Settling Ability of Jamaican Bauxite Residue based on Bauxite Feed Constituents and Vessel Design

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Abstract

Since 2015, the bauxite feed to the Jamalco refinery has undergone significant changes in composition, mainly in terms of the available alumina, reactive silica, goethite and phosphorous content. This shift in composition has drastically impacted the plant's alumina recovery, causticity, mud circuit performance and by extension, liquor chemistry and alumina yield. With higher bauxite impurities (mainly reactive silica and goethite), the plant has experienced increased scaling in the vessels, as well as reduced compaction and higher mud viscosity throughout the mud circuit. Other impurities (such as phosphorus), have impacted the plant liquor stability by reducing the available calcium in the circuit. The challenge of bauxite availability for blend specifications is significant and affects the overall production capacity and capital planning of the location. This paper explores the impact of the impurities in Jamalco's bauxite reserves on its mud circuit operation and efficiencies. Furthermore, it seeks to highlight the impact of the inverted cone washer design on the approaches taken for mud settling to maintain the alumina and caustic losses at desired levels.

Keywords: Bauxite residue, goethite, reactive silica, mud settling, available alumina.

1. Introduction

Jamaican bauxite residue is known for its difficulty to settle due to its small particle size and soil-like composition. The associated bauxite feed is typically red in colour but ranges from yellow to dark red based on the relative concentration of the constituent iron minerals, namely goethite and hematite. Jamalco, a low temperature digestion plant, has experienced significant changes in its bauxite feed since 2015. This change has impacted the plant's operations and associated costs due to the feed's constituent iron mineralogy, available alumina, phosphorus [5], and reactive silica.

Research shows that Jamaican bauxite can be categorized into three classifications: Jamaica – 1 (boehmite < 3 %), Jamaica – 2 (boehmite > 3 % and 30 % to 80 % iron mineral as goethite) and Jamaica - 3 (boehmite > 3 % and 90 % of iron content as goethite) [3]. With the decrease in available Jamaica – 1 bauxite reserves, the blending and processing of available pits to meet bauxite specification has become increasingly difficult; which poses challenges for low temperature plants such as Jamalco.

Jamalco's assigned reserves are found in Clarendon, St. Catherine and Manchester in the center of the island, where deposits are interspaced between limestone deposits. This orientation makes the shape and size of the pits irregular, deep and narrow in shape as well as increases the variability of the minerology within the pits. These irregularities underscore the need for efficient and effective bauxite blending strategies to ensure that the correct grade of bauxite is sent to the refinery for processing on a consistent basis.

The deterioration in the quality of the bauxite feed to process has led to a reduction in available alumina from a peak of 44 % in 2015 to a low of 39.6 % in 2018. This is in conjunction with a reactive silica increase from a low of 1.40 % in 2015 to a peak of 3.87 % in 2018 as shown in Figure 1 below. Throughout the period, the plant has experienced a shift in the aluminous minerals present in the bauxite feed, with an increase in the boehmitic content (AlO(OH)), also called monohydrate, from a range of < 1 % in 2015 to 1 - 1.6 % between 2017 and 2018 as well as increase in goethitic content. It has been noted that a strong correlation exists between the goethitic content in bauxite and the soluble phosphorus present [2]. This deterioration in the grade of the bauxite constituents and subsequently the bauxite residue constituents, has resulted in increased mud circuit instabilities. This change has been indicated by increased turbid levels and reduced flocculant efficacy, as well as higher alumina and caustic losses throughout the circuit.

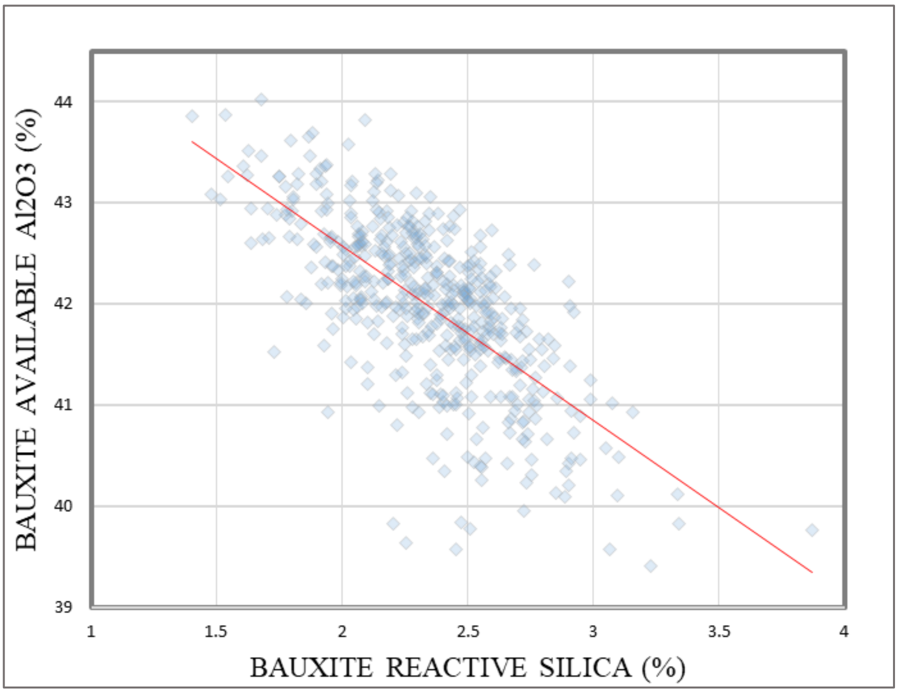

Figure 1. Available alumina and reactive silica in bauxite feed to process.

