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NEWSLETTER

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Foreword

Greetings to you from the ICSOBA Secretariat, Nagpur. We have great pleasure in bringing out this issue of the News Letter. A brief review of the developments since the release of the last issue is given here.

As a follow-up of the recommendations of the General Assembly held at the time of the Zheng Zhou Meet in November 2010, extensive efforts were made to organize the Bauxite Residue Seminar. The untiring efforts of the President of ICSOBA, and the Council Members have resulted in a two day Seminar to be held at Goa India on October 17 and 18, followed by a visit to the Hindalco Refinery at Belgaum; the latter should provide the delegates with a first hand information of the excellent progress made in the rehabilitation of the red mud storage areas. We have assembled an impressive list of speakers from all over the world for the Seminar; the final program for the Seminar would be uploaded on the ICSOBA Web Site shortly. We look forward to the pleasure of meeting with all of you in Goa on October 16, 2011.

This issue carries technical articles devoted to bauxite exploration, Indian red mud and design aspects of deep cone settlers and washers. Mr. Dominique Butty, a well known bauxite Geologist from Switzerland, has contributed a paper on building a sound and exhaustive data base on bauxite exploration; this paper should be of great interest to the investigators in this field. Mr. Butty has indicated that he will contribute further by way of interpretation of exploration data and resource modeling and we look forward to publishing more of his material in the forthcoming issues of the News Letter. The presentation from Slottee, Johnson and Guo from Paste Thick Associates and Westech Engineering deals with the design aspects of deep cone settlers and washers to minimize descaling; it should be of interest to the alumina technologists. Some aspects of bauxite residue in Indian alumina plants are elaborated by Mr. Goyal of the ICSOBA Secretariat this paper deals with disposal practice and red mud utilization in India.

We are firming up arrangements for the 2012 Meet in Brazil and have initiated discussion on the celebration of 50 years of ICSOBA in collaboration with VAMI and RUSAL. All these activities are a true reflection of the international nature of our vibrant organization.

We seek your cooperation in sustaining the activities of ICSOBA by enrolment of new members and contributing technical papers for the News Letter. We welcome your suggestions on improving our organisation.

(Ashok Nandi) (T.R. Ramachandran)

NEWS & EVENTS

The upcoming technical seminar and congresses of **ICSOBA 2011, 2012 and 2013**
ICSOBA INTERNATIONAL SEMINAR ON BAUXITE RESIDUE
OCTOBER 2011 IN GOA, INDIA.

World alumina production is close to 90 million ton per annum and the associated generation of bauxite residue is of a similar magnitude. This amount of residue could introduce a residue cover of more than 2 m thickness on an area of 5 km by 5 km.

Disposal of bauxite residue, a mixture of residue solids and alkaline liquid has shown a gradual evolution. Initially the residue was simply dumped in swamps, rivers or in the sea, followed by improved disposal in wet storage basins, leading to the state-of-the-art dry storage technology in combination with rehabilitation of filled storage areas. In parallel technologies for neutralization of bauxite residues were developed. R&D into the use of residue as feedstock has been receiving increasingly more funding, albeit still with limited applicable results.

Due to the recent dam failure of a wet red mud storage pond in Hungary, bauxite residue storage and potential utilisation of red mud as feedstock have attracted worldwide attention; these aspects are also important from the view of sustainability of alumina production. Against this background ICSOBA decided to organize an International Seminar on Bauxite Residue. This Seminar will bring together experts from academia, industry, government and other stakeholders from all over the world.

The seminar will be held from 17-19 October 2011 in Goa, India. The selection of India follows ICSOBA's practice of rotating the venue of it meetings to countries that are important for the global aluminium industry. The seminar is organized with support from Hatch whilst HINDALCO will host a field trip to the residue storage area of its Belgaum refinery, where red mud area is beautifully afforested. Several companies and organisations, including the International Aluminium Institute, Rusal, Chalco, Rio Tinto, HINDALCO, Nalco Chemicals, Outotec, Bokela, Weir-Geho, GHD and CSIRO have already confirmed their participation and presentation of papers.

This seminar is expected to be one of the most comprehensive International Events on Bauxite Residue and encompasses all key areas, including residue characterisation, residue processing and storage, case studies of residue storage avoiding hazardous discharges, storage area rehabilitation and use of bauxite residue as feed stock. The Seminar will conclude with a panel discussion on best available technologies and desired R&D projects for solving identified problems in any of the above areas.

ICSOBA has great pleasure in inviting you to ICSOBA-2011 and joining us in making the event a great success.

ICSOBA INTERNATIONAL CONGRESS ON BAUXITE, ALUMINA & ALUMINIUM, OCTOBER 2012 IN BELEM, BRAZIL

Brazil, one of the countries that shows a newly advanced economic development, is an important country for the global aluminium industry. Presently it accounts for 12% of world's bauxite, 10% of world's alumina and 4% of world's aluminium production. Brazil's untapped bauxite resources are massive and will serve as basis for future alumina and aluminium industry development. Bauxite production in 2009 was 26.1 Mt and is expected to grow to 40 Mt by 2013. Especially the recently developed Paragominas and Juruti mines readily serve future alumina refining developments. The Trombetas bauxite mine, with a capacity of 18 Mt/y, is famous for its successful mine rehabilitation program.

Recently Brazil pioneered bauxite transport by pipeline, presently transporting bauxite from the Paragominas mine to the Alunorte refinery, involving a transport distance of 250 km. This technology will see increasing global use as new bauxite developments are located more and more in isolated areas.

Brazil's current alumina production is 11.3 Mt; the world's largest alumina refinery, Alunorte, producing 6.3 Mt/y, is located in Brazil. The nearby CAP (Companhia de Alumina do Pará) project envisages the construction of a similar alumina producing giant forecast to initially produce 1.9 Mt/y. Other important refining operations include Poços de Caldas, CBA and the recently expanded Alumar refinery. The latter plant uses two huge digestion lines for a total alumina production of 3.5 Mt/y. Brazil's aluminium smelting capacity stands at 1.6 Mt/y and is set to modestly grow to 1.7 Mt/y by 2018. The 8,400 MW Tucuruí hydroelectric power plant is the world's fourth largest facility, feeding the Albras and Alumar aluminium smelters. Other important smelting operations include CBA, Alcoa in Poços de Caldas and Novelis in Ouro Preto.

The recent integration of Vale's aluminium business with Hydro Aluminium illustrates the importance of Brazil in the global aluminium industry.

In recognition of Brazil's achievements in the aluminium industry, it was decided to have the ICSOBA-2012 congress in October 2012 in Belem, Brazil, in collaboration with ABM, the Brazilian Metal Association. The selection of Brazil follows ICSOBA's practice of rotating the venue of International Meetings to countries that are important for the global aluminium industry.

The ICSOBA-2012 Conference will include key note addresses by eminent persons, Round-Robin sessions on Brazilian bauxite, alumina and aluminium industry and many other interesting presentations on global developments. We are working on the possibilities of organizing field trips to a bauxite mine, a bauxite transport pipeline, an alumina refinery, an aluminium smelter and a hydroelectric power plant, immediately after the Conference.

ICSOBA 50TH ANNIVERSARY AND ICSOBA-VAMI-RUSAL CONGRESS ON BAUXITE, ALUMINA & ALUMINIUM, SEPTEMBER 2013 IN KRASNOYARSK, SIBERIA, RUSSIA

ICSOBA is pleased to announce its 50th anniversary celebrations and the organisation of the ICSOBA-VAMI-RUSAL Congress on Bauxite, Alumina and Aluminium in Krasnoyarsk, Siberia, Russia in September 2013. The details will be announced shortly.

BAUXITE EXPLORATION - BUILDING A SOUND AND EXHAUSTIVE DATABASE

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Abstract

Bauxite exploration is a complex process addressing wide-ranging issues that extend well beyond geology and mining. But the primary objective of exploration is building a reliable and comprehensive database to underpin sound resource estimates that eventually will be declared on the stock exchange and support development studies. A Competent Person (CP, as per JORC 2004), with the relevant competences and experience of the target mineralization, oversees the overall process and, in particular, selecting the appropriate exploration methods, enforcing the applicable guidelines and standards, interpreting the exploration data and ultimately assessing the resources. The scope of this paper is reviewing the process of building a sound and exhaustive database to support the assessment of resources.

