AA16 - Iron Removal from Bayer Liquor: The Ma'aden Alumina Refinery Experience

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Abstract

High temperature alumina refineries that treat low-iron bauxite (5 to 10 %) can have elevated concentrations of iron-in-liquor. At Ma'aden an iron concentration in the bauxite above 10.6 % is targeted. Mine grade control and stockpile building and blending is carefully monitored to deliver this iron grade. When bauxite iron is exceptionally high (> 13 %) the Iron concentrations in Ma'aden liquor are at a minimum of 5 mg/L and can deliver a product Iron of 0.010%. Lower bauxite iron concentrations more typically deliver high iron-in-liquor concentrations (12 to 18 mg/L). Dissolution of Iron occurs during digestion, this represents an equilibrium concentration established between the iron-bearing minerals in the bauxite and the liquor. The iron is present as colloidal or nano-sized particles rather than being in solution and passes through security filtration. Hematite surface area, lime addition, free caustic concentration, temperature, holding time and mineralogy all influence the liquor iron concentration. Elevated SO_4, CO_3 and F concentrations in Pregnant Green Liquor (PGL) would also appear to favour lower iron liquors. As is evident from plant data lime injection into the digesters at 270 °C can bring down iron-in-liquor by up to 7 mg/L, lime addition is an important process operation for iron control and helps dramatically overcome high iron concentrations. To target a lower iron-in-liquor concentration requires an incremental approach, and for this reason a range of small improvements need to be targeted simultaneously. In the precipitation circuit iron is almost completely removed from the liquor and is coprecipitated with gibbsite as it crystallises and grows. An increased precipitation yield lowers the iron-in-product by a simple mass-dilution effect. Targeting an increased Alumina to Caustic (A/C) ratio can improve the precipitation yield, lower free caustic and help increase and maintain bank solids. Holding time and addition of reagents can help with the growth of colloidal iron particles, an increased colloid size will aid its removal during flocculation and filtration.

Keywords: Ma'aden, hematite, seeding, yield, digestion.

1. Introduction

During aluminium smelting the presence of iron in the melt reduces current efficiency, because compounds can be reduced at the cathode and re-oxidised at the anode. Incorporation of trace amounts of iron into aluminium metal also influences its physical properties. Quality considerations require iron concentrations to be controlled and continuously monitored. Iron concentrations as small as 0.015 % in smelter grade alumina (SGA = product) are sufficient to impact on the Cast House product specifications. There are also a limited number of smelters willing to purchase such product, and for these reasons high-Iron product achieves a marginally lower price on the open market.

Mine grade control and bauxite blending are the most critical areas for delivering a consistent bauxite iron grade especially when Iron grades are on average usually low (9 to 11 %). On digestion of bauxite the iron-in-liquor is found to be inversely proportional to the iron content in the bauxite [1]. This is a generic problem for the alumina industry and for this reason high iron-in-bauxite (> 10.6%) needs to be targeted to deliver a low iron-in-liquor composition (Table 1). There is no simple process solution to reduce Iron-in-liquor other than using the sweetening process but this is cost prohibitive. The other more realistic option for the reduction in iron is through an incremental mine and refinery improvement approach.

Table 1. Bauxite iron concentration and its effect on soluble iron, and product iron.

