Laboratory Experiments on Bauxite Processability in Al Taweelah Alumina Refinery

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Abstract

Alumina is extracted from bauxite, with each type of bauxite having its own distinct physical and chemical characteristics. These characteristics vary based on geographical location and source mine, making it crucial to understand their impact on refinery processability. Laboratory experiments are conducted to assess the processability of each bauxite type, providing an initial indication of potential limitations within the refinery. The results of these experiments can identify opportunities for optimisation or necessitate changes in maintenance, operating, and process procedures to overcome these potential limitations and production losses.

In accordance with standard procedures at the Al Taweelah alumina refinery, several laboratory simulations are performed prior to introducing the refinery to any new source of bauxite, or when using bauxite of relatively lower quality than the typical Al Taweelah alumina refinery bauxite feed from the same source. These laboratory tests include bauxite slurry viscosity measurements, flowability tests, breakeven point curves, settling tests, flocculants selection, liquor filtration, and mud filter press filtration simulations using different bauxite types and blends. This paper outlines the methodologies employed for Al Taweelah alumina refinery's various laboratory processability experiments and provides an evaluation of the results on how the outcome is applied to optimise the bauxite blend, refinery process parameters and to a financial model.

Keywords: Bauxite processability, Financial model.

1. Introduction

Al Taweelah alumina refinery has been processing mainly Guinean bauxite from the startup of the refinery and is now also processing non- Guinean bauxite. These bauxite types vary physically and chemically, and it is therefore necessary to understand the behaviour prior to feeding the refinery. Many laboratory experiments have been carried out, simulating plant conditions using different bauxite types and blends which will further support the refinery operations.

This paper describes the refinery's various laboratory processability methodologies and how these results are used as a whole: supporting plant scale operation and estimating the refinery capability to make strategic decisions.

2. Bauxite Quality

The difference in bauxite quality when comparing the Guinean and non-Guinean bauxite processed at Al Taweelah alumina refinery is in alumina, silica content and organics. Table 1 shows the range of the different bauxite qualities:

Table 1. Bauxite quality.

Bauxite type	Guinean bauxite processed at Al Taweelah alumina refinery	Non- Guinean bauxite processed at Al Taweelah alumina refinery
Total Al_2O_3, wt%	44–50	49–54
Total SiO_2, wt%	1.5–2.4	6–11
Fe_2O_3, wt%	18–27	10–16
TOC (total organic carbon), wt%	0.08–0.1	> 0.2
G/H (goethite to hematite ratio)	1.0–1.5	< 1

3. Laboratory Experiments Outcomes and Application

Laboratory results of the processed Guinean bauxite and historical plant performance are used as a baseline for the comparison to the non-Guinean bauxite for the applications which are described in the following sections. The Guinean bauxite types are referred as A and B while the non-Guinean bauxite types as bauxite types c, d, e, and f.

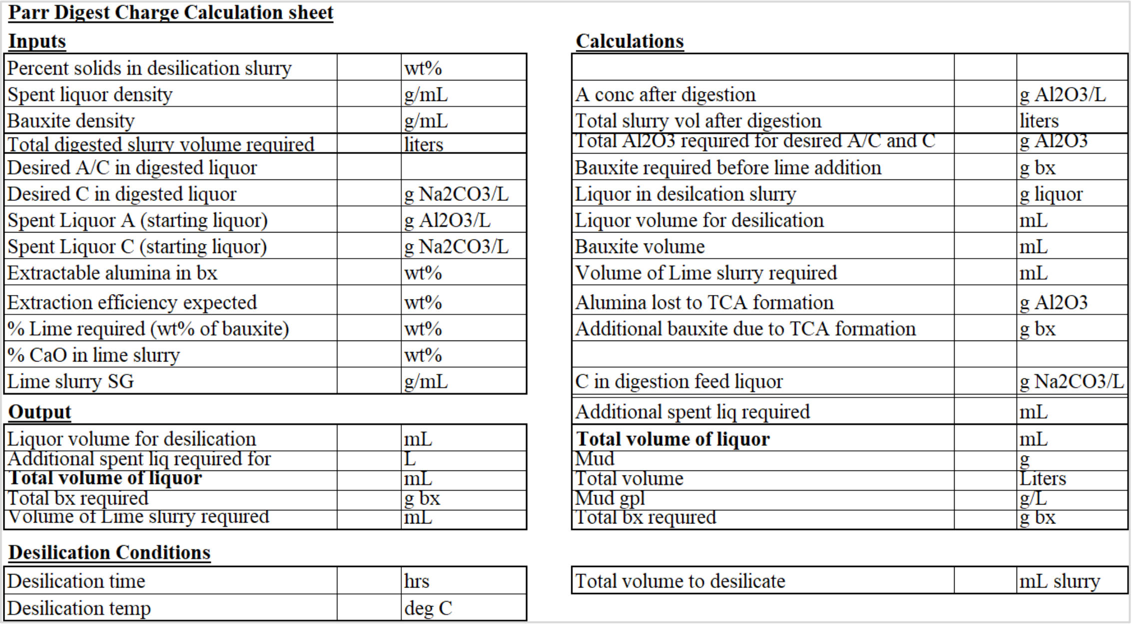
3.1 Laboratory Experiments: Equipment and Methodologies

3.1.1 Pre-Desilication Slurry (PDS) Preparation and Parr Reactor Digestion

To determine the appropriate quantities of bauxite charge, Milk of Lime (MOL) addition, and excess liquor for digestion, several input parameters were incorporated into the calculations. The prepared bauxite-liquor slurry was subsequently subjected to pre-desilication under controlled laboratory conditions. The slurry was placed in a rotating water bath maintained at a constant temperature of 75 °C for a duration of 16 hours. This setup was designed to simulate the pre-desilication conditions employed at the Al Taweelah alumina refinery prior to the Bayer digestion stage. Continuous rotation ensured uniform heat distribution and mixing, thereby facilitating effective interaction among slurry components and improving silica removal efficiency.

Bauxite digestion experiments were conducted using a high-temperature, high-pressure (HT/HP) Parr reactor at a target temperature of 280 °C, utilizing plant liquor feeding digestion (LTD) as the caustic medium. The bauxite was charged to achieve a target alumina-to-caustic ratio (A/C). For each test, the required amount of slaked lime was added to the reactor feed to simulate plant conditions.

Figure 1. Laboratory equipment. Left: Parr reactor, Right: filtration unit.