Keywords: Exploration manual, standards, guide lines, Quality Assurance (QA), Quality Control (QC), acceptance thresholds, exploration database.

Preamble

Successful exploration is based on a good understanding of local geology and mineralization, meticulous planning as well as effective operational and quality controls. The objective of exploration is collecting data and information to support studies that may eventually lead to economic mining/refining developments; relevant data and information concern wide ranging fields including logistics, geology, geotechnics, hydro-geology, beneficiation, mining and processing. The span and depth of data collection gradually increase from the scoping study through pre-feasibility- and feasibility studies. As mentioned earlier, the focus of this paper is the collection of bauxite related data required for resource assessment.

Like any projects, exploration includes the planning, execution and conclusion stages. In the case of exploration, planning consists in the preparation of a document - called the exploration manual, the exploration plan or method statement - laying down the scope, schedule and methods, including:

- Description of the exploration target(s)
- Project objectives and schedule
- Exploration organisation and team member qualifications
- Applicable standards and guidelines in terms of HSE (Health, Safety, Environment), exploration practices, QC acceptance thresholds and

resource reporting.

- •Exploration grid(s) and coordinate system.
- •Remote sensing, land and aerial survey requirements.
- •Geological mapping.
- •Geotechnical drilling and sampling requirements (e.g. CPT, thin wall sampling)
- •Selection of exploration methods and description of procedures regarding HSE, survey, drilling, sampling, sample preparation, sample storage, sample management and chain of custody, assaying, logistics and data storage.
- •Controls, validation, auditing.
- •Data processing and reporting.

The exploration manual is based on two fundamental principles:

- •Quality assurance to ensure that the data/information gathered is representative of the mineralization, complete, adequate and consistent with the project's objectives and reporting requirements.
- •Quality control to ensure that the data collected is statistically significant and within acceptance thresholds.

QA consists of all planned and systematic actions necessary to provide adequate confidence in the outcome and deliverables of exploration while QC includes the operational techniques and activities applied to satisfy quality requirements (based on ISO 1994).

Quality Assurance (QA)

QA has far-reaching implications starting with ensuring that the geological setting and nature of the bauxite deposit(s) are sufficiently understood to select the appropriate exploration methods, that the objectives are realistic and achievable within the established timeframe, that the project organisation provides the required supports, and that team members are sufficiently experienced and qualified to perform the tasks requested from each of them.

QA will be documented in the exploration manual and implemented using Standard Work Instructions (SWI) or Standard Operating Procedures (SOP) for each exploration activity with the purpose of enforcing efficient, standardized and safe practices.
Applicable standards and guidelines are in principle specific to the stock exchange where the resources owner is listed; hence JORC, SEC or NI 43 101 compliance may be required or other national regulations. International standards and guidelines (e.g. JORC,2004; CIM, 2003a, 2003b, 2005; CSA, 2005a) provide a strict framework for the performance of exploration activities and reporting of resources, hence have a major impact on the exploration plan. The CP will verify the compliance of the endorsed procedures and methods

with the above guidelines and oversee their application throughout the exploration programme. This paper assumes henceforth the application of the JORC guidelines.

Selecting the Exploration Grid Size and Orientation

The exploration grid size and orientation should be based on local geologic/geomorphologic conditions as well as on historical data. The initial grid size to achieve a specific resource categorisation can be based on the experience in the mining district or with similar deposits. Continuity drilling, i.e. drilling at intervals sub-multiple of the exploration grid, should be planned early in the course of the project to support variography at close range and verify the adequacy of the grid size. To this effect, achievable kriging efficiency (KE) and kriging slope of regression (KSR) are obtained for a variety of grid sizes to derive the optimum fit for the desired selected block dimension and resource categorisation. Given that all geostatistical calculations are based on the variogram(s) depicting the spatial variability of the mineralization, virtual exploration data can be used to project KE and KSR values. The Matheron diagrams for the determination of the extension variance offer another method to evaluate the drill grid spacing. Close spaced drilling of selected areas may also be required to support geostatistical simulations (e.g. simulate production grades and local variability), forecast drilling requirement for short-term mine planning and evaluate the variability of the floor and top of bauxite that may impact on mine loss and dilution.

One should avoid inferring anisotropy in setting out a grid system with a longer spacing in a specific direction, bearing in mind that elongated deposits do not necessarily show greater grade continuity in concordance with their long axis. In most instances, bauxite grades are isotropic in lateral directions. Hence, a square grid is a good choice unless the geometry of the deposits, such as narrow zones, dictates another approach, in which case the longer grid spacing should stay within the assumed range of the variogram(s).

World coordinates (e.g. UTM, WGS84 ellipsoid) should be preferred to local coordinates for all spatial data, maps and drawings, to allow seamless overlay with satellite imageries, aerial photos and DEM (digital elevation models).
Land surveys with total stations and GPS as well as regional topographical maps based on DEM initially provide sufficient support for field works. Aerial survey by aerial photography or LIDAR (Light, Imaging, Detection and Ranging) may be required when the time comes to establish detail topographic maps for civil engineering and mining studies.

Geological Mapping

Understanding the geologic processes that resulted in the concentration of bauxite is of utmost importance to effectively locate potential deposits. These

processes typically involve favourable source rocks and specific geomorphologic structures, e.g. plateaus, gentle hills/slopes or sinkholes, in well drained locations. Geological mapping, which usually involves remote sensing and aerial photography interpretation, is essential in the early stages of field investigations. The geological team is then the spearhead of exploration with the following operational tasks:

- Mapping rock formations and associated weathering cap across the exploration area, including the main geologic/geomorphologic features e.g. plateau edges, slope breaks, scarps, rock outcrops, rivers, sinkholes...
- Taking surface samples, sinking pits and/or holes with light drill rigs.
- Delineating drilling targets.
- Preparing drill plans and laying out access for drill rigs.

Applicable Sampling Methods

Although the selection of appropriate exploration methods is of paramount importance, the scope of this paper only allows for reviewing the most important issues.

The method(s) selected must be compatible with ground conditions and produce samples representative of the material occurring at the sampling sites. This implies a good recovery, no contamination and a sufficient size to evenly sample the bauxite constituents, which is an important consideration in cases of phase segregations.

Sampling lengths vary from 0.25m to over 1m, with in extreme cases composites taken across the bauxite layer. Long composites are inflexible for cut-off grade sensitivity studies and modelling, and for these reasons are not recommended. Sampling lengths around 1m or 3ft are probably most frequently used. The definition of thin bauxite layers, averaging say 5-4m, generally warrants sampling lengths ≤0.5m, particularly to support 3D modelling. Also, sampling lengths should preferably be less than the minimum mining thickness.

Sampling is carried out at fixed intervals if destructive drilling is used (e.g. augering) and thus the accuracy of the bauxite layer definition is inversely proportional to the sampling length. In this case, the decision on a fixed sampling length can be based on the achievable ore lifting precision in the vertical direction. Undisturbed sampling (e.g. coring) provides the opportunity for variable sampling lengths based on facies, which allows a reasonable mapping of natural breaks within the bauxite profile. Variable length sampling, usually involves defining a standard sample interval, say 0.5m applied across homogenous layers and maximum/minimum intervals, say 0.8m and 0.2m applied to transition zones. This method generally produces a relatively tight dispersion of sampling lengths and results in a better definition of the bauxite layer. For 3D modelling however, fixed lengths are preferred to ensure a constant grade support; an option is then to vary the sampling intervals only at

the top or floor of the assumed bauxite intercept.
The sample volume is proportional to the square of the sample radius; hence minor differences in core/hole sizes have a major impact on the sample volume, which in turn influences the variance of the grade population. For a given mineralization, the larger the sample size the lower variance of the grade population, which is not a trivial consideration for resource modelling. In addition, samples with wide diameter are less sensitive to wall contamination. For these reasons, the preferred sample diameters are ≥ 3" for coring and ≥ 4" for augering.