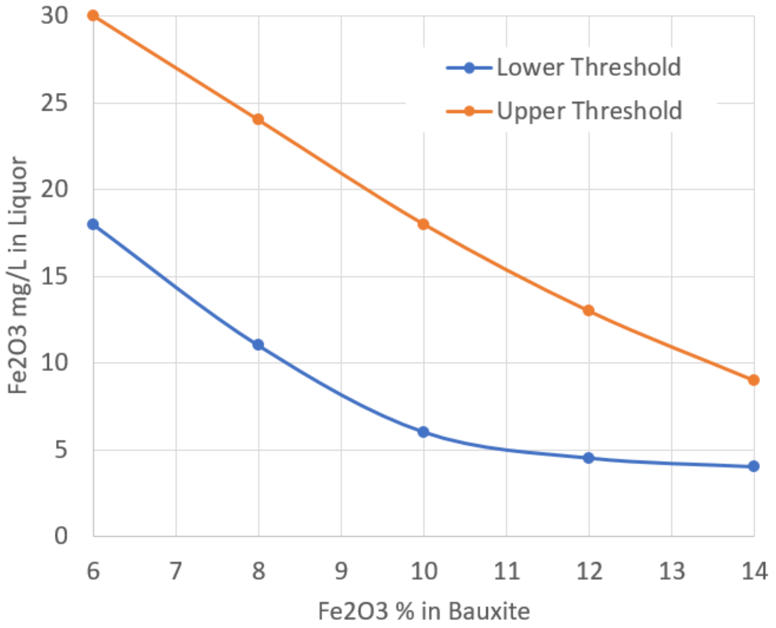
Bauxite Fe_2O_3 (%)	*Liquor Fe_2O_3 (mg/L)	*Product Fe_2O_3 (%)
> 10.6**	6 to 17	0.010 to 0.022
< 10.6	17 to 26	0.022 to 0.030

*Also partially dependent on precipitation yield.

An iron equilibrium concentration will be established between the iron minerals in the bauxite and the hot caustic Bayer liquor. The actual concentration is dependent on Iron mineralogy and iron content, mineral surface area, FC (Free Caustic), precipitation yield, temperature of digestion and the holding time (Table 1 and Figure 1). These factors have been identified from operational data and from experimental work on bauxites containing variable iron concentrations [1, 2]. It is the hematite surface area that is the most important factor for the removal of iron from liquor. A high surface area of hematite is capable of seeding iron from liquor with the precipitation and removal of the colloidal iron (Table 2).

Between 95 to 100 % of the soluble iron entering the precipitation tanks is removed during gibbsite precipitation. This fact allows a set of simple graphs to be drawn. As indicated in Figure 2, the product Fe_2O_3 can be calculated if the liquor iron concentration and precipitation yield are known. The target product quality region is the shaded area for achievable precipitation yields of between 80 to 90 g/L. Elements which also behave in an identical way to Iron-in-liquor include: Ca, Ti, Zn, Cu, Zr, Mn, Mg, Be, Nb, REEs [3]. These are found in significantly lower concentrations in liquor and are also coprecipitated with gibbsite.

After operating the Ma’aden refinery for over 4 years, the relationship between iron-in-bauxite and its impact on liquor and product is now well established. A maximum acceptable iron-in-product is targeted at 0.015 %. Total iron-in-bauxite needs to be above 10.6 % to maintain an iron-in-liquor concentration of below 17 mg/L. However, even when lime injection into liquor at 270 °C is practiced it has been observed that elevated iron concentrations can still occur. The lime addition into digestion must be ~ 25 Kg per tonne of bauxite, otherwise high iron concentrations will result (> 20 mg/L). Only after prolonged periods (3 to 4 days) of using low-iron bauxite stockpiles does it starts to make a clear impact on product quality.



Data acquired during addition of ~ 2.5 % lime into digestion at 270 °C
and variable CaO in bauxite

Figure 1. Liquor iron concentration as a function of bauxite iron concentration at Ma'aden.

Estimates from Ma'aden plant data suggest the equilibrium iron concentration in liquor is on average ~ 12 mg/L at 270 °C (FC after digestion ~ 70 g/L, bauxite Fe_2O_3 ~ 11 %) - see Figure 2. This delivers a product composition of around 0.015% iron. When bauxites are low in iron, or when lime injection is turned off, the Iron-in-liquor rapidly responds with a rise to 25mg/L or more. This can result in a product iron concentration above 0.025 %. To date an increased goethite content in the bauxite has not been shown to have a major impact on the iron in liquor concentration. Anomalies have usually been related to total iron concentration in the bauxite.