At Jamalco, it has been recognized that the design of the mud washer plays a critical role in maintaining stability within the washing circuit. Jamalco operates an inverted cone, tangential discharge washer or flat bottom washer as shown in Figure 2 along with high rate last washers. It has been recognized that with the flat bottom washers, the mud is accumulated in front of the rake at the periphery of the vessel, while the mud is accumulated in the cone of the high rate washers. The ability for the rake to push the mud around the flat bottom vessel is the linchpin of the vessel design. This design utilizes two mud discharge outlets (45°) apart, making the movement of mud in the underflow of each vessel dependent on the rake rotation; this means, most of the mud mass at the vessel discharge is removed with the passing of a rake arm infront of the discharge points making the conical bottom design more robust and efficient for mud movement.

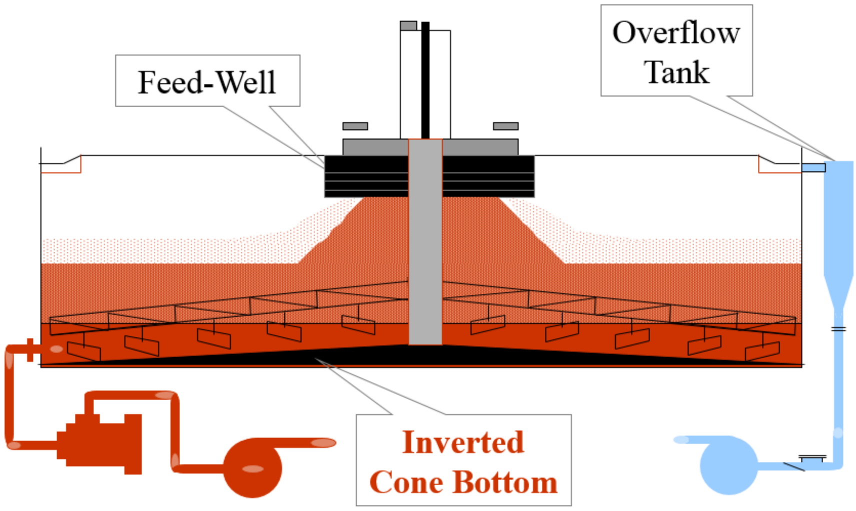

Figure 2. Schematic representation of mud washer design.

The inverted cone washers are therefore susceptible to increased mud residence time which results in higher gibbsite auto-precipitation. A measure taken to maintain washer stability is to maintain lower turbid mud levels while utilizing underflow pumping redundancies to aid in the mud throughput within the circuit. The addition of rheology modifiers to the washing circuit has proven to be effective in augmenting mud throughput capacity without physical system upgrades.

2. Available Alumina and Production Rates

The reduction in available alumina in the bauxite feed to process has caused a gradual increase in the washer mud factor over the years, as shown in Figure 3, resulting in reduced production due to mud capacity constraints. In August 2018, the refinery began mining to supply higher available alumina grade bauxite to process to increase its production rates. This decision facilitated phased implementation of initiatives to aid the plant's ability to process the mining reserve average. The practice of selective mining is not sustainable due to the reduction in the availability of ores with substantial amounts of hematite [3].

