65 to 70 % of Al_2O_3 and to separate more than 75 % of quartz of initial HQ Bauxite of Los Pijiguaos. The quantity of Al_2O_3 recovered strongly depends on the pre-treatment process. In order to reach a Yield of Al_2O_3 greater than 80 %, it is necessary to recover the fine fraction of particles < 100 µm. This recovery process by hydrocylones and thickeners plus dewatering filters are more cost intensive than the simple process of wet screening, but it was found that the overall recovery of Al_2O_3 and the quality of the washed bauxite would be improved significantly.

The following table summarizes the results of the favorable process with respect to Al_2O_3 recovery and product quality.

Table 3. Test result for upgrading of high quartz bauxite from Las Pijiguaos.

	HQ Bauxite	BENEFICIATED BAUXITE after separation of different fractions from original bauxite		
	global	Coarse Bauxite	Medium Bauxite	Fine Bauxite
M.-Recovery (%)		61.0	70.0	66.5
LOI (%)	23,6	27,5	27,2	27,5
Al_2O_3 (%)	43,4	51,2	50,6	51,1
TiO_2 (%)	1,0	0,9	1,1	1,0
Fe_2O_3 (%)	7,9	8,4	9,3	9,0
SiO_2 total (%)	23,8	11,8	11,5	11,2
Quartz (%)	22,8	10,8	10,6	10,3
$Al2O_3/SiO_2$ total	1.8	4.3	4.4	4.6
Separated Fraction:		- 2mm	< 2 – 0,2 mm	< 2 – 0,1 mm

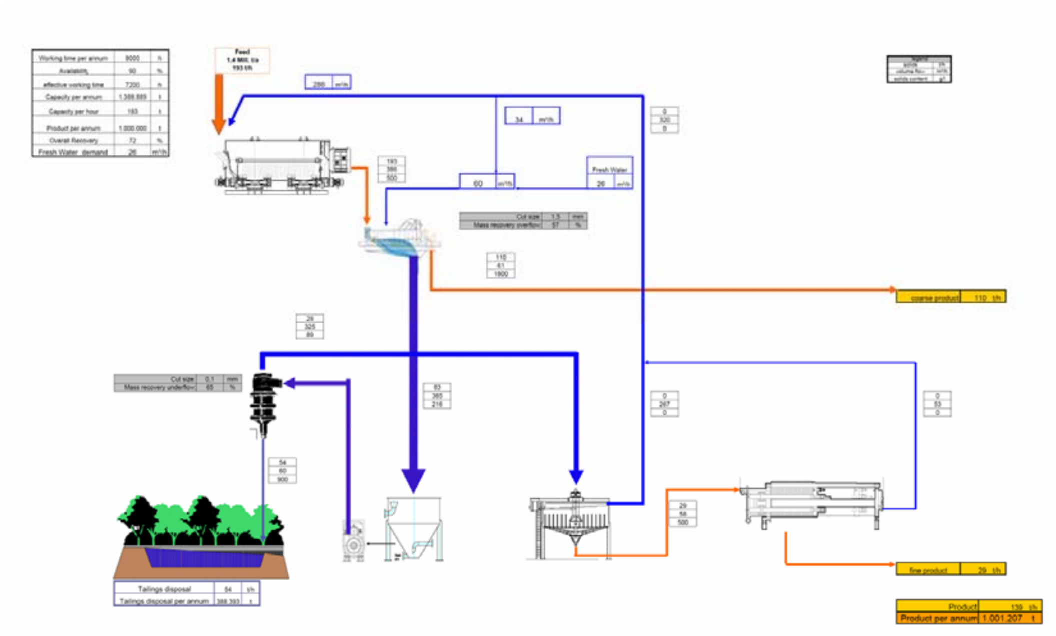

Figure 3. Flow sheet of a beneficiation plant for upgrading of high quartz bauxite.

3.2. Improvement of the efficiency of the Bayer process

Together with a customer, an intensive laboratory test work was carried out to improve the quality of different types of bauxite from Indochina. The overall aim of the test work was to improve the quality of the future refinery feed, with respect to the necessary investment and operational costs.

The washing tests should provide following information:

- The bauxite’s suitable for kaolin removal through washing.
- The specification of wash plant equipment requirements.
- The consumption of wash water per ton of bauxite.
- The settling characteristics of flocculated wash tailings.

Based on the experience of AKW Apparate+Verfahren GmbH with bauxite ores from different origins, the basic concept of the test work was determined as follows:

- Pre-classification of the coarse bauxite particles (+ 100 mm);
- Elutriation of the bauxite – 100 mm;
- Separation of the fines (clay);
- Dewatering of the Al_2O_3 rich fraction;
- Gravity separation and/or magnetic separation of iron rich minerals;
- Process water recycling for elutriation and classification.