The iron in solution is colloidal in size and capable of passing through a 0.45-µm filter, this suggests that the iron particles are so small they are essentially in "solution". For the iron-in-liquor the role in any complexation with other impurities in the liquor is uncertain. Complexing with SO_4 or with organics is a possibility, however at Ma'aden the sulphate and organics concentrations are usually low (Na_2SO_4 < 3 g/L, TOC < 3.5 g/L). Historical data shows that at elevated sulphate and carbonate concentration in PGL would appear to favour lower iron concentrations in liquor even when iron concentrations in bauxite are marginal.

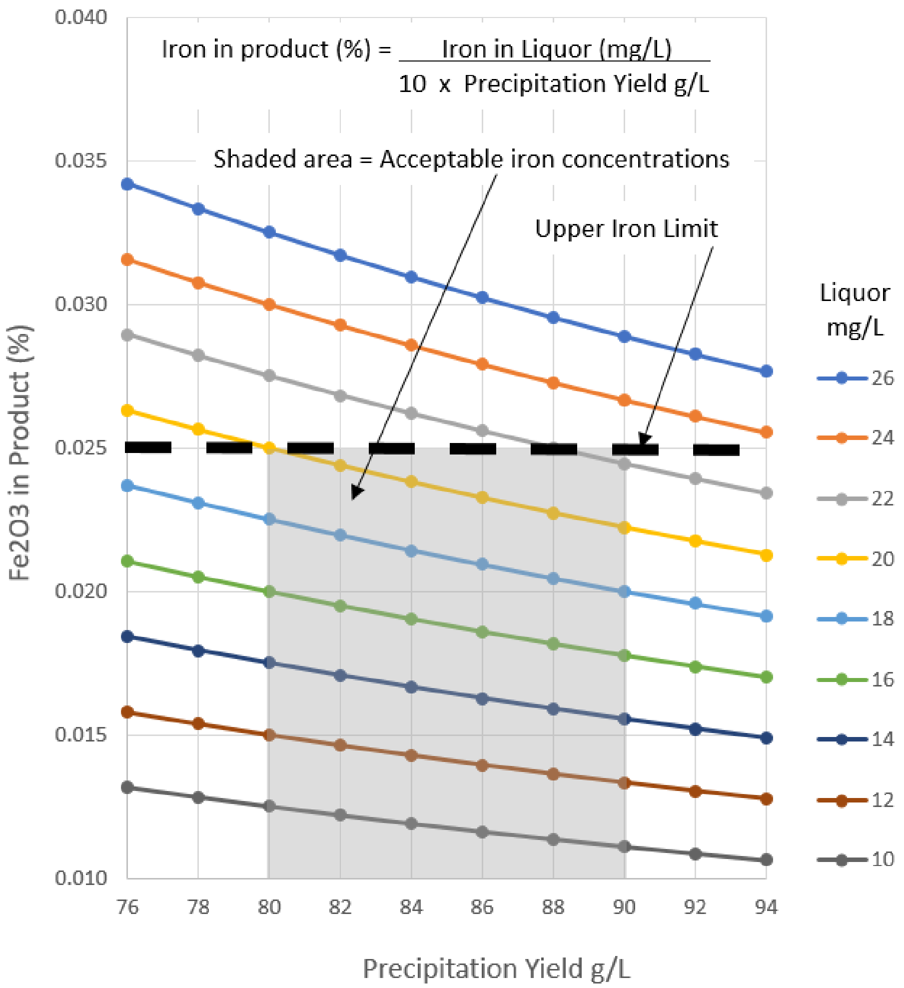
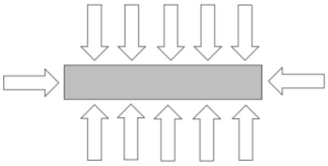
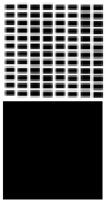
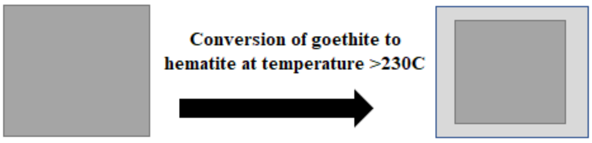
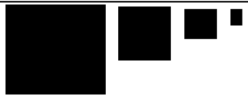


Figure 2. Calculating the theoretical product iron from liquor composition.