Parr Digest Charge Calculation sheet

Inputs

Percent solids in desilication slurry		wt%
Spent liquor density		g/mL
Bauxite density		g/mL
Total digested slurry volume required		liters
Desired A/C in digested liquor		
Desired C in digested liquor		g Na2CO3/L
Spent Liquor A (starting liquor)		g Al2O3/L
Spent Liquor C (starting liquor)		g Na2CO3/L
Extractable alumina in bx		wt%
Extraction efficiency expected		wt%
% Lime required (wt% of bauxite)		wt%
% CaO in lime slurry		wt%
Lime slurry SG		g/mL

Output

Liquor volume for desilication		mL
Additional spent liq required for		L
Total volume of liquor		mL
Total bx required		g bx
Volume of Lime slurry required		mL

Desilication Conditions

Desilication time		hrs
Desilication temp		deg C

Calculations

A conc after digestion		g Al2O3/L
Total slurry vol after digestion		liters
Total Al2O3 required for desired A/C and C		g Al2O3
Bauxite required before lime addition		g bx
Liquor in desilcation slurry		g liquor
Liquor volume for desilication		mL
Bauxite volume		mL
Volume of Lime slurry required		mL
Alumina lost to TCA formation		g Al2O3
Additional bauxite due to TCA formation		g bx
C in digestion feed liquor		g Na2CO3/L
Additional spent liq required		mL
Total volume of liquor		mL
Mud		g
Total volume		Liters
Mud gpl		g/L
Total bx requred		g bx

Total volume to desilicate		mL slurry

Figure 2. Example of the applied calculations for the Parr reactor test.

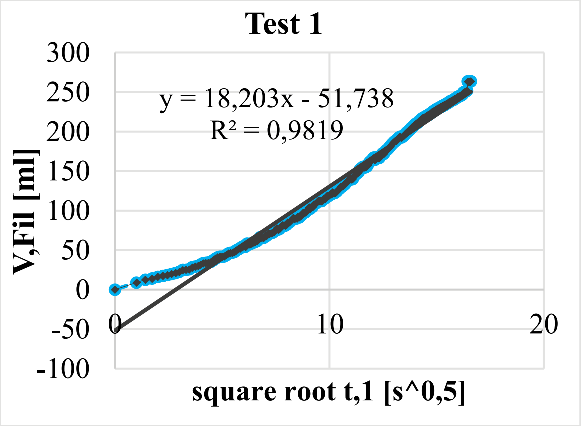


Figure 3. Example of output parameters from a filtration test.

3.1.2 Settling Tests of Parr Digested Slurry

Upon completion of the digestion process, the resulting slurry was discharged and transferred into settling cylinders to simulate the clarification stage of refinery operations. Depending on the bauxite source, dilution of the slurry was performed to align with refinery conditions. Flocculant dosing either as a single dose or co-dosing was applied to the slurry to evaluate settling performance and determine the optimal dosage for achieving maximum settling rates. Supernatant liquor was subsequently analysed for turbidity and total suspended solids (TSS) to assess the efficiency of mud settling. Additionally, mud compaction was measured and compared across varying flocculant dosages to evaluate its influence on solids consolidation.

3.1.3 Clarifier Overflow Liquor Filtration

Following the settling tests, liquor filtration was performed using a laboratory filtration unit to simulate the filtration process employed in the Al Taweelah alumina refinery. In this setup, Tricalcium Aluminate (TCA) was added to the clarifier overflow liquor, maintained at a temperature above 80 °C and subjected to a compressed air pressure of approximately 1.5 bar. The filtration rate was subsequently measured and recorded, with observed variations corresponding to differences in flocculant dosage and total suspended solids content.

3.1.4 Last Washer Underflow Mud Filtration

Following compaction measurements of the clarifier underflow, the mud was centrifuged and diluted to replicate the conditions of the refinery's final washer underflow. The prepared slurry was then transferred to the laboratory scale filtration unit for mud filtration testing, conducted at approximately 70 °C and a cake formation pressure of around 4.7 bar. In addition to the filtration rate, key parameters such as cake moisture content, cake thickness, and cake mass were concurrently measured and documented.

3.2 Application Using Laboratory Experiments Outcomes

3.2.1 Plant Scale Operation

To support the plant scale operation, tests were done to determine optimised bauxite blends for identifying potential equipment and process limitations, optimised alumina extraction with breakeven curves, optimised flocculants dosages for liquor clarity and mud compaction, as well as the impact on liquor filtration, mud filtration, and mud cake moisture.

3.2.2 Plant Capability, Production Planning, and Strategic Decisions

The change in bauxite feed can potentially reduce the plant capability. The results will indicate the impact on the equipment's performance and therefore, mitigations can be put in place. Furthermore, these results will also be used to simulate raw material requirements with the associated costs for each individual bauxite type.

4. Results and Discussion

The evaluation period was from January 2025 to April 2025. The exact plant bauxite blend ratios will differ from the laboratory experiments and therefore, plant data selection would aim to be as close to laboratory experiments' conditions as possible. The following results will show the comparison between laboratory and plant data. As a standard for comparison, bauxite type A or B will be used as reference.

4.1 Plant Scale Operation

4.1.1 Slurry Viscosity and Flowability in Pre-desilication Tanks

To indicate the impact of viscosity and flowability, hydraulic limits, and potential blockages in the slurry storage system, laboratory experiments were done for different bauxite types on solids concentration and/or blend ratios. An increase in viscosity and lower flowability for bauxite types d and f were observed compared to the reference, hence posing a potential risk without any blending of other bauxite(s); the solids concentration would either have to be reduced or these bauxite types should be blended in low quantities. Bauxite types c and e showed similar viscosity and flowability to the reference bauxite types. The section below describes two separate examples of the different blends and solids concentration with bauxite types d and f.

Figure 4. Pictures of flowability tests at 700 g/L. Left: type d, Right: type A.