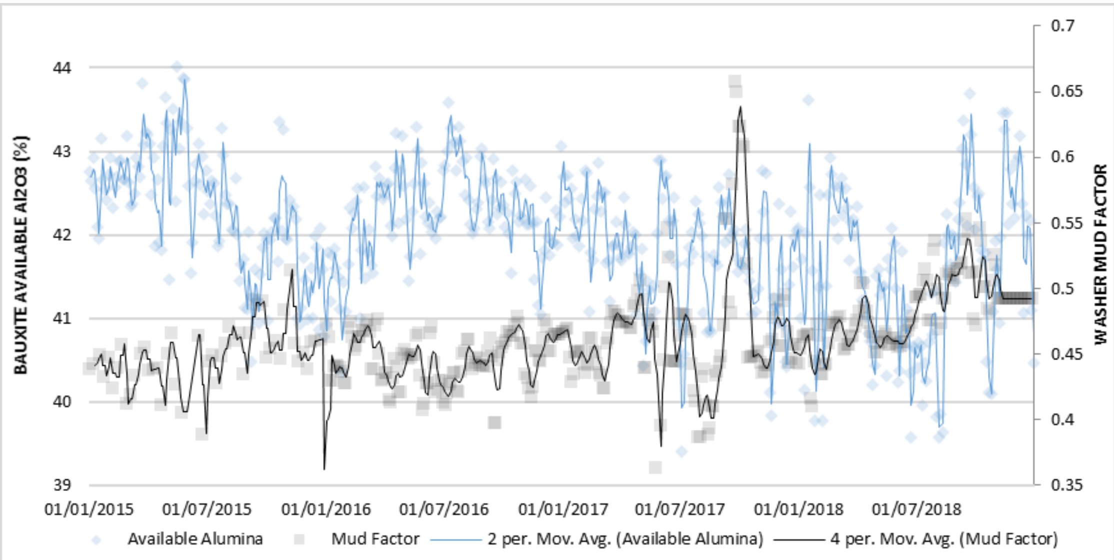

Figure 3. Impact of available alumina on the washer mud factor.

The lowered available alumina to process has resulted in an increase in the mud generated and load to the washers. This increase in mud generation has pushed the location to frequently operate at its capacity of 4300 t mud/day without the benefit of increased production as shown in Figure 4. This increased mud load has increased washer feedwell solids thus reducing the efficacy of utilized flocculants [4]. The requirement to adjust the ratio of the diluent stream to feed slurry to return the feedwell solids to design has been limited due to the underflow limitations related to the inverted cone design. The recovery process for unstable conditions is therefore extensive and results in increased opportunity losses for the refinery.

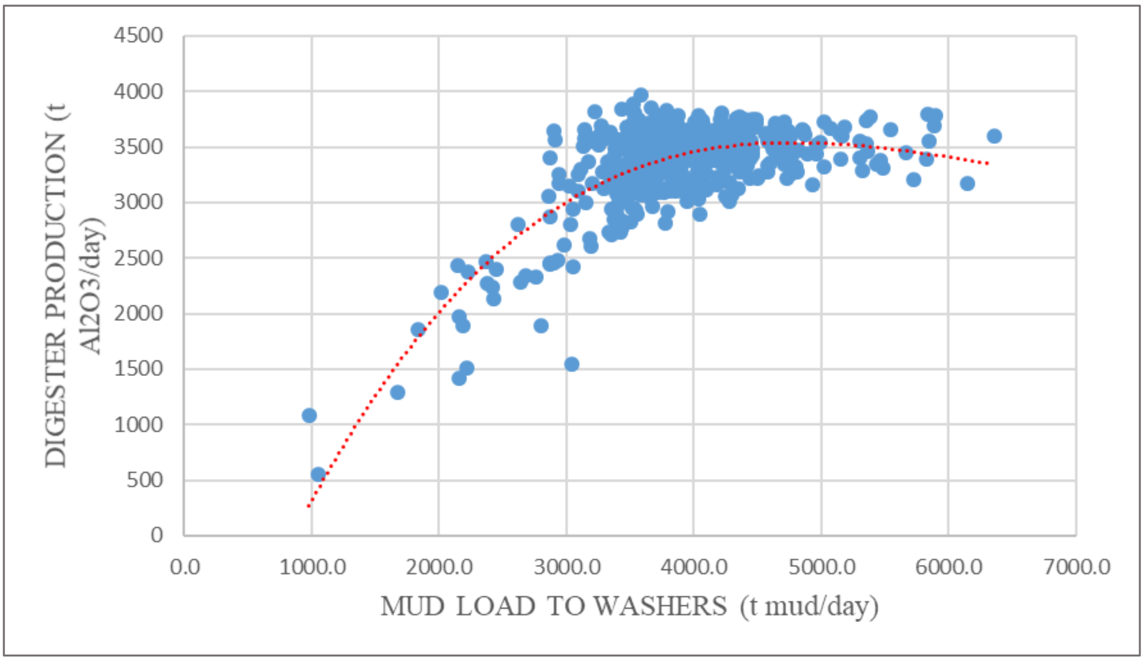

Figure 4. Relationship between the washer mud load and digester production rates.

Initiatives such as an increase in the number of washing trains have helped to maintain the refinery's production rate with lower available alumina and higher mud loads during the period of February – April 2018.

3. Reactive Silica and the Stability of the Mud Washing Circuit

Desilication product, DSP, is formed by a transformation of the reactive silica in bauxite by dissolution and precipitation reactions. DSP significantly impacts settling rates, overflow clarities and flocculant dosages [6] within the mud handling process. The gradual increase of reactive silica in bauxite since 2015 and by extension the DSP in bauxite residue, has led to a rise in the turbid levels within the washing circuit as demonstrated in Figure 5 below by the average mud siphon levels. This increase in the turbid levels has led to supressed overflow alumina to caustic ratios (A/C ratio) leaving the 1st washer resulting from reduced washing efficiencies. This reduced A/C ratio typically leads to increased instabilities in the precipitation circuit.