Table 1. Increase of Grade Variance with the Reduction of Sample Size

Change of Sample Size	Volume Decrease	Variance Increase		
		SiO_2 %	Fe_2O_3 %	Al_2O_3 %
Full core PQ3 to half core duplicates, same sample	2 x	14%	3%	4%
Half core 6" to half core 3" samples, twin holes	4 x	29%	18%	32%

Sampling is carried out with various drilling methods and pitting or trenching in specific cases, with each method having its strong and weak points.
Drilling fluid used for core drilling tends to wash fines away from the surface of core samples; unless a protection is applied onto the sample (e.g. PQ3 core barrel, 3.27" core diameter) or no/limited fluid is used while coring bauxite.
Sonic drilling does not use drilling fluids and yields uncontaminated core samples and good recovery, but it tends to compact soft material and fragment hard material, hence it does not produce cores usable for physical characteristic measurements (strength, density).

Core and sonic drilling are applicable for deep holes (up to 150m for sonic and beyond for core drilling) and difficult ground conditions (wet, high hydrostatic pressure). While both coring methods are applicable to most geologic formations, core drilling is more efficient in medium hard to hard rocks and sonic drilling in soft to medium hard rocks.

Reverse circulation (RC) drilling tends to produce cavities in soft/pulverulent material, with the attendant sample dilution. The method uses compressed air to lift cuttings through a hollow inner tube and is applicable for deep holes (up to 500m) in dry and humid conditions given that compressed air tends to dry cuttings and alleviate the nuisance of moisture (slurry formation).

Auger drilling is prone to wall contamination, an effect which is reduced by using large auger diameters (≥6") and by lifting the drill string to sample

wet/humid material. For thick bauxite and deep holes, wall abrasion can result is a significant overestimation of bauxite thickness if the drill string is not retrieved for sampling. In the absence of casing, soft/loose material at the top of holes can generate substantial contamination, notably with TOC. Auger drilling is usually limited to depths of about 30-35m in dry and moderately humid conditions.

Air core drilling, similar to RC but using smaller sized equipment, hollow stem auger drilling which produces broken but uncontaminated cores in dry/humid (but unsaturated) ground conditions, as well as vacuum drilling efficient in dry ground conditions are other methods commonly used in bauxite exploration. RC, auger, air core and vacuum drilling are all destructive drilling methods.

Wall/channel sampling in pits tends to over sample fines unless the cut geometry is maintained within tight dimensions (as in Fig. 1). Pitting depth is limited by wall stability and safety (investigation depths down to 10-20m).

Pits and trenches are invaluable to take large samples for geotechnical or process tests, to measure densities across profiles and obtain information regarding the vertical/horizontal distribution of rock facies as well as short scale variations of contacts with off-grade material within bauxite or at the top and floor of bauxite.

One word of caution when using different sampling methods, for validation purposes or successive exploration campaigns, a similar sample size –in terms of length and section - should be maintained to ensure the compatibility of the sample populations.

Figure 1. Wall Sampling in a Bauxite Pit

This is particularly true for pit samples vs. drill samples.

All above sampling methods are applicable within a specific range of ground conditions and therefore must be selected accordingly, and then validated in the

course of exploration using an alternative sampling method at randomly chosen grid positions (e.g. twin holes). The exploration manual will describe the sampling methods, the equipment selected, the controls thereof and will refer to the relevant SWIs.

Density Measurements

Density is frequently a significant source of error in resource estimates. The reasons are that density varies laterally/vertically and with facies, and that most of the time insufficient determinations are available. The task of gathering sufficient density figures is not trivial, bearing in mind that at least 30 measurements are necessary to obtain a statistically significant density estimate for each bauxite facies. The preferred method for measuring density consists in digging small pits (e.g. 30 x 30 x 30cm) at various depths in the floor of excavations (exploration pits or trenches) dug through the bauxite profile. For easy volume measurement, the pit should have regular walls and floor, and cleaned of any loose material. Volume measurement is obtained with water and thin plastic sheet lining of the pit, or with calibrated sand. The excavated material is immediately sealed in plastic bag and sent to sample preparation for wet/dry weighing. Density measurement from undisturbed cores is frequently used. This method, however, tends to make use of the most cohesive bauxite facies, which in turn may yield biased density estimates. Another interesting option, which requires local calibration, is to acquire continuous gamma-gamma log measurements down boreholes.

Logging Samples

Pictures of cores will be taken prior to logging and attached/referenced to log sheets. Cores will not be sprayed with water or washed for this purpose. Each photograph should include a “header board” showing project name, date of drilling, hole number, core size, box number for the hole, and ‘from’ and ‘to’ hole depth for the start and end of the box. The cores should be split open to provide a clean face for logging.

Physical characteristics that are relevant for the local geologic setting and the project requirements should be captured as much as allowed by the conditions of the samples. Evidently, core samples will be amenable to detailed geologic descriptions and measurements whereas samples from destructive drilling will only support basic observations that should nevertheless be recorded. Logging should be factual and capture structures, textures, granulometry, macroscopic mineral assemblage, colours using charts, consistency, strength, stickiness, degree of humidity and typical facies. The geologist will refer to the drill master log to supplement his own observations. Sampling intervals will be selected while logging. In terms of modelling, the objective of logging is to support the definition of specific domains, while in terms of mining logging may contribute to

estimating ground stability, bearing capacity, trafficabilty, blasting requirement and handling characteristics.
The exploration manual will contain the applicable logging codes with relevant descriptions and blank forms of log sheets and of any other forms used in the field to record, in particular, the geologist and driller names, type of drill and sampling, the sampling site, date, method, purpose, the sample intervals and descriptions.

Sample Preparation

Sample preparation consists in stepwise operations to reduce the sample size and granulometry, and ultimately produce pulp samples for standard assays, quality controls and storage. These operations, including sample homogenisation, splitting, crushing, drying and milling, are thoroughly codified by several norms and standards [1, 2, 3, 4] to ensure that sub-samples produced are representative of field samples. A wide range of sample preparation methods and equipment are documented in the norms listed in references.
The most critical points are:

- Thorough homogenisation is required prior to splitting. Sample fragments must be free flowing, i.e. not sticking nor agglomerated; hence drying and crushing may be required prior to sample homogenisation.
- For a given granulometry, split samples must remain above a certain minimum mass to be representative of the initial sample. In this respect, Pierre Gy's preferred sample mass nomogram [5-6] provides a reliable guideline. Tailored sample mass nomograms can be built for specific bauxites using the method proposed by Minnitt and al. [7].

The preferred reduction method is splitting using a riffle splitter with dimensions adjusted to the sample granulometry (slot size at least twice the nominal top size of particles, minimum eight slots for each half of the riffle [1]). The same equipment can be used for homogenisation by passing 4-5 times the sample through the riffle splitter prior to actually splitting the sample.

The preferred method to produce pulp sample is milling with large size ring mills (≈1kg sample capacity), which ensure a thorough homogenisation of sufficient pulp to cover the project's needs, i.e. provide samples for standard and duplicate assays as well as for the investigation of minor oxides, trace elements, phases, XRD and for storage.

Sample storage may concern:

- Half cores.
- Coarse samples: drill rig cuttings or crusher duplicates, which still display recognizable textures/structures.
- Pulp material.

A word of caution with half core:

- Sampling half cores may result in a sub-optimal sample size and unequal sampling of segregated phases, as indicated earlier. As a result, quality control may show that half cores are not representative of the full core, i.e. the combined assays of both half cores, as shown hereafter (Fig. 1, Table 1).
- Unless cores are very homogeneous, it is therefore preferred that after taking photographs and logging the full core sample intervals be sent through sample processing. Crusher duplicates will be kept in storage.