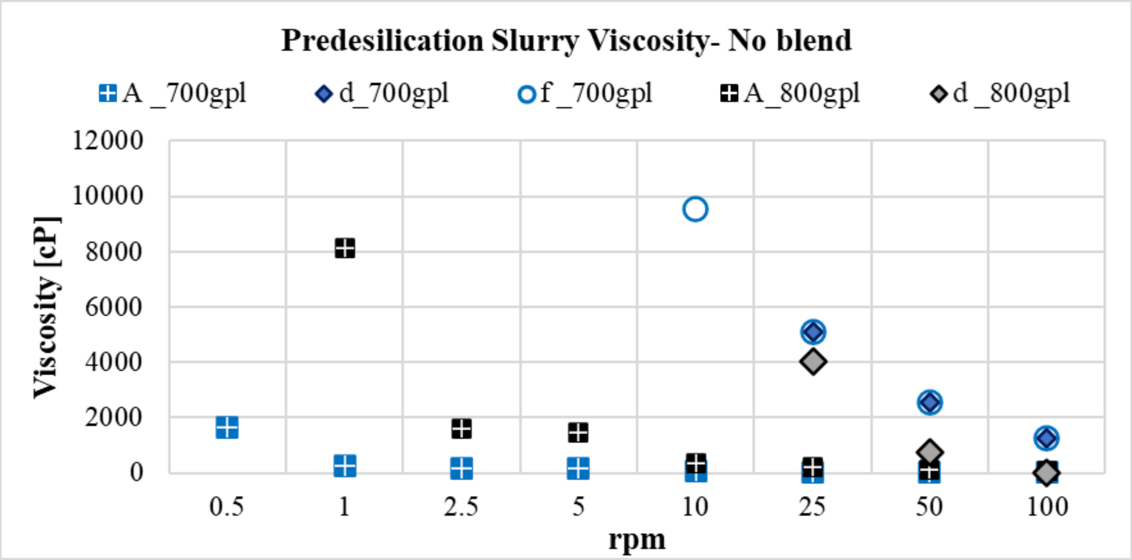


Figure 5. Lab: viscosity vs different solids concentration and bauxite types. (Results at low rpm were out of the instrument's range for bauxite types d and f).

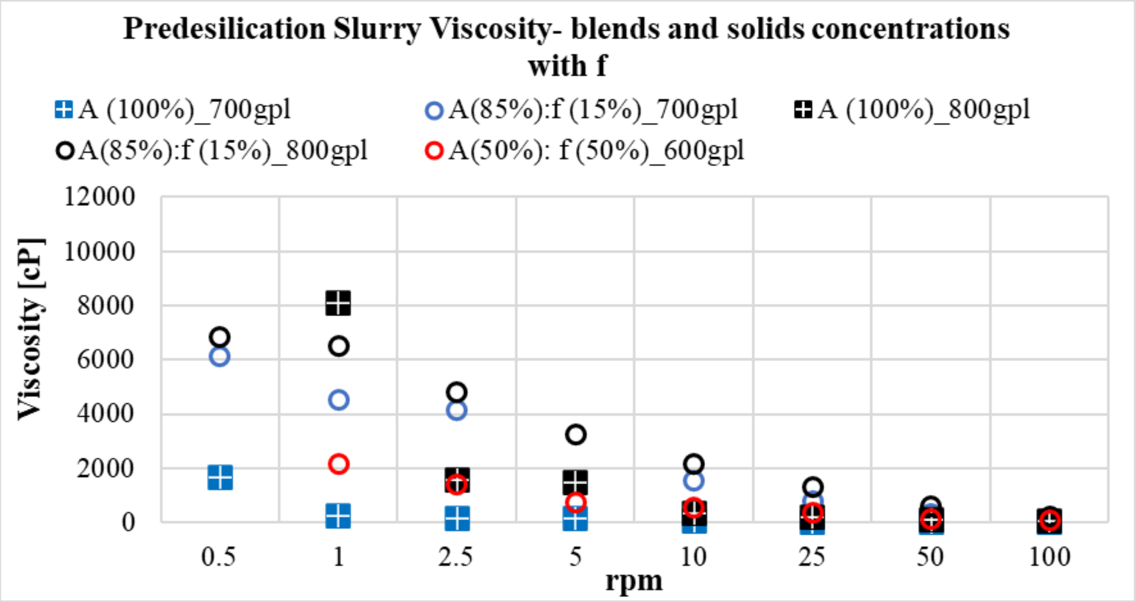


Figure 6. Lab: viscosity vs different solids concentration with blend A and f.

Bauxite type f (5 %) with solids concentration of 750–800 g/L did not affect the slurry storage system. Increasing bauxite type f to 12 % with reduced solids concentration to 700 g/L showed a slight pumping performance deterioration but still manageable in terms of hydraulics. The highlighted areas in the charts (Figures 7–8) below display the period of these bauxite blends.

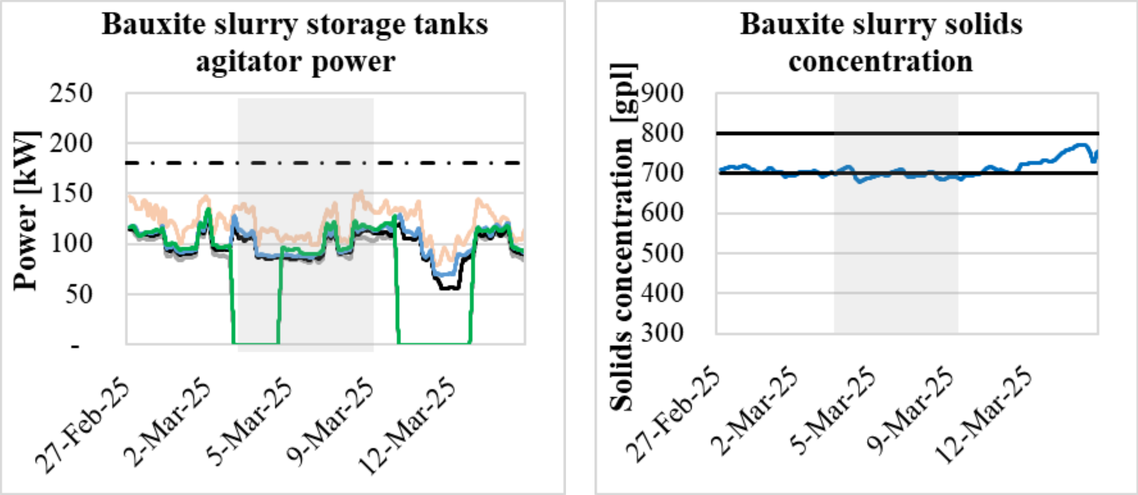


Figure 7. Plant data with blend A (88 %): f (12 %). Left: tank agitator power, Right: slurry solids concentration.