The presence of DSP has led to an increase in the polyacrylate flocculant dosages throughout the circuit, a consequence of reduced flocculant efficacy caused by the adsorption of dissolved silica on hematite [1]. Onsite laboratory tests have shown that polyacrylate flocculants require up to 70 % increase in dosage to achieve the same settling rate with higher reactive silica feeds. It has been noted that the effects of DSP on settling can be minimized by the type of flocculant used; with hydroxamates responding better than polyacrylates in high DSP scenarios [6]. The concept of flocculant blending with hydroxamates and polyacrylates for improved overflow clarities and settling have been tested and proven during high silica regimes within the washing circuit.

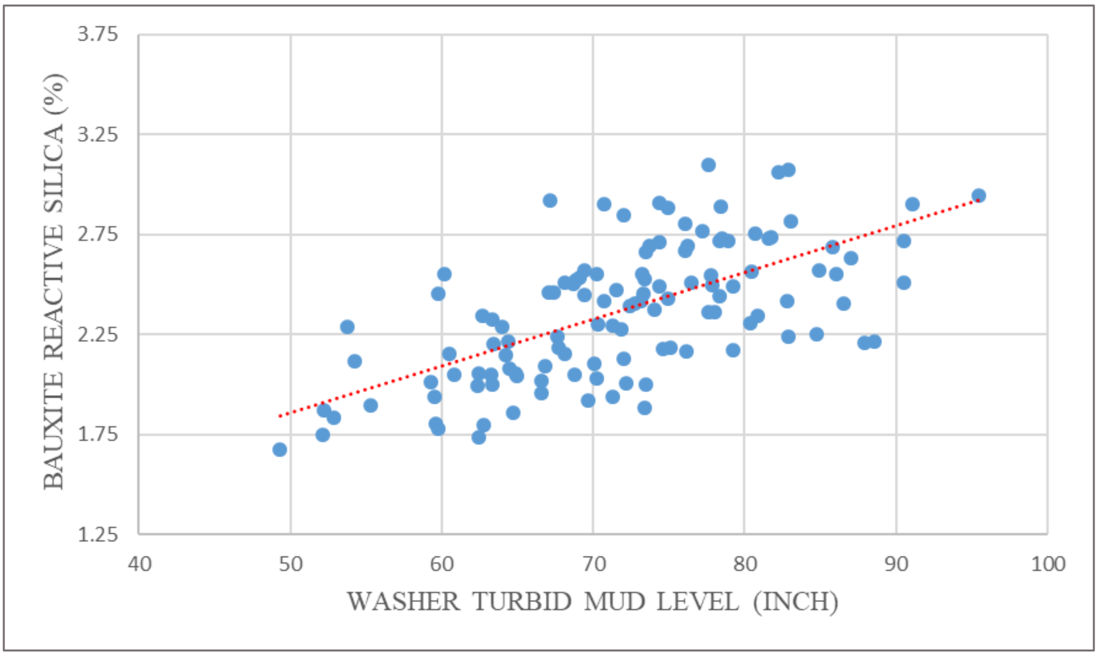

Figure 5. Impact of reactive silica on washer turbid mud levels.

The combination of low available alumina and high reactive silica have proven to be problematic for Jamalco's refinery operations and cost. It has been recognized that a strong correlation exists between the two parameters within some of the remaining bauxite reserves as shown in Figure 6 below.

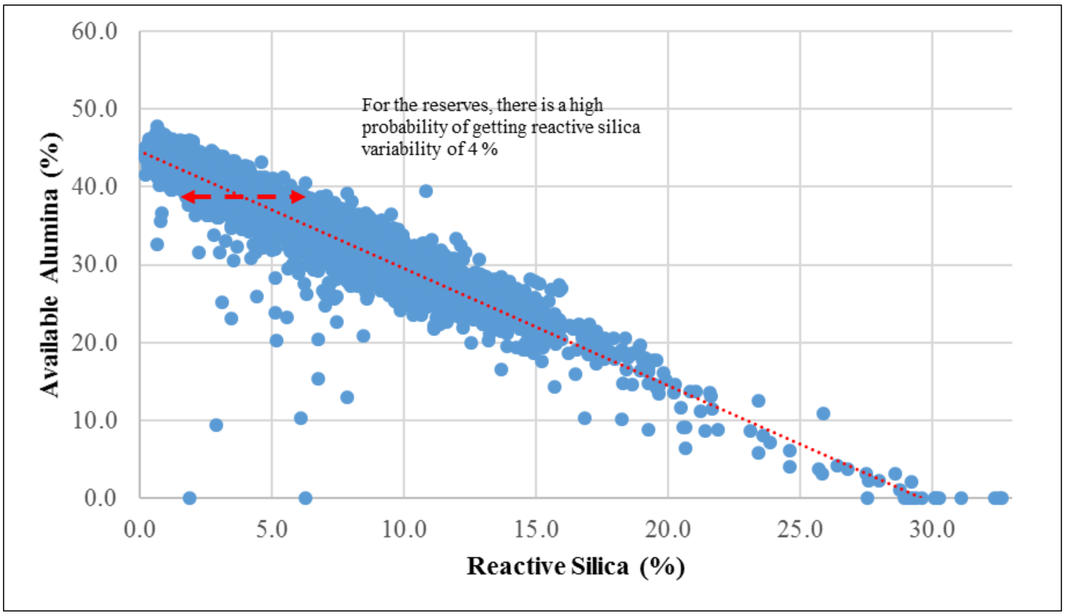

Figure 6. Correlation between available alumina and reactive silica in Porous Victoria Town mining pits.