Figure 2. Differences between PQ3 Half Cores

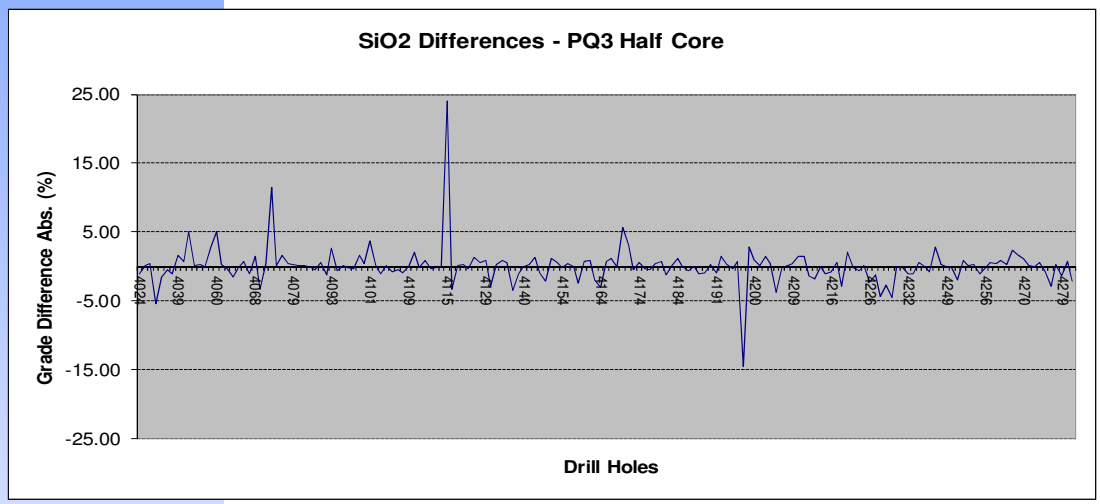

Table 2. Half Cores ARD Statistics

Assay	ARD < 15% half core I vs. half core II	ARD < 15% full core vs. half cores
SiO_2	39.8%	64.0%
Fe_2O_3	52.6%	80.7%
Al_2O_3	93.6%	99.4%

Field duplicate pairs should have 90% of ARD values <15% (see Quality Controls). Non compliance with threshold criteria demonstrates the necessity of field sample homogenisation prior to splitting and, in this case, the need to process full cores.

The exploration manual will contain the sample preparation flow sheet showing the successive stages of sample reduction, drying, crushing and milling as well as the samples produced for assays, sample duplicates and storage. The exploration manual will also describe the scheme for inserting quality control samples in the sample flow - including blanks, standard reference material (SRM) prepared with local bauxite, certified reference material (CRM) and pulp duplicates for third party laboratories – as well as pulp duplicates for

special investigations including minor oxides, trace elements, XRD, available alumina (AA) and reactive silica (RSiO2) assuming that AA and RSiO2 are not systematically assayed. The exploration manual will also refer to the equipment used and SWI for each sample preparation activity.

Assay Methods

Standard assays, generally applied to all exploration samples, typically consist of major oxides (SiO2, TiO2, Fe2O3, Al2O3) and LOI, which together add to about 100% and thus provide a useful "checksum" for validating data capture and modelling results. In addition, standard assays, with or without additional assays of selected minor oxides and organics, generally support estimates of available alumina and reactive silica by multi-linear regression formulae or dedicated algorithms (BQuant, BauxQ).

Minor oxides (typically Na2O, MgO, P2O5, K2O, SO3, CaO, MnO), trace elements (Va, Ga, Ge, Cr, Th, Zn, Au etc…) and organics (Total Organic Carbon TOC, Extractible Organic Carbon EOC i.e. that part of TOC dissolved in the Bayer process) contribute to the characterization of bauxite and reveal potential issues with processing (sulphur and/or organics build up in the liquor).

Available alumina (AA) and reactive silica (RSiO2) are the most essential components of metal grade bauxite. Both the high and low temperature digests should be tested to support estimates of the alumina phases (gibbsite, boehmite, clays) and silica phases (quartz, clays) and unveil potential issues with processing (e.g. boehmite >4% with low temperature digest).

Minor oxides, trace elements, organics, AA and RSiO2 are usually assayed for a limited number of samples, chemically and spatially representative of the bauxite mineralization. In some cases however, AA and RSiO2 are assayed for all samples or composites.

XRF (X-Ray Fluorescence) and ICP (Inductively Coupled Plasma Spectrophotometry) can be put to good use for assaying most the above oxides and elements. Accurate measurement of SO3 and organics require specific analytical instrumentations (e.g. combustion infrared detection technique by LECO). LOI is determined by thermo-gravimetry (TGA or furnace at 1000C°). AA and RSiO2 are assayed by bomb digest followed by ICP or microwave digestion followed by ICP. Of the numerous other assay methods applied to bauxite, the FTIR [8] (Fourier Transform Infra-Red) technique is particularly interesting in that it can provide estimates of recoverable alumina, reactive silica and many other components in a single analysis. FTIR is however not very precise and may fail quality controls for specific components.

One word of caution with the AA determination at a low temperature digest (AALT at 145C° or similar): for low grade bauxite, with AALT < 41%, boehmite

may be partially dissolved unless a higher bauxite charging ratio is applied (Alcan method 1253). Boehmite dissolution results in overestimating AALT.

Investigating Mineralogy

Commercial laboratories usually provide quantitative/semi-quantitative XRD results using the Rietveld method and a conventional X-Ray tube with a relatively high limit of detection of phase constituents. High energy synchrotron radiation offers a much higher degree of resolution, but the scarcity of available sources restricts its use to research [9]. XRD is applicable to the bauxite's mineralised fraction only. The quantity of unreported phases, amorphous and/or cryptocrystalline, varies (up to 30-50%) depending on the nature of bauxite – age, source rocks, position in the bauxite profile, vegetal cover, biological activity, geochemical processes etc…- and the detection limit of the XRD method applied. The usual practice is to normalize the proportion of mineral phases to 100% under the speculative assumption that the mineralized fraction detected is representative of the undetected material. XRD is therefore no substitute for chemical assays but it provides essential data on the mineral assemblage, the degree of crystallinity of minerals and the degree of substitutions in mineral lattices (e.g. alumogoethite). It also corroborates phase estimates obtained from chemical assays (e.g. bomb digests, BQuant, BauxQ).

Quality Controls (QC)

The purpose of quality controls is to verify that the imprecision and inaccuracies of the data stored in the exploration database stand within acceptable limits. The subject is vast and cannot be reviewed in details; references are provided for the interested readers. We will focus on assays results which generally constitute the largest and most critical data set.

Statistical controls will report and quantify:

- The precision of the sample preparation procedures by taking field and/or crusher duplicates as well as pulp duplicates, all processed with the same procedure and assayed by the same laboratory.
- The presence of bias and/or calibration drifts of analytical instruments/procedures, by inserting SRM and/or CRM as well as submitting pulp duplicates to third party laboratory.
- The accuracy of assays results by submitting CRM, or SRM provided that its grades are deemed sufficiently reliable (Round Robin assays) and pulp homogenization is flawless (frequently a weak point of SRM).
- The absence of contamination by inserting blanks. Blanks are effectively the same as standards but contain a concentration below detection limit as regards the element(s) of interest. Blanks are not often used in bauxite exploration since grade levels are such that contamination is difficult to demonstrate.

Accuracy is the closeness of agreement between a measured value and a true value. Accuracy is measured through the bias, i.e. the systematic difference between test results and the accepted reference value [10]. The bias is usually calculated as the difference between the average value of a series of measurements of the CRM/SRM grade over a certain period of time and its reference value, divided to the reference value. Accuracy compliance is also measured in terms of deviations from the reference value, in the same way as precision.

Precision is the closeness of agreement between measured values obtained by replicate measurements of the same or similar samples, under specified conditions. Repeatability assumes constant conditions in terms of measurement procedure, operators, measuring system, operating conditions and location. Reproducibility allows for variable conditions of the same. Precision is quantified in terms of the dispersion of differences between pair values, which reflect the errors of sample preparation, sample management and/or assaying. These errors are reported within ±1 σ and multiplied by 2 to express precision (and accuracy) within the 95% confidence interval.