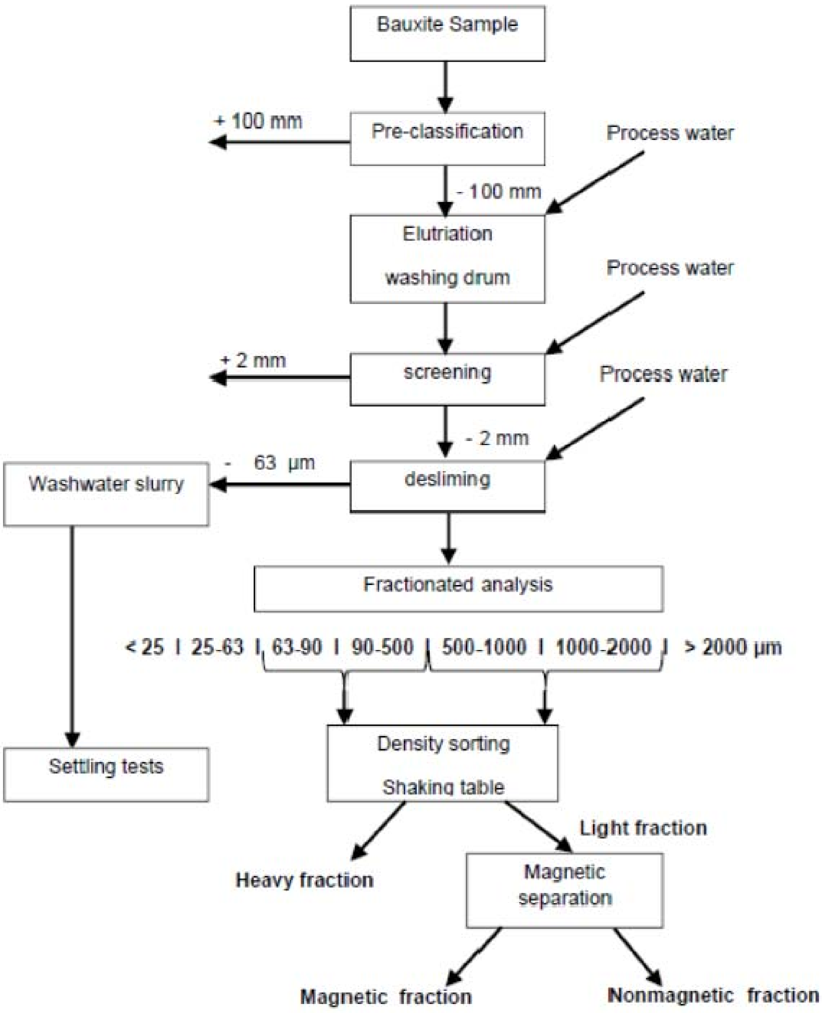

Figure 4. Exemplary test run procedure.

Following figure shows some photos of the testwork.

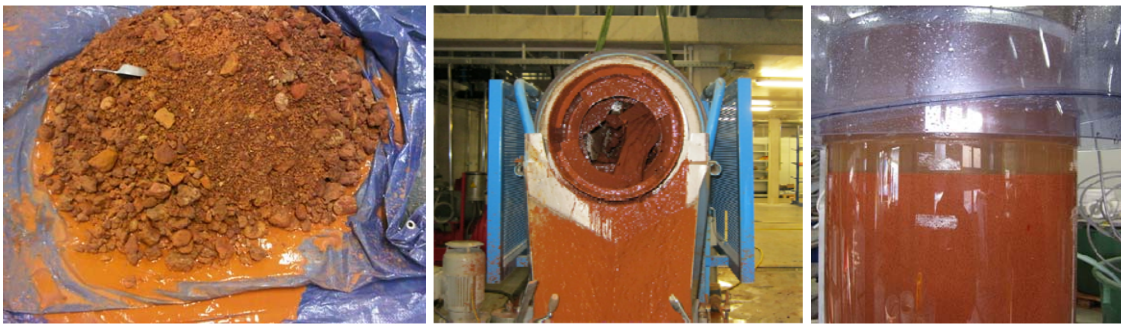

Figure 5. Photos of the conducted test work (from left to right): R.O.M. sample; washing drum outlet of dissolved material; wash water clarification test in thickener (type AKA-SET).

Taking into account the necessary investment cost of a plant and the achieved results with respect to mass-recovery and product upgrade, it was decided to proceed further without gravity separation and magnetic separation. The effect with respect to the quality was quite impressing, but the mass recovery was very low.

Following preliminary flow-sheet was designed for a beneficiation plant for 560 t/h of washed bauxite.