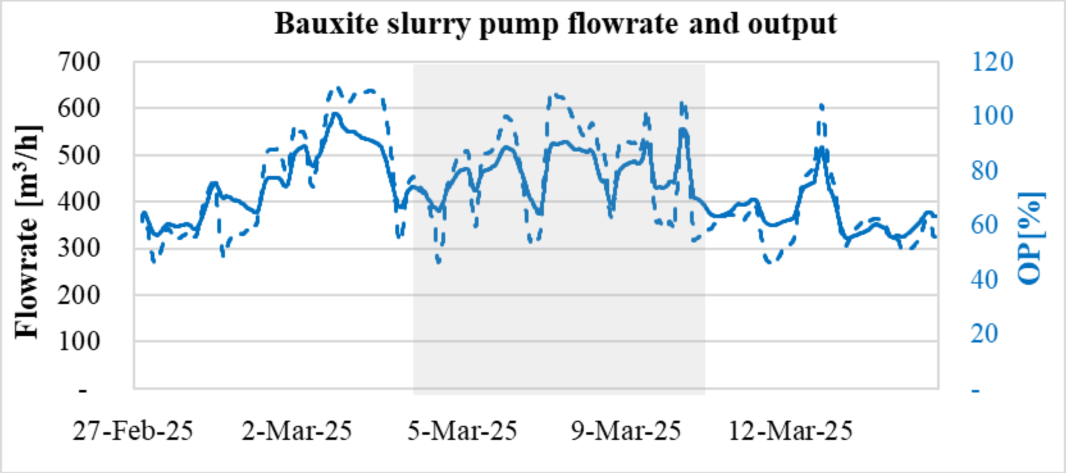


Figure 8. Plant data with blend A (88 %): f (12 %) for slurry pump flowrate and output.

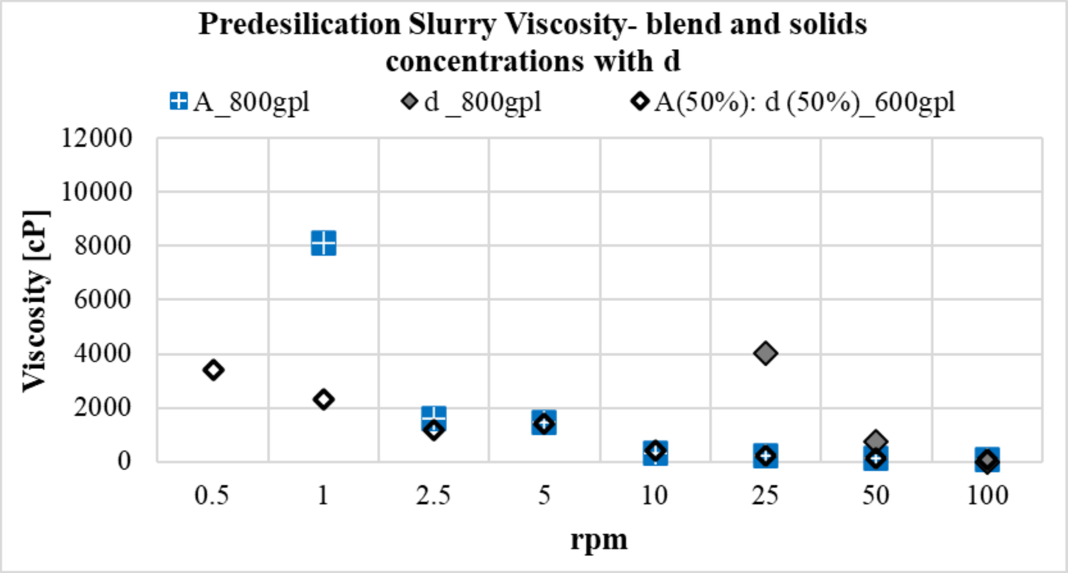


Figure 9. Lab: viscosity vs different solids concentration with blend A and d. (Results at low rpm were out of the instrument's range for bauxite type d).

The plant did not face restrictions when blending bauxite type d (50 %) with bauxite type A (50 %) at 750-800 g/L (Figures 10–11).

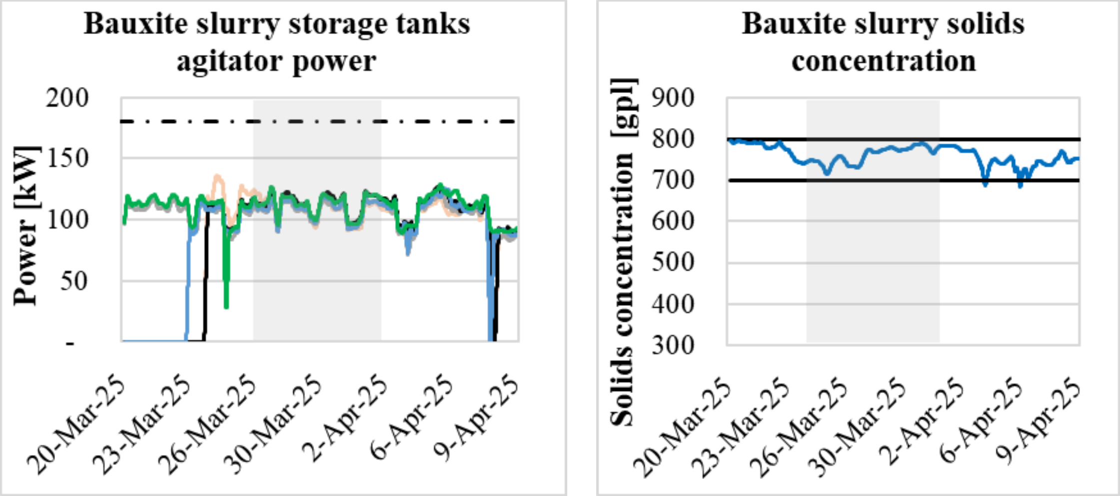


Figure 10. Plant data with blend A (50 %) and d (50 %).
Left: tank agitator power, Right: slurry solids concentration.