There is a variety of statistical procedures that can be put to good use to quantify errors, precision and accuracy; a limited selection is presented hereafter.
Relative Difference RD = (x1-x2)/(x1+x2), also called the Half Relative Difference (HRD), is a comparison of one population of paired values against another where x1 and x2 are the individual values returned from each pair of samples. Plot of RD values are indicative of precision and reveal bias between paired values.
Mean Percentage Difference MPD= 1/n · Σ [100 · RD] is the mean of relative differences between paired data, expressed in percent. MPD should tend to zero. The algebraic sign taken into account when calculating the MPD makes it a measure of bias between pairs of results.

Absolute Mean Percentage Difference AMPD = 100 · (|x1-x2|)/(x1+x2), also called Half Absolute Relative Difference (HARD), is a measure of the differences between paired results. It indicates the spread of values without regard to the order in which they are considered or any bias that may be present. The mean AMPD value for n pairs of data stand as **(∑ [AMPD2]/ n)0.5** . The mean AMPD approximates relative error to half a standard deviation**.**

Absolute Relative Difference ARD = 2 · (|x1-x2|)/(x1+x2) is the absolute difference between a pair of samples relative to its mean**.** ARD results can be plotted against their relative ranking to assess performance against threshold criteria. The Mean Absolute Relative Difference for n paired data computed as

MARD = (∑ [ARD2] / n)0.5 estimates error to 1 standard deviation.
The Coefficient of Variation CVAVR = 100 · (2/n · ∑ [(x1-x2)2/(x1+x2)2])0.5 for n paired data, reportedly the best estimator of errors between data pairs of similar grade ranges [11], defines relative precision to 1 standard deviation.
The relative bias of assay deviations from SRM and CRM is estimated as ***100 · 1/n · ∑ [(m-x)/m]*** where m is the expected or certified value, x the value returned from the laboratory and n the number of samples.

The standard deviation of assay differences with SRM and CRM is computed as ***(1/n · ∑[(m-x)2])0.5*** where m is the expected or certified value, x the value returned from the laboratory and n the number of samples.

The relative error of assay differences with SRM and CRM can be estimated with ***AMPD = 100 · (|x1-m|) / m*** where m is the expected or certified value. The mean AMPD value is obtained as ***(∑ [AMPD2] / n)0.5*** and provides the relative error estimate to 1 standard deviation. It compares with the above standard deviation of assay differences.

Table 3. ARD and MPD Statistics – Third Party Laboratory Checks

	Lab 1 vs. Project Lab		Lab 2 vs. Project Lab	
Assay	**ARD < 5%**	**MPD**	**ARD < 5%**	**MPD**
SiO_2	97.7%	-0.05%	96.7%	-0.68%
Al_2O_3	100.0%	0.03%	100.0%	-0.12%
Fe_2O_3	100.0%	0.18%	100.0%	0.12%
TiO_2	100.0%	-0.24%	100.0%	-0.63%
LOI 1000	100.0%	0.02%	100.0%	0.31%

The above table demonstrates the compliance of laboratory checks with acceptance thresholds, with more than 90% of ARD values < 5% and MPD values showing the absence of bias.

Statistical Process Control (SPC) charts are used to detect the bias and drifts of calibration by plotting over time the deviations from the reference value of CRM, SRM and/or blanks. Deviations from CRM provide a measure of accuracy, from SRM a measure of precision (or accuracy) and from blanks a control of instrumental calibration or contamination.

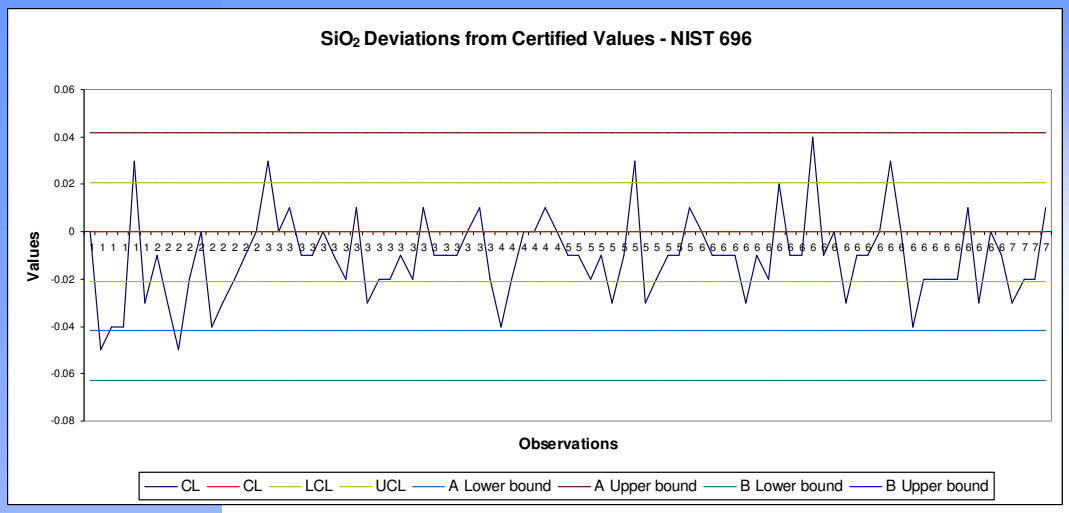

Figure 3. SPC Chart – SiO2 deviations form certified value

CL (blue =deviations, CL (red) =mean deviation (showing no bias), LCL / UCL ±1 σ intervals, A Lower/Upper bound ±2 σ intervals, B Lower/Upper bound ±3 σ intervals. Abscissa = sample batch number. Accuracy is shown by the A Lower/Upper bound i.e. 0.042% which equates to a 1.1% accuracy given a certified value of 3.79% SiO2 (0.042 / 3.79 · 100 = 1.1%). 98% of deviations stand with ±2 σ and 100% ±3 σ.

Suggested threshold criteria (the list is not exhaustive) include the following:

- •90% of field duplicate pairs should have ARD values < 15%.
- •90% of crusher duplicate pairs should have ARD values <10%.
- •90% of pulp duplicate pairs or pulp re-assay pairs should have ARD values of <5%.
- •Assays accuracy should be ± 5% of a certified value within the 95% confidence interval.
- •Over the time of the exploration campaign, 95% of assay values returned for CRM and SRM should be within 2 standard deviations of the reference value and 99% of assay values returned should be within 3 standard deviations.

Proportion of Control Samples **[11]**

Reliable control of sample precision is achieved by using approximately 5% to 10% of field/crusher duplicates and 3% to 5% of pulp duplicates. These duplicate samples should be prepared and analyzed in the main laboratory.

Bias/drifts in the analytical results can be identified by including 3% to 5% of the CRM / SRM in the sample flow.

Approximately 5% of the duplicate samples (field samples, crusher duplicates and pulp) should be assayed by an umpire laboratory

Sample Management, Sample Security and Chain of Custody (COC)

The appropriate organization, supervision, logistics and procedures must be in

place to ensure the integrity and traceability of samples from the sampling sites through the sample preparation, laboratories, sample storage and finally into the database system.

Most errors occur with loose sample tracking as well as manual form filling and data entry. The extent of the problem is revealed by assay results discrepancies occurring with sample duplicates, SRM and CRM, which are too excessive to result from assaying errors. The sample flow from the field through the sample preparation can be organized in easily manageable batch sizes - e.g. one sample batch per borehole - with each batch having its own COC form, which at each stage of the sample flow (e.g. sample receipt, drying, crushing, reduction, milling, dispatch, storage, assay receipt and data capture) allow for the traceability and systematic checks of individual samples against the COC form. A dedicated computer system with bar coding and scanning could prove necessary to keep track of a high sample throughput.