This correlation means that bauxite having an available alumina of 40% can have reactive silica ranging from 1% to 5% making the requirement to have robust management of the bauxite on the ground and refinery management system very important.

4. Impact of Goethitic Bauxite on the Bayer Process

Goethite, the hydrated form of iron oxide, is the iron mineral which gives bauxite its yellow colour, and this form of iron oxide is known for its impact on the Bayer process. Its smaller particle size leads to an increase in the bauxite specific surface area resulting in greater mud volume generation with elevations in the goethite to hematite ratio [3]. The rise in the goethite to hematite ratio to process has caused a reduction in the achievable g/L solids throughout the mud circuit as shown in Figure 7 below. It is typically expected that with an increase in the goethite content in mud, a decrease will occur in the compaction of the washer mud bed [3].

With increased goethite in bauxite, it has been observed that the underflow capabilities within the washing circuit also decreased. This has been attributed to the increased mud yield stress due to increased goethite content in mud. Desmond et al. [3] states:

"*Despite this decrease in solids concentration the viscosity of the settled mud increases with increasing goethite content of the mud.*"

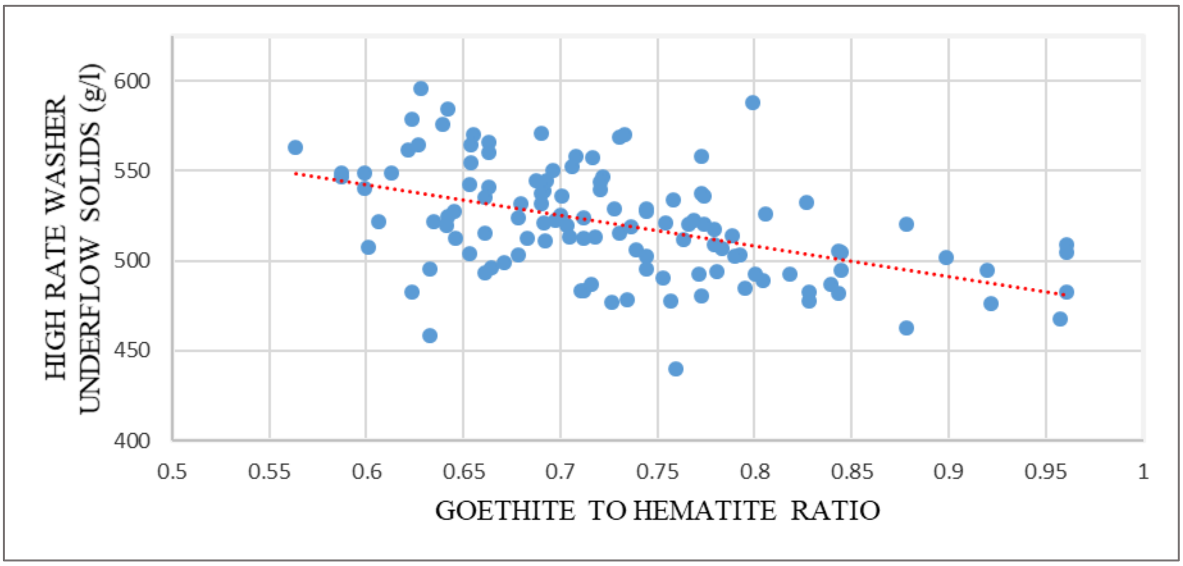

Figure 7. Relationship between goethite to hematite ratio and underflow solids.

The lowered g/L solids in conjunction with higher mud viscosities have led to an increase in the mud accumulation in the flat bottom and high rate washers. This accumulation has reduced ability to settle mud in the flat bottom washers at the desired rate.

The shift in the bauxite quality has negatively impacted the mud compaction within the washing circuit and the soluble caustic loss for the refinery. The average soluble soda loss increased from 33.77 kg NaOH/t Al_2O_3 to a peak of 39.66 kg NaOH/t Al_2O_3 for January – July 2018. With the temporary implementation of selective mining in August 2018, the average soluble soda loss reduced to a low of 22.06 kg NaOH/t Al_2O_3 for August – December 2018.