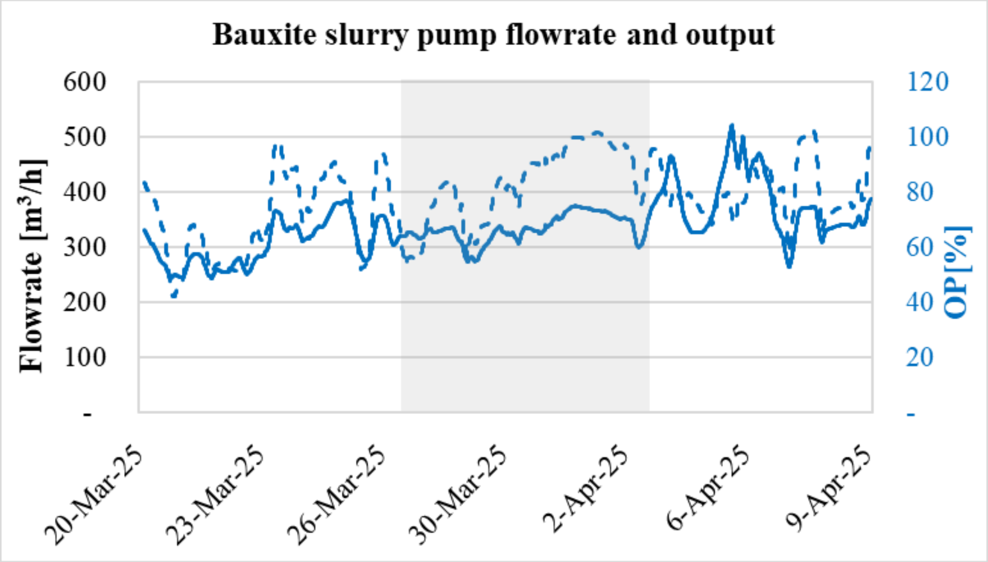


Figure 11. Plant data with blend A (50 %): d (50 %) for slurry pump flowrate and output.

4.1.2 Extraction

To set the plant A/C ratio, break-even curves were developed for each bauxite type. Both bauxite types c and d are relatively higher in extraction compared to bauxite type A. Although the break-even curve for type c tested in the laboratory was not conclusive, results from plant step testing on bauxite type c showed a relatively good break-even point. Actual plant target A/C data will not be presented due to its variability affected by other factors, which can be misleading.

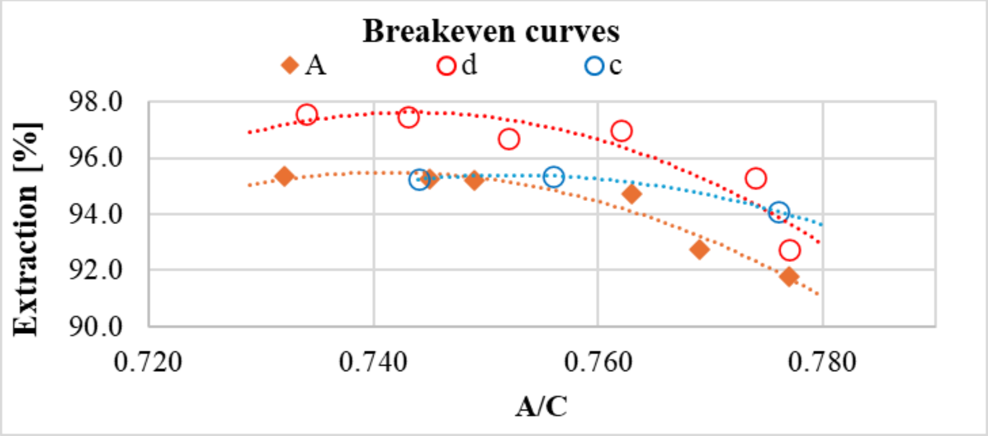


Figure 12. Lab break-even curves for bauxite types d and c.

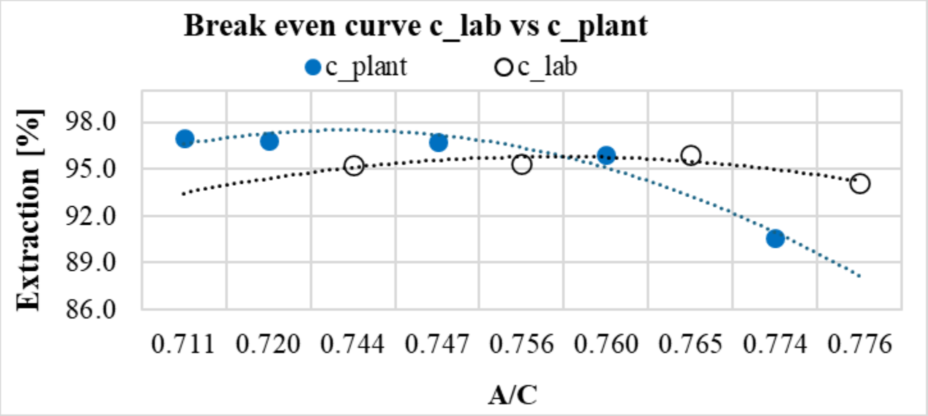


Figure 13. Lab vs plant break-even curves for bauxite type c.

4.1.3 Settling Rate: Clarity and Mud Compaction

The standard Al Taweelah alumina refinery laboratory settling procedure was modified to be able to settle the mud by reducing the feed solids from typical 65–75 g/L to 40–50 g/L as reflected in the next charts. Settling tests results were consistent with relatively higher flocculant dose requirements, low settling rate, good clarity and low mud compaction. Flocculant dose would double in requirement and mud compaction was half of the typical non-Guinean bauxite.

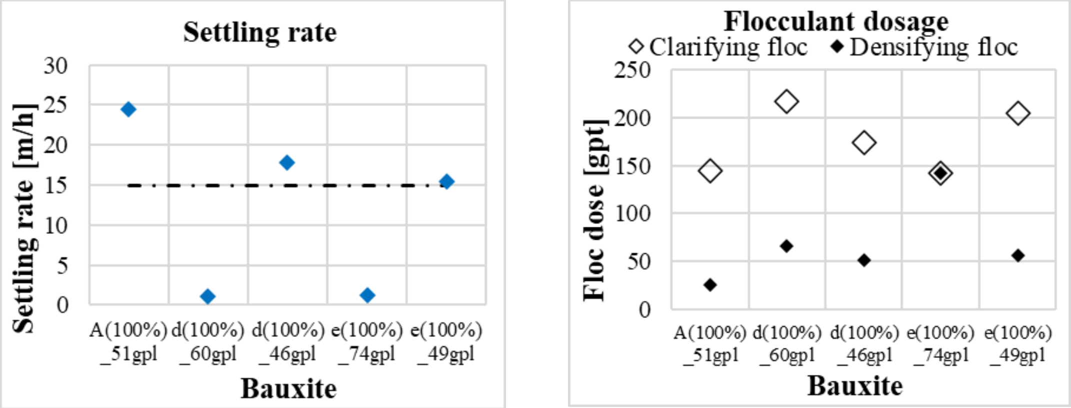


Figure 14. Lab data: settling tests with different feed solids reflected on the x-axis and bauxite types. Left: settling rates, Right: flocculant dosage.