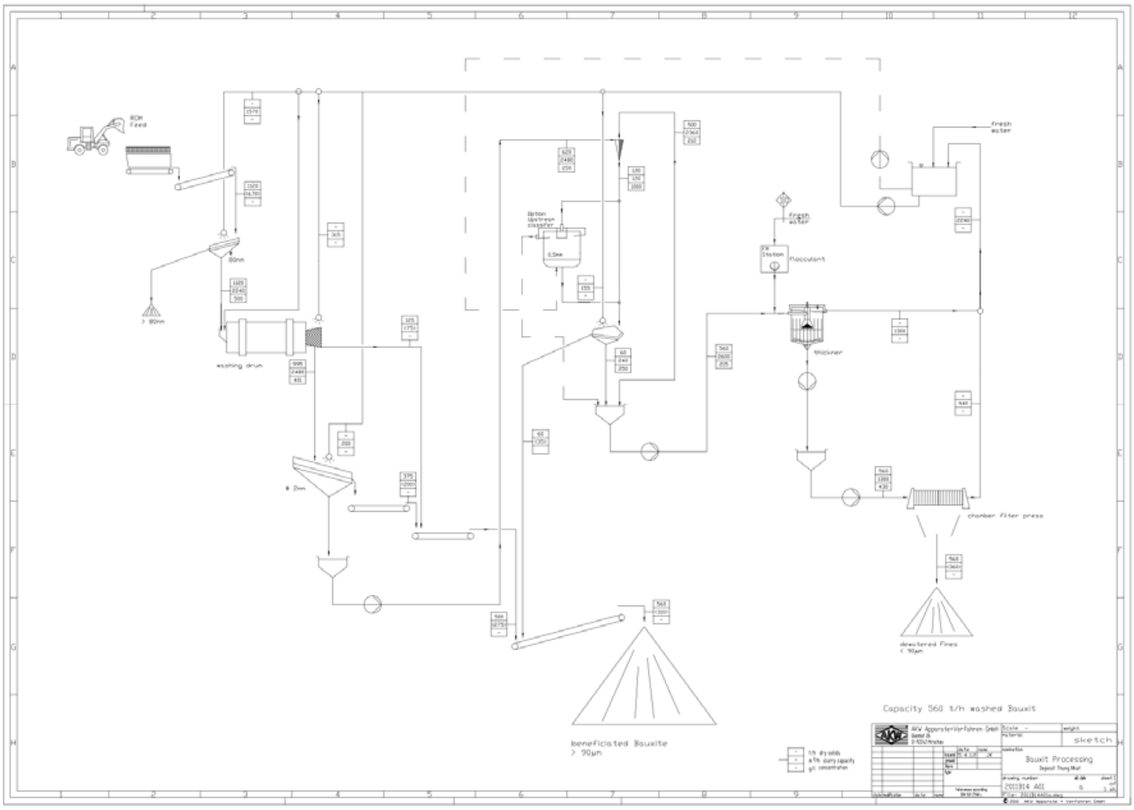

Figure 6. Preliminary flow-sheet of a washing plant for 560t/h washed bauxite.

4. Conclusions

The trend for an improved mineral processing of R.O.M. bauxite is likely to continue. Several reasons for a tailor made processing of the mined ore exist. Among these reasons the most important are:

- **Improvement of the sustainability of mining operations;**
  By using adequate technology, it is sometimes possible to improve the lifetime of an existing mining operation. The advantage of this this option is obvious.
- **Improvement of the efficiency of the Bayer process;**
  The mineral processing technologies to separate minerals with a negative impact on the Bayer process are existing and are used in mining operations of different ores. Besides gravity separation of coarse and fine material, magnetic separation has been tested with good success.
- **Improvement of infrastructure cost;**
  The positive idea of hydraulic transport of bauxite slurry with pipelines will lead to a more advanced mineral processing at the beginning of the pipeline as well as at the end.

AKW A+V is looking forward to be a reliable partner for testing these processes for a given ore, as well as for planning and implementing a customized processing plant.

5. References

1. Forté, G. and Girard,R., Bayer Process Alumina Production, Pressure Hydrometallurgy 2004, 34th Annual Hydrometallurgy Meeting, OCTOBER 23-27, 2004 (BANFF, ALBERTA, CANADA)

2. Bárdossy, G. and Bourke, D.J. An assessment of world bauxite deposits as sources for greenfield alumina plant developments, ALUMINIUM – vol. 69. N°10, pp.888-894, ISSN 0002; 1993.
3. Buntenbach, S. et al, Beneficiation of Bauxite – Upgrading of Recoverable Al2O3, XVIII International Symposium ICSOBA□2010, Zhengzhou, China.
4. Papoutes, A.: ‚Beneficiation plant for the bauxite of Silver & Baryte Ores, Mining Co. S.A., TRAVAUX de l'ICSOBA, No. 30. 1999. pp. 85-88.
5. A. P. Chaves, M. Bergerman, C. A. V. Abreu, N. Bigogno, Concentration of bauxite fines via gravity concentration, Revista Escola de Minas, vol.62 no.3 Ouro Preto July/Sept. 2009, Print version ISSN 0370-4467, http://www.scielo.br.
6. Rousseaux, J.-M., Verschuur, H., Flores, P., Buntenbach, S., Beneficiation OF High Quartz Content Bauxite From Los Pijiguaos, Light Metals 2006, Edited by A.T. Tabereaux, TMS (The Minerals, Metals&Materials Society), 2006.
7. Buntenbach, S., Bauxite Beneficiation, Aufbereitungs Technik 48 (2007) Nr.3, Germany.
8. Buntenbach, S., Mineral Processing Technologies in the Bauxite and Alumina Industry, 8th International Alumina Quality Workshop 2008, Darwin, Australia
9. Buntenbach, S., Innovations and solutions for cost-effective and environmentally friendly Bauxite processing, 13th Bauxite&Alumina Seminar, March 2007, Greece`.