Database Systems and Data Processing

Exploration database systems come in a variety of flavours and complexity. Data capture - e.g. of logs, assays, borehole collars - is frequently performed in spreadsheets used as a front-end software for storage and validation. Data is then uploaded into a database system providing for easy queries, editing, visualisation, interpretation as well as data analysis and modelling in the most advanced systems. Spatial field data in a digital format - e.g. mapping and survey data from hand-held computers, GPS or survey total stations - is typically uploaded into a GIS database where are stored DEM data, digital/vector maps, satellite images, aerial photos and aerial survey data.

Exploration data capture must be validated by automated logical tests build in spreadsheets or databases and physical checks, i.e. input data sheets (digital or paper) vs. the database content. Error rates are then reported and used to qualify the reliability of the database. This auditing process, by a third party, should also cover backup, data synchronisation, version controls as well as hardware and software solutions.

The exploration manual should review the data workflow, the procedures of data capture, validation, traceability, processing, reporting and refer to the relevant SWIs.

Legacy data from earlier exploration campaigns always raise the issue of compatibility. This underlines the importance of maintaining consistent sampling methods, similar standards of precision and accuracy in the measurements of exploration data as well as compatible geo-reference systems.
Logs, X-sections, maps, data analysis and preliminary models will be produced during exploration to monitor work in progress, acquire a better understanding

of the deposits, report achievements and support operational decisions. Data processing should preferably be carried out on site, given that it is an on going process crucial for efficient exploration management.

The foregoing considerations on exploration and the process of building a sound exploration database will be followed by reviews on the interpretation of exploration data and resource modelling, which will be published in the future issues of the ICSOBA newsletter.

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Disposal Practice and Utilisation of Bauxite Residue in India

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Introduction

The Bayer's process for the production of alumina, commercially established for well over a century, involves the digestion of bauxite with caustic soda at temperatures in the range, 105℃ to 260℃. Most of the alumina part of bauxite goes into solution while the undissolved constituents containing Al, Fe, Ti and Si are separated by sedimentation or filtration as bauxite residue or red mud. The generation of red mud mainly depends on two factors, bauxite quality and digestion parameters; typically 1.2 to 1.5 t of red mud is produced per t of alumina. The annual production of the waste in Indian alumina plants is ~ 5.0 - 5.2 mt per annum while the corresponding figures for the world is ~ 100 mt. Decreasing quality of bauxite and commissioning of new alumina refineries will push this figure higher. The current alumina production capacity and mud generation in various Indian alumina refineries are given in Table – 1.

Table - 1 Current Production and Mud Generation of Alumina Refineries in India

Alumina Refinery	Alumina production, ktpy	Mud generation, t/t alumina
Hindalco Ind. Ltd., Muri	310 – 320	1.50 – 1.55
Hindalco Ind. Ltd., Renukoot	700 – 710	1.35 – 1.40
Hindalco Ind. Ltd., Belgaum	375 – 385	1.40 – 1.45
National Alu. Com., Damanjodi	1550 – 1600 2100 (after current expansion)	1.25 – 1.30
Vedanta Alu. Ltd., Lanjigarh	690 – 710	1.35 – 1.38

Characteristics of Red Mud

Red muds are generally highly alkaline, spongy, fine sized, irregular and aggregated. The chemical and mineralogical compositions of red muds vary widely depending on the bauxite source and the Bayer process parameters. The main constituents are oxides of Al, Fe, Ti, Si, Na, and Ca along with those of minor / trace elements such as V, P, Ga, Cr, Zr, U, Th, Mg, Sr, Ba, Li, K, Pb, Cu, Mn, Ni, Zn, Co and Rare Earths. In addition

there are many (15-20) mineral phases, the amounts of which depend on bauxite source and digestion process parameters. Some of these phases are derived from the constituents of bauxite while others such as sodalities [sodium alumino silicate (NAS)], cancrinite, calcium alumino silicate (CAS), sodium titanate, calcium titanate, and calcite form during the digestion process. Typical chemical composition of Indian red muds is shown in Table - 2. Red muds are thixotropic in nature and posses poor soil-mechanical properties. The presence of so many mineral phases with different properties is responsible for the complex and unpredictable behaviour of red muds. Consequently, these have a bearing not only on the disposal method but also on potential utilization.

Table - 2 Composition of Indian Red Muds

Alumina Refinery*	**Typical Chemical composition**						
	Al_2O_3	**Fe_2O_3**	**TiO_2**	**SiO_2**	**Na_2O**	**CaO**	**LOI**
Hindalco Ind. Ltd., Muri	15-16	39-40	14-15	10-11	7-7.5	2.5-3	8 – 9
Hindalco Ind. Ltd., Renukoot	17-19	38-40	14-16	8 – 9	5 – 6	1.5-2	9 -10
Hindalco Ind. Ltd., Belgaum	19-20	40-41	9 -10	10-11	5-5.5	1-1.3	9 - 10
National Aluminium Company Damanjodi	17-18	54-56	4 - 5	7 – 9	3.5-4	1.5-2	9 -10
Vedanta Alu. Ltd., Lanjigarh	18-20	38-42	9 -11	6 – 8	4 - 5	2 - 4	8 -10

**Presently, Balco, Korba and Malco, Metturdam alumina plants of Vedanta group are closed.*

Based on the information presented in Table-2, Indian red muds can be classified into two main categories, for the purpose of promoting R & D activities towards utilization:.

1. Iron rich and low titania red mud (e.g.Nalco alumina plant) generated from East coast bauxite.
2. Moderate iron and high titania red mud (such as that of Hindalco's Renukoot and Muri and Vedanta (Lanjigrah, plants) generated from the central Indian bauxites.

The Red Mud quality of the Belgaum plant lies in between the above two categories. The red mud quality of the Vedanta Lanjigarh alumina plant (once it starts using East Coast bauxite) and the green field alumina refineries such as Utkal Alumina International Ltd., Anrak Aluminium Ltd., JSW Aluminium Ltd. is also likely to be the same as that of Damanjodi plant.

Red Mud Handling and Disposal Practice

Digested slurry containing sodium aluminate liquor and suspended particles of undigested alumina, iron, titania and silica (bauxite residue) is pumped to thickeners in which suitable flocculants are added to improve the settling behavior of the mud particles. The clear aluminate liquor is taken into the system for further processing by control filtration and precipitation of aluminium hydrate whereas the settled mud is washed counter currently in a series of mud washers (3 to 5). The mud from the last washer is thickened by using deep cone thickener / vacuum or pressure filtration. The thickened mud is conveyed or pumped to red mud disposal yard / area.

There are three methods by which the mud is disposed and stored :

a) Slurry pond
b) Dry stacking
c) Sea disposal

Slurry Pond Disposal

This is the oldest practice and is being adopted by most of the plants in the world. In this method, the washed mud slurry containing 30 – 50 % solids is pumped to the impoundment area or pond / lake or to the natural basin adjacent to the alumina plant. Generally, natural embankment is preferred for storage of the mud slurry. But if a suitable embankment is not available, additional dykes or barrage are constructed on one or all the sides around the storage area. The mud settles in the pond and the supernatant liquor from the pond is recycled to the plant. The impoundment area consists of three zones namely, slurry discharge, transition and consolidation. Once the pond is filled up, the mud is stored in a newly prepared pond. Nalco, Damanjodi and Vedanta, Lanjigarh alumina refineries are adopting this method.

This practice of mud disposal has the following limitations:

- Problem of large land requirement and its cost.
- Seepage of alkali water into neighboring soil underground water and water supply streams or canals.
- Over flow of mud slurry especially during rainy seasons.
- Chances of dyke / dam burst due to excessive load in the mud lake or due to local seismic activity.
- Air borne dust carrying fine sized brown particles which contain caustic and cause air pollution / aesthetic damage.
- Dyke maintenance cost.
- Damage to the flora and fauna in the neighborhood.