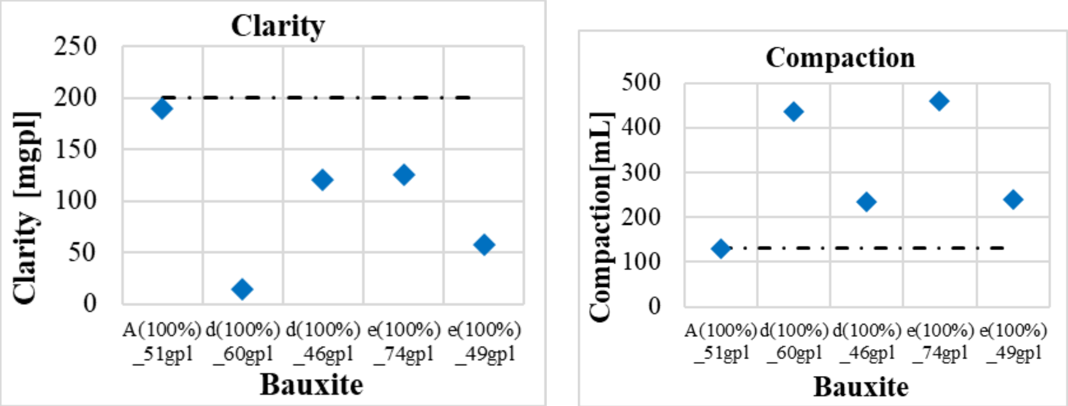


Figure 15. Lab data: settling tests with different feed solids reflected on the x-axis and bauxite types. Left: clarity.,Right: mud compaction.

Plant data for flocculant dosages show that both clarifying and densifying flocculant tripled to keep light mud levels in the required range. After changing the flocculant addition point for the densifying flocculant from the feed line into the feed well, light mud levels were kept in range without the need to add clarifying flocculants for all different bauxite blends as shown in the highlighted area in Figures 16 and 17. This had a positive impact on both the overflow clarity and clarifiers underflow solids concentration: the period from mid-February 2025 to mid-March 2025 should not be considered as this is during the planned half plant shutdown.

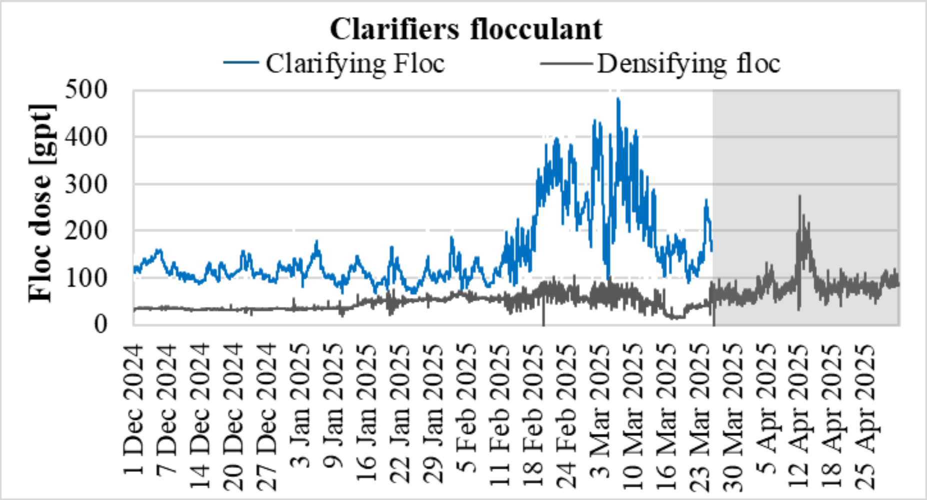


Figure 16. Plant: clarifiers flocculant dosage.

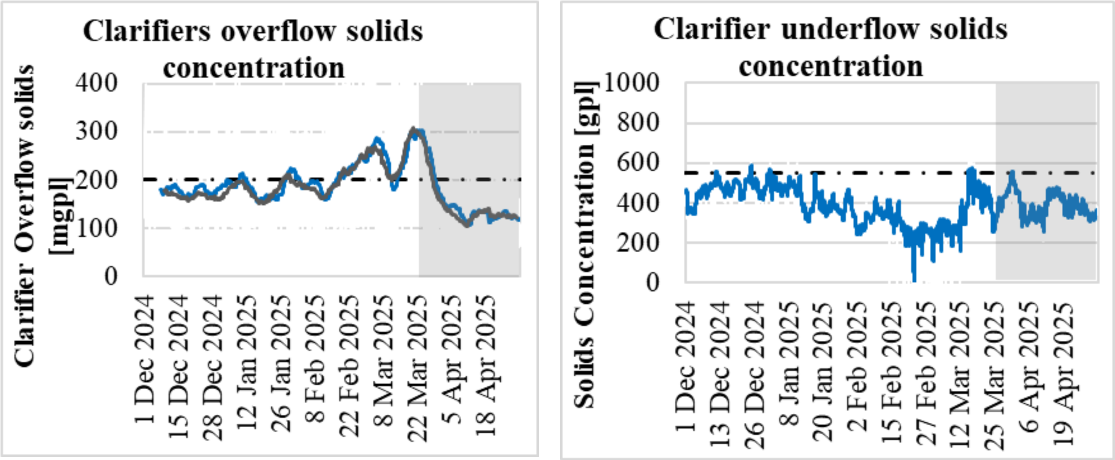


**Figure 17. Left: plant clarifiers overflow solids concentration.
Right: plant clarifiers underflow solids concentration.**

4.1.4 Filtration: Liquor and Mud

Overall laboratory overflow liquor results show better clarity corresponding with higher liquor filtration rates as well as compared to bauxite type A. Plant data shows high liquor filter resistance prior to the change in densifying flocculant point addition.

