Process Control in a Refinery Based on NIR Real Time Analysis of Bauxite or Coal

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Abstract

Online analysers are increasingly adopted in mineral processing to provide real-time insight into key material streams. Major industrial players are deploying a multitude of sensors throughout their operations, from mine feed to process input and by-product recycling, to improve process control and material balance.

Among available technologies, near-infrared (NIR) spectroscopy has gained wide acceptance across minerals industries due to its unique advantages. Unlike elemental sensors, NIR is sensitive to both organic components (including moisture) and minerals as it interacts with the bonding structures, enabling direct measurement of complex material properties with high accuracy and representativity, often surpassing that of conventional sampling and laboratory analyses.

In bauxite refining, NIR enables direct, real-time quantification of available alumina and reactive silica, rather than relying on calculations based on oxide content. It also effectively measures impurities (organic) that impact the operation the precipitation circuit.

For coal, a critical energy source in some refineries and smelters, NIR provides immediate analysis of total carbon, volatiles, elemental composition (C, H, N), as well as ash and sulphur, supporting optimized combustion and emissions control.

This paper presents case studies from China demonstrating the long-term accuracy, robustness, and process representativity of online NIR analysers applied to bauxite feed characterization and coal quality monitoring. The results illustrate how real-time chemical and mineralogical data can enhance process control, improve operational efficiency, and reduce downtime.

Keywords: Near infrared, Online analysis, Reactive silica, Available alumina, Coal.

1. Context

Alumina refineries face increasing demands to optimize productivity, energy efficiency, and product quality while minimizing environmental impact and operating costs. Achieving these goals in a complex, multi-stage chemical plant requires precise control of key process parameters in real time. However, one of the persistent challenges in refinery operation is the high variability of input raw material streams, particularly bauxite feedstock, which can exhibit wide fluctuations in mineralogy and chemical composition due to sourcing from various domestic and/or international mine sites and inadequate bauxite stockpile blending

The mineralogical composition of bauxite, specifically the proportions of available alumina (typically as gibbsite, boehmite, and diaspore) and reactive silica (usually from kaolinite and other

soluble silicates), directly influence digestion extraction efficiency, caustic consumption, scaling propensity, and ultimately, alumina yield. Conventional laboratory-based analysis of bauxite feed is often too slow to support proactive process adjustments. As a result, many refineries operate with conservative margins in digestion conditions and caustic dosing to compensate for unknown feed variability which can lead to suboptimal performance.

Near-infrared (NIR) online spectroscopy offers a practical solution to the problem of delayed laboratory bauxite analytic results which impairs feedforward process control. NIR analysers provide continuous, real-time measurements of bauxite mineralogy, enabling advanced process control strategies such as feedforward and feedback loops. When integrated into the refinery's Distributed Control System (DCS) or Advanced Process Control (APC) platform, NIR data can significantly enhance process responsiveness, reduce variability, improve yield, and lower reagent and energy consumption.

This paper explores the role of online NIR analysis in addressing key process control challenges in alumina refineries, with a focus on its application for monitoring bauxite feed composition/mineralogy and its integration into digestion and product quality control loops. The discussion also considers the broader context of real-time monitoring of other critical input streams required for efficient and uninterrupted production.

2. Challenge: Impact of Bauxite Mineralogy on Digestion and Process Efficiency

In the Bayer process, bauxite is digested at elevated temperatures and pressures in a relatively concentrated caustic soda (NaOH) solution, weak in sodium aluminate dissolving the soluble alumina-bearing minerals and some other impurities. The resulting sodium aluminate liquor is clarified and cooled then subjected to precipitation, recovering alumina trihydrate, which is then calcined to produce smelter-grade alumina.

Each stage of the process, from digestion to precipitation to calcination, depends critically on the chemical and mineralogical characteristics of the feed materials and process streams. Variability in bauxite feed composition, liquor chemistry, etc. introduces significant challenges for process control and optimization.

The mineralogical composition of bauxite feed exerts a primary influence on digestion performance, caustic consumption, and scaling behaviour. Key mineral phases of interest include:

- Gibbsite, boehmite, and diaspore — sources of **available alumina.**
- Kaolinite and other reactive silicates — sources of **reactive silica**, which consume caustic and promote scaling.
- Iron oxides (hematite, goethite) and titanium minerals — typically inert (depending on digestion temperature) but affect red mud characteristics and product quality.
- Other minerals (here listed in their oxide form) like MnO_2, V_2O, P_2O_5, and also the above mentioned TiO_2, contaminate or consume the liquor and may promote scale formation.
- Organic carbon affects liquor productivity, precipitation kinetics, reduces filterability of alumina hydrate and impact alumina product quality.

Variations in the relative proportions of these minerals can have significant operational impacts. For example, wide fluctuation in reactive silica leads to greater consumption of caustic soda to form desilication products (DSP), reducing available soda for digestion and increasing scaling in heat exchangers (see Figure 1).

variations in bauxite reactive silica input, optimizing digestion efficiency (alumina recovery), improve bauxite stockpile blending to minimize wide variation in the alumina, silica feed to the refinery and reducing operational risks such as digestion piping wear caused by high quartz input in bauxite feed and DSP scaling of pipe caused by perturbations in reactive silica in bauxite feed. Furthermore, the high-frequency data generation supports Advanced Process Control strategies, including feedback and feedforward loops, which improve material blending, reduce off-spec product generation, and increase overall process stability.

Case studies from leading global alumina producers, including installations in Australia and China, demonstrate the long-term stability, robustness, and operational benefits of NIR online analysis implemented by SpectraFlow Analytics. As refineries continue to face challenges related to feed variability, complex blending requirements, and energy efficiency, the adoption of NIR technology within integrated control systems will be pivotal to achieving enhanced process performance and sustainable production.

In summary, NIR online analysers constitute a valuable tool for modern alumina refineries seeking to advance digitalization, improve process intelligence, and achieve superior control over critical material streams, ultimately contributing to more efficient, flexible, and environmentally responsible operations.

7. References

1. Petra Mühlen, Near infra-red based online mineral phase analysis of bauxite, *Proceedings of 36th International ICSOBA Conference,* Belem, Brazil, 29 October–1 November 2018, *TRAVAUX* 47, 139–154
2. Edouard G. M. Mofor et. al, Practical use of online chemical analyser for spent anodes quality control, *Proceedings of the 41st International ICSOBA Conference*, Dubai, 5–9 November 2023, *TRAVAUX* 52, 1069–1079