Table 2. Factors that affect soluble iron removal from Bayer liquor.

Iron Removal Factors	Comments / Possible Mechanism / Impacts (during high temperature digestion)
Seeding onto He surfaces.	 Individual He particles act to seed and precipitate + remove the Fe colloids from liquor. Some iron oxides present in bauxite as ultra-fine grains.
Higher %He = Higher He SA = Higher extraction of Fe from liquor	 Dramatic difference in SA for ultrafine and coarse He particles. Porous He grains will have a significantly higher surface area. Hematite remains unaltered through process. The finer the He the better for increased surface area.
Go conversion to He. (also with partial Fe release into liquor)	He reaction rim formed on surface of Go  Presence of unconverted Go can lower the effective surface area of He available for seeding and iron removal capacity.
Colloid particle size	 Decreasing size of colloidal particles → progressively more difficult to remove by flocculation and filtration.
Increased Digestion Temperatures	Promotes increased equilibrium Fe concentrations in liquor. Promotes Go to He conversion. Promotes increased reaction kinetics. Promotes seeding rate onto He surface area. Promotes growth of He colloids in liquor. Promotes increased crystallinity of all reaction products, including goethite.
Total Fe_2O_3 in sample	Possible non-conversion of Go at elevated temperatures and lower He surface area. Insufficient Fe in sample may not allow Fe removal from liquor. Ma'aden required at least 10 to 11 % Fe_2O_3 in the bauxite to get below 18 mg/L in liquor.
Lime injection (at 270°C)	$3CaO + Al_2O_3 + 2SiO_2 + 2H_2O + Fe_2O_3$ (soluble components in Liquor) → $3CaO.(Fe_2O_3)_x(Al_2O_3)_{1-x}\ 2SiO_2.2H_2O$ (hydrogarnet) Katoite incorporating Fe_2O_3 into structure on formation. Plant tests suggest Fe_2O_3 removal from liquor is almost instantaneous and reduce Fe_2O_3 concentrations. An Increased lime addition will increase Hydrogarnet formation and remove increased iron concentrations from liquor. Reduction of < 5 to 10 mg/L will require only small quantities of Hydrogarnet formation which incorporates soluble Si Fe Al and Ca.
Free Caustic (FC)	Iron concentration dependent on Free Caustic after Gibbsite + Boehmite dissolution. Presence of high SO_4 and CO_3 concentrations in liquor favour low iron in liquor, even when iron concentrations in bauxite are marginal.

He – hematite, Go – goethite, SA – Surface Area

2. Analysis of Slurries and Liquors

On cooling (< 85 °C) of a saturated Bayer slurry or liquor (0.65 to 0.75 A/C) gibbsite can partially precipitate and simultaneously coprecipitates part of the iron from the liquor. Auto precipitation occurs more readily in slurries which contain active solids rather than liquors that are solids-free. Solids in the liquor or slurry act as nuclei and promote gibbsite precipitation, and for this reason Blow-Off (BO) slurries (containing > 80 g/L solids) are often consistently lower in iron than PGL (Pregnant Green Liquor). At Ma'aden the PGL that passes through Diastar filtration maintains an elevated temperature, is essentially solids free and is considered to have a more representative liquor iron content.