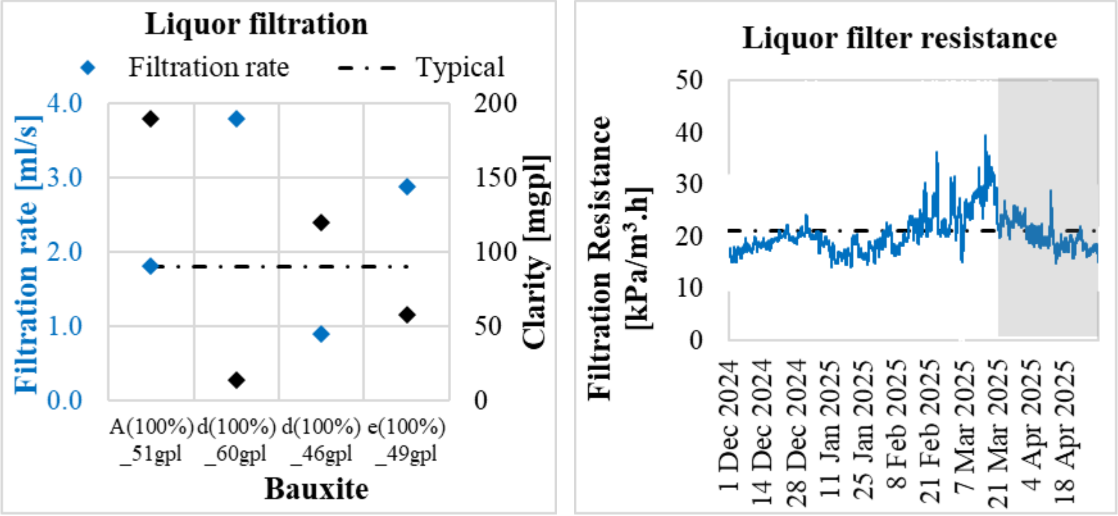


Figure 18. Liquor filtration. Left: lab different feed solids and bauxite types. Right: plant liquor filters performance.

Plant data for the washer underflow solids also show a reduced mud compaction, affecting mud filtration negatively which is consistent to the lab results except for bauxite type e (100 %). Mud filter cake moisture also shows an increase compared to the typical bauxite in the laboratory and plant, however, also with a higher moisture content in the plant.

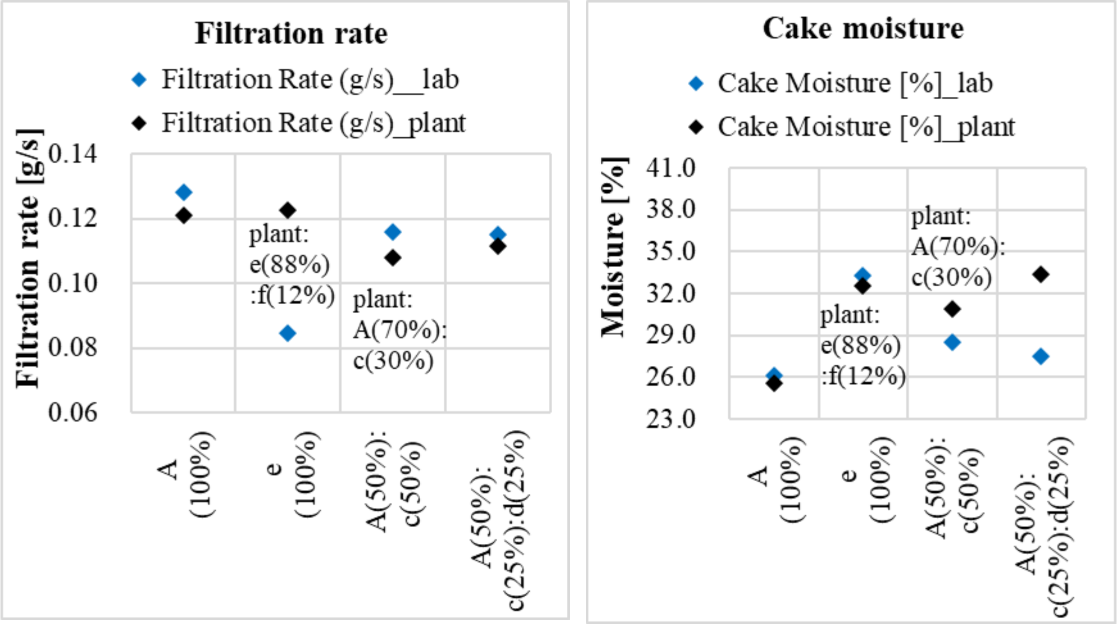


Figure 19. Lab and plant data. Left: mud filtration rate, Right: mud cake moisture.

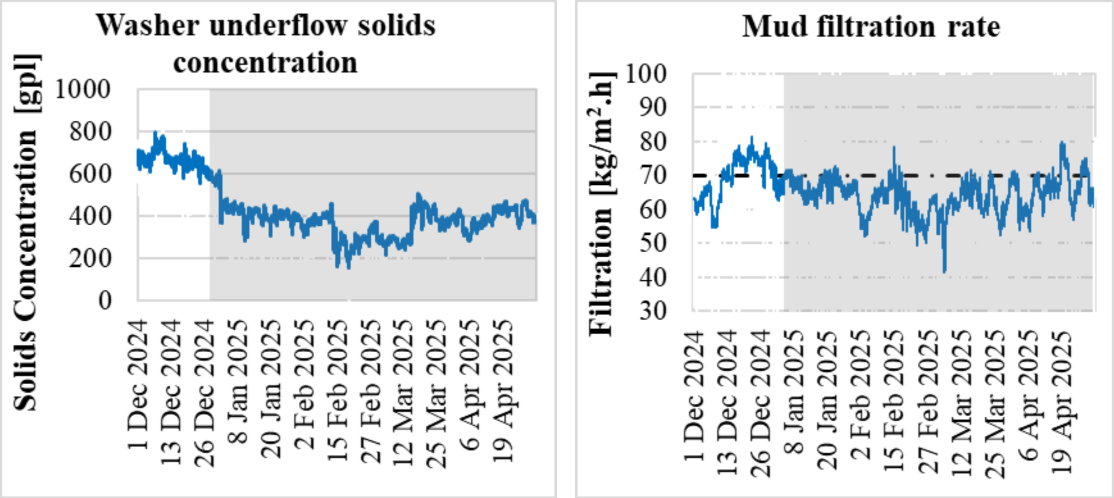


Figure 20. Plant data: Left: washer underflow solids concentration, Right: mud filtration rate.