The gradual increase in the goethitic content in the bauxite feed to process has been accompanied by an increase in the phosphorus content. This simultaneous increase suggests a certain association between soluble phosphates and goethite [2], as shown in Figure 8 below.

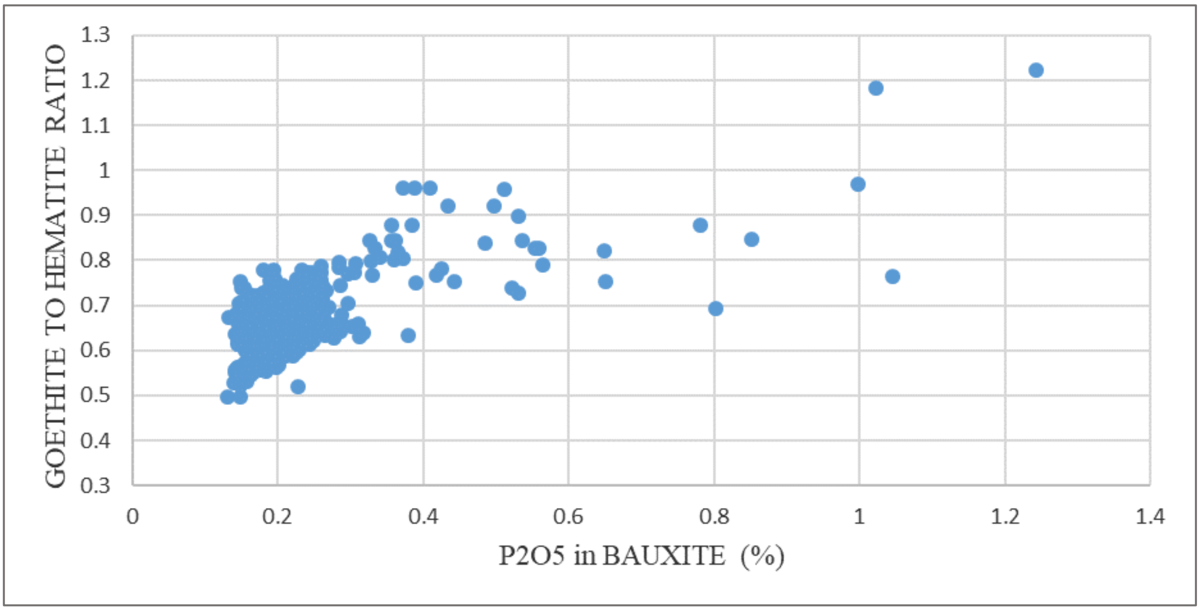

Figure 8. Correlation between goethitic content and phosphorus in bauxite.

4.1 Impact of Phosphorus on Liquor Stability

Lime is often described as the "aspirin" for the Bayer process [7], due to its numerous benefits in aiding nucleation inhibition and improving liquor stability. One of the many uses of lime within the Bayer process is phosphorus control. Phosphates are removed through a reaction with calcium to form carbonate-apatite (a non-alumina containing compound) [2]. The formation of carbonate-apatite interferes with the stabilizing effect of lime which increases the probability of liquor instabilities. Typically, lime is charged, based on the plant's carbonate balance, to overcome the reactions with phosphorus as well as maintain the liquor causticity. Therefore, a direct correlation has not been observed between phosphorus content in bauxite and the attainable calcium in liquor.

A reduction in calcium in liquor leads to an increase in alumina losses within the washing circuit; this is as a result of reduced inhibitive action of calcium on gibbsite precipitation [9]. Additionally, a proportional relationship exists between increased calcium and A/C ratios leaving the circuit as shown in Figure 9 below.

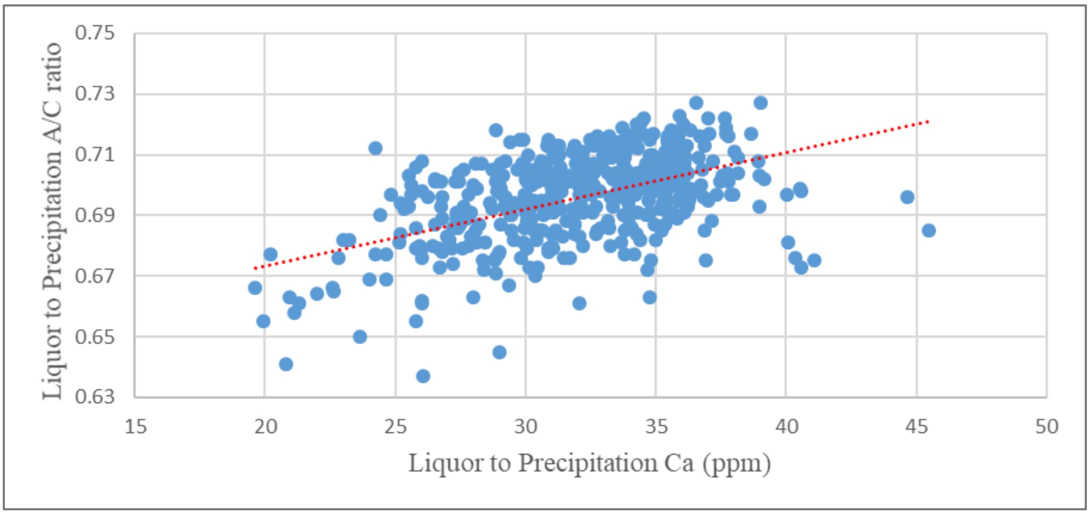

Figure 9. Relationship between liquor to precipitation Ca and A/C ratio.