Dry Stacking

Developments in technology and increased demand for alumina and aluminium metal have led to many fold expansion of alumina production capacities. Increasing land cost and environmental concerns have resulted in the evolution and

adoption of new method for mud disposal practice known as dry stacking or thickened tailing disposal (TTD). Increased consistency of mud having 50 – 70% solids is the pre-requisite for this method. This is achieved by treating the mud slurry from the last washer in vacuum or pressure filters or by using deep / high rate thickener. The bauxite tailings, thus thickened, is then transported to the impoundment area by dumper / trucks or pumped using special high pressure diaphragm pumps capable of handling high consistency slurries. The disposed mud gets dried and hardens over a period of 15 – 20 days, enabling leveling through earth moving machinery. This practice does not need recycling of supernatant liquor to the plant at all. However, run-off water during the rainy season is collected into a catchment pond and recycled in the plant. All the alumina plants of Hindalco have been adopting this practice. It is likely that all new alumina refineries in India will also follow this method.

Dry stacking disposal practice has the following advantages

- Requirement of much less land (about 30 – 45%) for mud impoundments in comparison to the conventional slurry disposal system for the same capacity of alumina production.
- Consolidation and hardening of mud promotes stable deposits which is environmentally compatible and suitable for reclamation and vegetation of the disposal area.
- Less chances of seepage and hence pollution of ground water.
- Requires less energy for pumping of slurry and recycle of caustic.

Sea Disposal

Disposal of red mud into sea is the simplest method but suitable only if the alumina refinery is located near the sea shore. In this method, the mud slurry from the plant is pumped to the impoundment area and the weak caustic soda solution is neutralized/ diluted with the sea water and discharged into the sea. In another practice, the mud slurry is transported through barges to deep ocean / sea and disposed of at a distance of above 200 km from the sea shore and discharged at a depth of 30 m, with the help of flexible hose pipe. The application of this method is very limited due to the environmental effects on marine life. The location of alumina plants in India does not favor this method of disposal.

Red Mud Utilization

Utilization of red mud by conversion to some useful products will not only conserve the mineral resources but will also help in pollution abatement and its safe disposal and storage. However, the problem of mud utilization is as old as the Bayer process because of its intrinsic properties and has attracted the attention of many researchers in the world in the past. However, in the last 4 - 5 decades serious R & D efforts have been made and are still continuing.

In our country, almost all alumina refineries have taken up in house R & D or through sponsored projects to many academic institutions and R & D laboratories as indicated in Table – 3.

Table – 3: R & D laboratories and academic institutions working on utilisation of Red Mud in India

Institution	Areas of investigation
Central Building Research Institute, Roorkee	Development of Red mud + clay bricks , Red mud + fly ash bricks, stabilized red mud blocks.
Metallurgical Engg. Dept., BHU, Varanasi	Development of Red mud + fly ash bricks, Red mud + fly ash stabilized blocks, additive to cement motors & concrete, low density / hollow bricks & blocks.
National Council for Cement and Building Material, Ballabhgarh	Use of 10 -15% red mud with raw mix for manufacturing of Portland cement.
Institute of Minerals & Materials Technology, Bhubaneswar	Development of process for making paints & pigments, special cements, extraction of iron
Advanced Materials & Processes Research Institute, (AMPRI), Bhopal	Development of RM polymer-sisal fiber products such as door panels plastic sheets, pipes & reinforced polymer composites :- Development of process for making radiopque materials using red mud.
Jawaharlal Nehru Aluminium Development & Design Centre, Nagpur	Development of glass ceramic tiles, red mud fired bricks / blocks / foam bricks & artificial ceramic stone chips
The Energy and Resources Institute (TERI), New Delhi	As catalyst for hydrocarbon cracking

Potential applications of red mud can be grouped into following categories :

- •Building constructional materials such as fired bricks, stabilized blocks, additive to cement raw mix or mortars concretes and foamed blocks.
- •Metallurgical raw material for production of iron, titania, alumina and recovery of alkali, minor elements.
- •Waste treatment such as liquid effluents, industrial gases.
- •Ceramics / Refractories such as floor tiles and sanitary ware special refractories
- •Other uses such as for soil treatment, red mud plastic sheets, as catalyst etc.
- •Detailed investigations by the institutions listed in Table-3 for uses of red mud have led to the following conclusions:
- •Technically, iron, titania, alumina, silica, can be recovered from red mud but the processes are not economically viable and cannot compete with the well established process used with the standard raw materials.

- While many direct or indirect applications have been investigated and some of them are economically viable; however the quantity of mud consumed is almost negligible (hardly 5%) in comparison to mud generated.
- The potentially important applications using large / bulk quantities of red mud involve production of building / constructional materials, construction or repair of road / dyke with treated mud and additive to cement.

In this regard, it may be mentioned that the NCCBM, Ballabhgarh has already investigated and recommended that 10 – 15% mud can easily be used with raw mix for manufacturing Portland cement. It was also reported that the red mud generated at Mettur dam alumina plant was regularly in use by nearby cement plants. Hence, it is suggested that all alumina refineries may also try to persuade nearby cement plants for using the red mud with their usual raw material mix for cement manufacturing.

Similarly, the alumina refineries may take up construction of mud bricks with some agency and the same can be used for making small houses for the weaker section of people and for making boundary wall etc. This activity can serve as a good example for the aluminium companies for mud utilization as well as towards its corporate social responsibility. Substantial efforts have already been made on vegetation of filled up or abandoned mud ponds for proper environment in the surrounding areas. As Nalco red mud is quite rich in iron content, it may be interesting to study the techno-economic aspects of recovery of iron from their red mud.

The safety aspects of the bauxite residue storage areas need to be constantly monitored. A common practice is to have sample points around the periphery of the embankment /mud pond area at an interval of 200 m. and up to 1 km. to monitor the contamination of underground water due to caustic seepage; the data are reported to the State Pollution Control Board.

It has been pointed out in the section dealing with slurry pond mud disposal that there are chances of dyke / dam burst due to excessive load in the mud lake or due to local seismic activity. There has been an unfortunate accident in the bauxite residue disposal site near Ajka in Hungary by the sudden release of an enormous amount of water and the inherent caustic content that caused injuries and the tragic loss of life. This accident has caused a great concern to the world aluminium community. In this connection the International Committee for study of Bauxite, Alumina & Aluminium (ICSOBA) is organizing a Bauxite Residue Seminar in Goa India, on October 17 – 18, 2011 to examine various aspects of bauxite residue, its disposal and worldwide safe and sustainable bauxite residue storage management. More details on the Seminar are given in a separate announcement in this News Letter.

Designing Deep Cone Settlers and Washers to Minimize Descaling

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Abstract

Deep cone type paste thickeners, such as the Deep Bed™, are rapidly becoming the standard for red mud settler and countercurrent decantation washing for Bayer and sinter process alumina installations. The opportunity for increased stage efficiency due to higher underflow density is a significant driver for the deep cone design. Increasing the stage efficiency can produce significant advantages in wash water reduction and/or reduction of the number of washing stages. There are interlocking parameters to be optimized for equipment design - for example, liquor and solids retention time variations for each stage and increased solids retention time to maximize density. Increased solids retention time needs to be balanced with the associated increase in scaling. Tank design must also accommodate descaling. The steep-floor sloped elevated tanks can be designed with special access to accommodate scale removal, and the raking mechanism is designed with minimum surface area.

Introduction

WesTech Engineering is a manufacturer of deep cone type settlers and washers. WesTech's experience with high torque drives required for these types of thickeners is well established. Mechanical and process designs are based on PasteThick™ Associates' world-class experience with deep cone type thickeners for many different types of applications including red mud washing circuits.

Paste thickener technology has been established as a way to produce non-settling solids at concentrations much higher than conventional or high-rate thickeners by incorporating modern synthetic polymeric flocculants. The drives, tank designs, and mechanisms offered with paste technology provide significant advantages over conventional, flat bottom, and high rate thickeners for the separation and washing of red mud.

The deep cone type paste thickener is the basis for the design of settlers and washers in the alumina industry. This thickener produces non-segregating, non-settling suspensions of solids at concentrations higher than conventional and high-rate thickeners. Producing red mud at such high solids concentrations in conventional washers and settlers is not feasible because thickener geometry, rake design and torque do not allow settling and discharge of a rheologically "thick" bed with high viscosity and the presence of a yield stress.