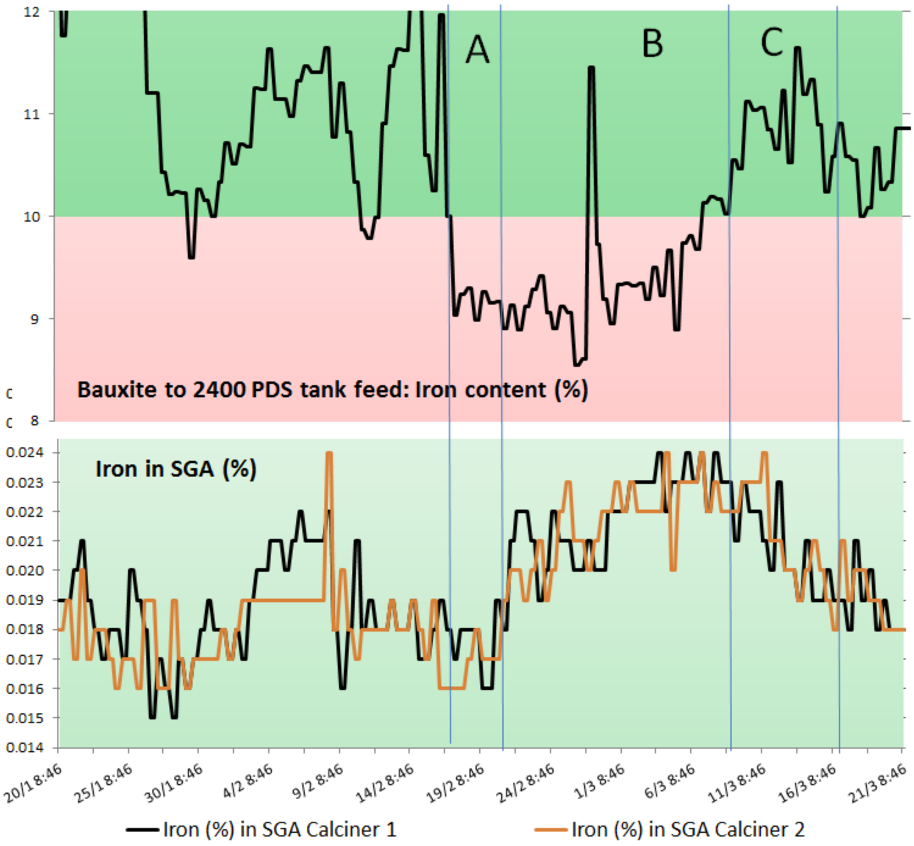
Following the sampling of a liquor or slurry stream the samples are always subjected to some degree of cooling, and partial loss of Fe will inevitably occur as cooling is the driving force for gibbsite crystallization. The true analysis is usually higher than that analysed, the actual concentration is likely to be at least 1 - 2 mg/L higher and will depend on the cooling history, handling and solid content of the sample. Immediately after sampling of a slurry or liquor, it is recommended to keep the liquor hot (> 90 °C), and the filtered sample for ICP analysis should be diluted immediately.

During laboratory digestions at temperatures above 200 °C dissolved iron can originate from the metal bomb itself and illustrates the impact that high FC liquors can have on metal (caustic embrittlement). Contact of plant liquor with metallic scats from the breakdown of mill balls, and on pumps, piping and tanks can all help raise the soluble iron concentration in high FC environments (mainly in evaporation, caustic cleaning and areas exposed to spent liquor). When conducting laboratory experiments it is advisable to carry out control experiments to quantify the release of iron into liquor following the reaction of FC with the metal surfaces inside the bomb or autoclave.

The iron concentrations in plant and laboratory experimental data are usually small (5 to 20 mg/L). Identifying real changes in the analytical data sets can often be inconclusive owing to the unstable nature of slurries and liquors. The analysis and quantification of iron in unstable liquors does cause problems as these can easily have a significant sampling/preparation error. However, this disadvantage could possibly be turned into an advantage for iron removal purposes. The fact that cooling of liquor leads to the coprecipitation of iron suggest that holding the liquor or slurry at a marginally lower temperature (85 to 95 °C) could promote partial crystallization and help iron removal. Inducing a small amount of auto-precipitation to help precipitate gibbsite and the partial removal of iron from liquor has been shown to be a possible process option and is likely to be highly temperature dependent.