5. Factors Affecting Gibbsite Auto-Precipitation

Gibbsite auto-precipitation can occur from primary or secondary nucleation [8] and is generally affected by several conditions such as: increased supersaturation, reduced stabilizing effect of calcium, increased presence of unextracted gibbsite in mud, increased presence of other seeds in mud and increased mud factor [2]. Typically, gibbsite auto-precipitation is promoted by the presence of seed [8].

With the increased boehmite content in bauxite under low temperature digestion conditions, the ability to promote the precipitation of dissolved alumina rises [4]. However, analysis of the impact of boehmite content in bauxite on auto-precipitation showed little to no correlation. The increase in the goethitite content in bauxite was accompanied by a reduction in the plant's alumina recovery as shown in Figure 10 below.

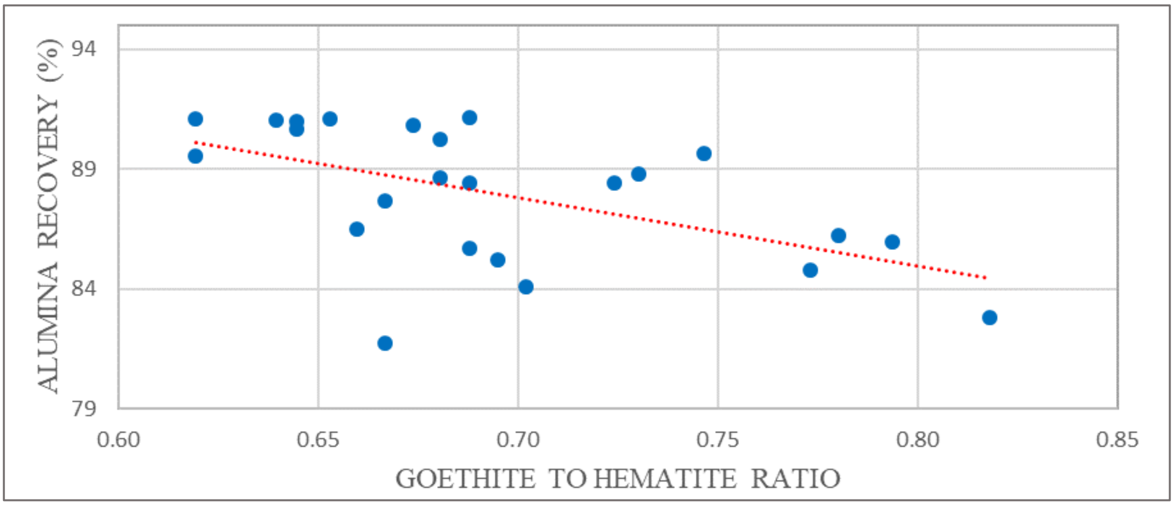

Figure 10. Relationship between alumina recovery and goethite to hematite ratio in bauxite.

This reduction was initially attributed to increased auto-precipitation caused by the presence of goethitic seeds. However, further investigation into the relationship between the goethite content in bauxite and auto-precipitation showed that there was little to no correlation between the parameters. However, the impact of goethite on mud compaction and therefore its impact on mud mass flows offers an explanation for its negative impact on alumina recovery in the washing circuit.

X-Y plots of digester blow-off (DBO) gibbsite in mud and decanter auto-precipitation, confirmed its negative impact of increasing auto-precipitation. However, the plot did not provide enough evidence to support the concept of gibbsite being the major contributor to decanter auto-precipitation as shown in Figure 11 below.