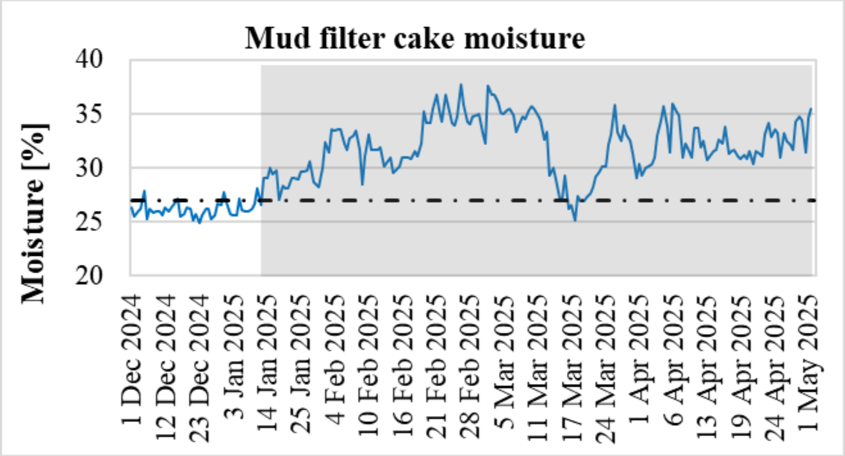


Figure 21. Plant: mud filter cake moisture.

4.2 Plant Capability, Production Planning and Strategic Decisions

The laboratory results give guidance on the potential plant capability and restrictions. Countermeasures were taken for:

Reduced bauxite ship unloading rates due to different moisture content and/ or particle size:
  - Modifications to the unloading system: replacement of liners type in chutes
  - The addition of auxiliary equipment: so-called air cannons
  - Optimizing maintenance and operational strategies: bypassing downstream crushers
  - Unloading at different ports

Bauxite blend ratio control:
  - Bauxite shipment offloading of the different bauxite types in allocated zones
  - Mills fed from the allocated zones as per requirement
  - Mills fed with same blend ratios to minimize feed variability in case of mill breakdowns
  - Additional stockpiles areas and additional heavy and mobile equipment

Typical PDS slurry solids concentration:
  - Operating additional pumps, slurry recirculation across the tanks, tank levels/ agitators' control and dilution control

Mud filtration mitigated by:

- Optimizing filter feed solids and filtration rates: use of chemicals
- Optimizing filter cycle times
- Increasing filtration area and filter availability

These laboratory results are, except for the predicted refinery production rates, synchronised to managing the raw materials inventory. Furthermore, and of more relevance, is that these results support the comparison of the processing costs from the typical processed bauxite against other bauxite types on the evaluation whether procuring bauxites from certain sources is economically feasible. A financial model has been developed to simulate such different cases.

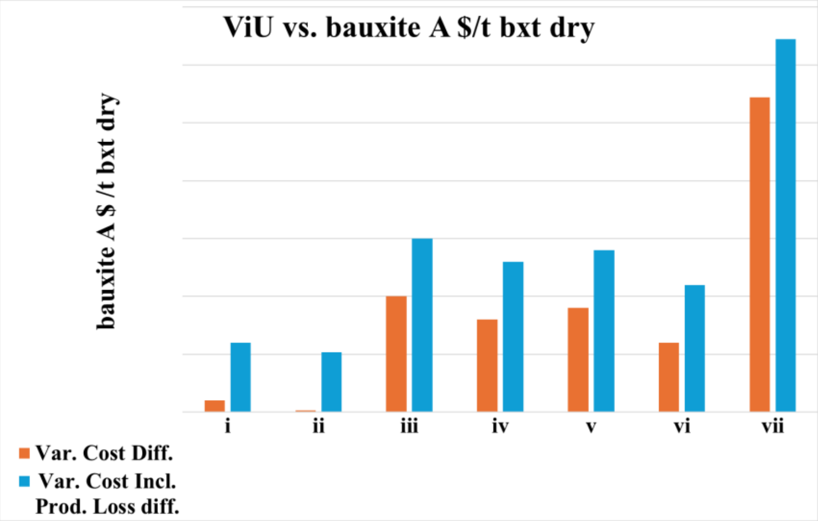


Figure 22. Example of the output from the financial model comparing different bauxite types.

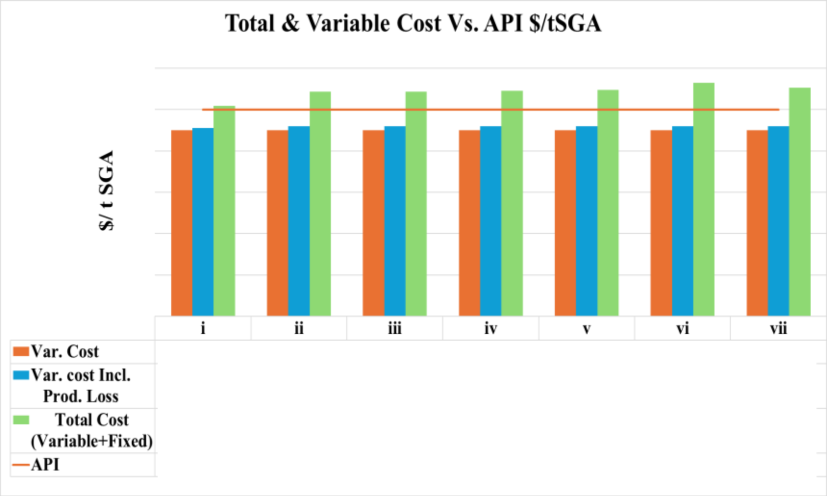


Figure 23. Example of the output from the financial model comparing different bauxite types.

5. Conclusions

Refineries are designed for a specific bauxite type. Hence, deviating from the design bauxite will lead to efficiency losses and may also introduce restrictions in parts of the process e.g. hydraulic, capabilities (higher mud load, mud filtration, organic removal etc.). So far Al Taweelah alumina refinery has been managing well. Each bauxite type comes with individual challenges, in terms of its characteristics, e.g., silica, rheology impact, settling behaviour, filtration rates in liquor and mud filtration, underflows mud compaction, oxalate generation and hence, nucleation control and white side filtration. The process has to be adapted, not only for operations but also for maintenance strategies and tactics, e.g., to accommodate different turnover regimes for tanks and equipment due to different scaling behaviour.

Lab results are relative and might not always show quantitative results even when simulating experiments under the same plant conditions, however, most results were consistent when comparing to plant data with very few inconclusive results.

6. References

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