The Deep Bed™ settler and washer design offers the following advantages compared to conventional and high-rate thickeners:

•Sands do not need to be separated
•The final washer maximizes underflow density
•Lower capital costs (fewer wash stages, less steel, less pumps, less instrumentation)
•Tank cleaning reduced because of less steel and fewer thickeners
•Smaller footprint (up to 10x less)
•Higher underflow densities for each stage increase the stage efficiency;
•Higher stage efficiency reduces wash water demand
•Smaller diameter produces shorter liquor residence times which means less time for unwanted precipitation
•Lower soda loss in disposal because of higher washer underflow concentrations

A recent WesTech installation in red mud washing shown below of five 18 m diameter Deep Bed washers and decanters and one 14 m decanter illustrates the small footprint of a deep cone type CCD (countercurrent decantation) washing circuit.

Red mud decanter and washer circuit using deep cone type thickeners

Paste Thickener Design

The sizing criteria used for deep cone type paste thickeners are not based on unit area which is used to determine high rate thickener diameter and underflow density. The unit area assumptions of a standard bed height and solids retention time do not apply to deep cone thickeners. Deeper beds and longer solids retention times are used in paste thickeners which have steep floor slopes and tall sidewall heights. When compared to a high rate thickener with the same solids loading, the deeper bed compensates for the smaller diameter by producing higher underflow solids concentrations.

The use of synthetic polymer for flocculation of settler and washer feed solids produces high settling rates. The deep cone type settler and washer take advantage of these higher settling rates to produce clear overflow with a smaller diameter. There may be a different flocculants required for the settler than what is used in the washers because the flocculation conditions are quite different. The addition of flocculant to thickeners in general, and settlers and washers specifically, is well-established technology based on many years of industry experience.
The method and location of adding flocculants is closely associated with the effectiveness of feed dilution and choice of polymer. WesTech's feedwell and feed dilution designs are developed with this in mind to avoid over-flocculation and excessive mixing shear, and to provide optimum mixing. Similar design and techniques are shared between paste thickeners, high rate thickeners, and settlers and washers.

The Deep BedTM drive and rake mechanism are unique. With the production of higher density underflow the mechanism must promote the settling, raking and discharge of a rheologically "thick" bed with high viscosity and the presence of a yield stress. The rake arms consist of a low-profile fabricated tube to reduce drag, and rake blades are spaced below the arms on posts to keep the leading-edge surface area of the mechanism out of the most dense mud. The torque required for this mechanism design is greatly reduced compared to traditional designs used by the industry. The conventional truss rake arm and blades used in high rate thickeners would have inhibiting drag if used to move paste.

Paste thickeners require very heavy duty drives. The drive is essential to moving and discharging the thick paste out of the thickener and distinguishes manufacturers that can produce a heavy duty paste thickener from those who cannot. The convention used to rank the drive and mechanism is the 'K-factor'. The K-factor normalizes the drive system between different thickeners by relating the available torque of the drive to the thickener diameter. Paste thickeners have K-factors 5 to 10 times greater than high rate thickeners. Thickener manufacturers use different K-factors for their red mud paste thickeners. The proper use of K-factors that safely match the rheological nature of the paste produced is essential to the design of a paste thickener.

Design Factors for Aluminum Recovery and Scale

The recovery of the leach liquor is accomplished with settlers and multiple stage countercurrent decantation circuits. The aluminum recovery is inhibited by the precipitation (scaling). Impurities, mainly silica, iron and titanium oxides from the digestion process, affect the aluminum oxide precipitation process and precipitate on metal surfaces throughout the decantation and mud washing circuit, causing downtime for descaling. The effect of impurities on precipitation is

a function of time and temperature. Negative effects on the aluminum oxide precipitation can be decreased by creating a faster separation of the digestion liquor before it is sent for further processing.

The use of deep cone type paste thickeners for the settlers and the washers offers advantages to reduce scaling problem. The smaller diameter reduces the retention time of the liquor. For example comparing the clarification zone (the volume from the bottom of the feedwell to the top of the liquor level) of a deep cone to a high rate thickener, the liquor retention time would be shorter by a factor of the cross-sectional area ratio. This assumes the feedwell height is the same for either thickener. The shorter retention time allows the liquor to be collected and discharged faster than in high rate thickeners. This shorter retention time also benefits the process with less heat loss of the liquor going to the next processing stage.

The deep cone settlers and washers produce higher underflow densities than the high rate thickener resulting in higher stage efficiency. This higher efficiency of each stage can result in reduced number CCD stages. Fewer stages reduces the overall process time.

The WesTech low-profile rake mechanism reduces the amount of metal surface area in the thickener compared to other thickeners. The surface area of the paste mechanism is reduced resulting in less area to accumulate scale.

Successful Design Approach

The design of a Deep BedTM paste thickener is flexible and is based on the end user's preferences in operation of the system. The thickener manufacturer, consulting engineer, and the end user should work closely together to identify the critical site, operational, and preferred parameters that can affect the thickener design such as:

- Settler liquor minimum retention time,
- Wash water availability to select number of washing stages
- Balance between increasing underflow density and solids retention time to limit scaling, particularly in the settler and early wash stages
- Added capacity to accommodate liquor storage in the washer tanks, providing surge capacity
- Selection of the number of swing units and their design
- Instrumentation preferences
- Other thickeners needed for the circuit (for example seed thickening, cauterization)

Working closely with those responsible for the design and operation of the circuit insures the successful project. The WesTech/PasteThick process engineers can provide guidance, mass balance calculation for the CCD circuit, and integrate the customer's guidelines with the appropriate thickener design.

Settler and Washer Design Features

The Deep Bed™ design as applied to settlers and washers has the following features:

- •Capacity for deep mud bed levels
- •Low solids and liquor retention time
- •30 degree floor slope
- •High mechanism drive torque designed to overcome any bed condition
- •Process control design to maintain operation at optimum conditions at minimum flocculant dose and controlled underflow density.
- •Feedwell designed to produce feed solids dilution for optimum flocculation
- •Openings for scale removal including top, side, and cone manways for access

Conclusion

The use of deep cone thickeners such as the WesTech Deep Bed™ paste thickeners in alumina red mud settling and washing has several advantages to reduce scaling in the settler and washer circuit. The sizing criteria used for paste thickeners takes advantage of the higher settling rates when modern flocculants are used. One benefit of having smaller diameters is the reduced liquor retention time. Recovering the aluminum more quickly reduces loss to scaling. Reduced liquor retention time also reduces heat loss.

Paste thickener underflow is higher in density than other thickeners, increasing the efficiency of each washing stage. With higher efficiencies, the number of stages can be reduced, shortening the overall processing time. Less time equals less scale. The paste thickener raking mechanism has less metal surface area than high-rate thickeners, reducing the area for scale formation.

International Seminar on Bauxite Residue organised by The International Committee for the Study of Bauxite, Alumina & Aluminium (ICSOBA) in Hotel Vivanta by Taj Panaji, Goa India October 17 – 18, 2011

The International Committee for the Study of Bauxite, Alumina and Aluminium (ICSOBA) is organising an International seminar on Bauxite Residue (Red Mud) in Hotel Vivanta by Taj Goa on October 17 and 18, 2011. The Seminar will focus on various aspects of bauxite residue and its disposal with extensive discussion on worldwide safe and sustainable bauxite residue storage management.

This Seminar will bring together experts from academia, industry, government and other stakeholders from all over the world. It will have key note addresses delivered by eminent personalities in the field and have sessions related to residue characterization, processing for storage, rehabilitation of storage area and utilization as feed stock for various applications. The papers will be presented by experts drawn from all over the world. A visit will be organized for the delegates to the HINDALCO Belgaum alumina refinery on October 19, 2011 to familiarize them with the excellent rehabilitation work carried out in the residue storage area.

More details and application forms for registration are available at the ICSOBA web site www.icsoba.org.

ICSOBA

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