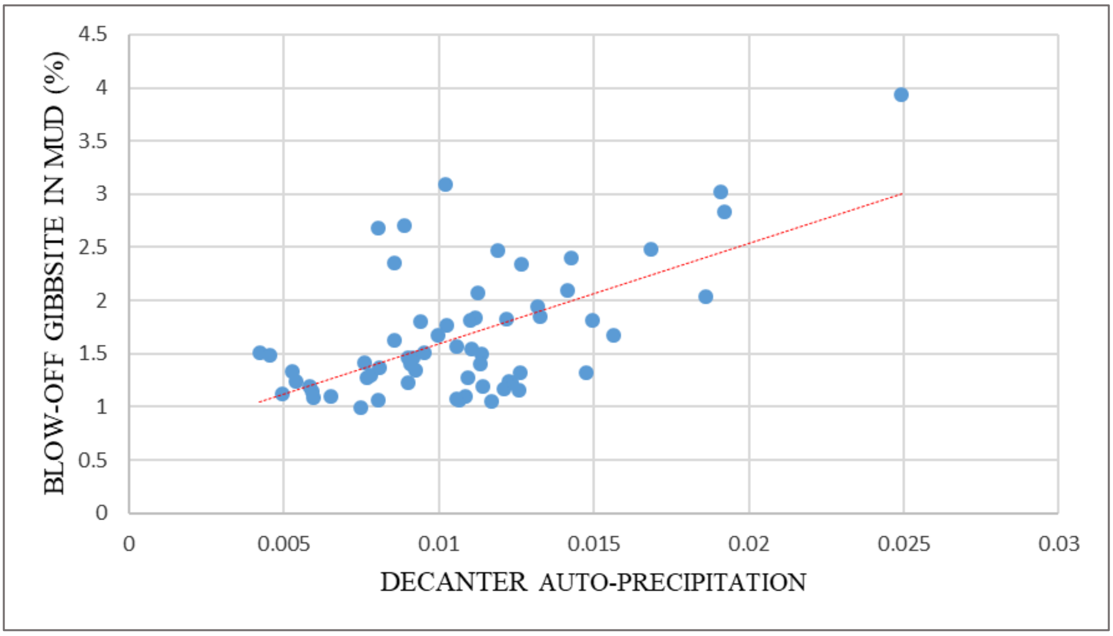

Figure 11. Relationship between DBO gibbsite in mud and decanter auto-precipitation.

Within the context of the Jamalco operations, supersaturation, gibbsite seed (unextracted or reverted) and the reduced stabilizing effect of calcium can be cited as the major contributors to gibbsite auto-precipitation. The increased mud generation to the washers due to greater decanter auto-precipitation has led to increased washer turbid mud levels and higher production losses due to mud control.

6. Future Plans

The capital expenditure plan focuses on the alignment of the projects associated with the mining operations while addressing the major implications of raw material changes on the refinery. The development of such plans includes assessing the viability of new bauxite feedstocks, creation of new access roads to mining pits, land acquisition and reducing variability in the bauxite quality to process.

The changes in bauxite feed characteristics described in this paper have necessitated a strategy shift in the flocculant dosing system design and the optimization process for rheology modifiers addition to aid in the settling characteristics and flowability of the mud within the circuit. Also, several modifications to the decanter and washer layout have been undertaken to increase the mud circuit capacity. It is expected that these actions and bauxite exploration will facilitate the refinery's ability to handle the proposed mining plan and yield improvements in the plant's alumina recovery and production rates.

7. Conclusion

Jamalco's operations and associated costs have been significantly impacted by the deterioration of the bauxite quality to process since 2015. Despite significant focus on the impact of goethite on mud settling and plant stability, the combination of low available alumina and high reactive silica have proven to have a greater impact on mud settling than solely the impact of goethite. Several modifications have and will continue to be implemented to facilitate the efficient production of alumina while utilizing the available bauxite reserves. These initiatives will enhance the plant's alumina recovery and minimize the opportunity losses due to washer instabilities while continuously securing Jamalco's future in the alumina industry.

8. Acknowledgements

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9. References

1. Alexander Senaputra et al., Sodalite solids formation at the surface of iron oxide and its impact on flocculation, *Light Metals 2013*, 77-82.
2. Desmond Lawson et al., Impact of Jamaican bauxite minerology on plant operations, *Light Metals 2008*, 113-118.
3. Desmond Lawson et al., Approaches to the processing of Jamaican bauxite with high goethite content, *Light Metals 2014*, 11-18.
4. José Carlos M. Vieira et al., Boehmite bauxite usage at low temperature digestion an case of study at alumar refinery, *Proceedings of 36th International ICSOBA Conference*, Belem, Brazil, 29 October – 1 November 2018, *TRAVAUX* 47, 219-228.
5. Keddon Andre Powell et al., Characterisation of alumina and soda losses associated with the processing of goethitic rich Jamaican bauxite, *Light Metals 2009*, 151-156.
6. Senaputra A et al., The impact of desilication product on bauxite residue flocculation, *Proceedings of 9th International Alumina Workshop*, 2012, 186-192.
7. Max A. Wellington, Effect of lime causticization on silica, calcium, oxalate and organic carbon levels in the Bayer process washer overflow liquor, *ChemExpress*. Vol. 8, No. 3, (2015), 208-213.
8. Keddon Andre Powell, Benjamin Kieran Hodnett and Luke Jonathon Kirwan, The effect of chemical additives on gibbsite auto-precipitation and bauxite residue flocculation when processing goethitic bauxites, *Proceedings of 19th International ICSOBA Conference*, Balem, Brazil, 30 October – 2 November 2012.
9. Marie Raty et al., Calcite in the mud washing of the bayer process: experimental solubility and adsorption, *Light Metals 2004*, 105-108.