3. Chemical Trends in Plant Data

To understand the impact of bauxite quality changes or the short-term impact of lime addition on product iron the daily plant operation must be fully understood as there are many activities going on in the refinery during any single day. The exact timing of the sample collection (e.g. bauxite, PGL, SGA) must be accurately known. For example, a snap-shot study taking samples at a certain time, on a certain day would be a waste of time. It takes around 20 hrs for the bauxite slurry to travel from the mill feed to predesilication discharge, then a further 10 hrs to pass through to the security filtration. The liquor volume in precipitation also requires ~3 days to be totally flushed out and replaced by a fresh batch of liquor. A change in bauxite quality will therefore take around 2 days to have a definite impact on liquor quality and then a further 3 days to have a clear impact on product iron. Figure 3 illustrates the time lag that bauxite iron concentration can have on PGL and product samples.



A = Lag period ~3 or 4 days – bauxite Fe has little impact on product, product does not respond
B = Persistent low bauxite Fe – eventually leads to increasing Fe-in-product
C = Improved bauxite quality, Fe-in-bauxite increase - Fe reduction in product and plant re-equilibrates.

Figure 3. Spatial relationship between low Fe bauxite feed and its eventual impact on product.

4. Bauxite Grade Control and Blending

At the mine 4 to 5 pits are operated simultaneously to control the average iron concentration of bauxite sent to the refinery. A considerable amount of effort is made by mine and stockpile personnel to deliver a constant blended grade. High iron blocks that have been left behind during mining can be used to supplement the iron concentration when the iron-in-bauxite is low. Mine estimations of grade are available and are based on borehole core analyses of the bauxite layer. These estimates are used for helping identify the bauxite stacking sequence (either onto the East or West stockpile). Delivering bauxite with consistent grade and quality (Al_2O_3, SiO_2, Fe_2O_3, Mineralogy, hardness, particle size, impurity content) is difficult if there is a large in pit variability. While all attempts are made to deliver bauxite to a specific alumina grade the Fe_2O_3 content gets lesser attention. This is unfortunate as the Fe_2O_3 and SiO_2 concentration can vary (± 2 mass %) even when the mine has attempted to smooth out such grade variations.

Within the Ma'aden bauxite hematite predominates (70 to 50 %) over goethite (30 to 50 %). At temperatures higher than 200 to 230 °C goethite transforms to hematite and is mediated by CaO [4], the crystallinity of the goethite also increases. In the bauxite supply the goethite content can suddenly increase, possibly through poor bauxite blending. Yet, it has not been shown to severely impact on product quality. It is suggested that ultrafine goethite may actually transform into ultrafine hematite and create a high hematite surface area for iron removal. Low total iron-in-bauxite and problems with lime injection can often amplify the iron-in-liquor concentrations.

5. Lime Injection

At Ma'aden there are 2 digestion circuits (Units 1 and 2). An Individual Unit is made up of a Jacketed Pipe Unit (tube-in-tube heating - 100 to 200 °C) and 3 x Vertical Digestion Units (heating with live steam - 200 to 270 °C) (2 operational and 1 spare). The Blow-Off streams from Units 1 and 2 are individually sampled to monitor soluble iron and this allows differences between the two units to be identified.

The Injection of lime slurry (250 g/L) into bauxite digestion at 270 °C can reduce the equilibrium iron concentration from ~ 20 to ~ 13 mg/L (Figure 4). This ability to control iron is very clear from available operational and experimental data. Plant data also shows an immediate increase in iron concentrations when the lime pumps are turned off. Returning the lime supply (35 m^3/h) then lowers the iron-in-liquor to below ~ 13 mg/L. This illustrates conclusively the efficacy of lime's ability to reduce iron-in-liquor.

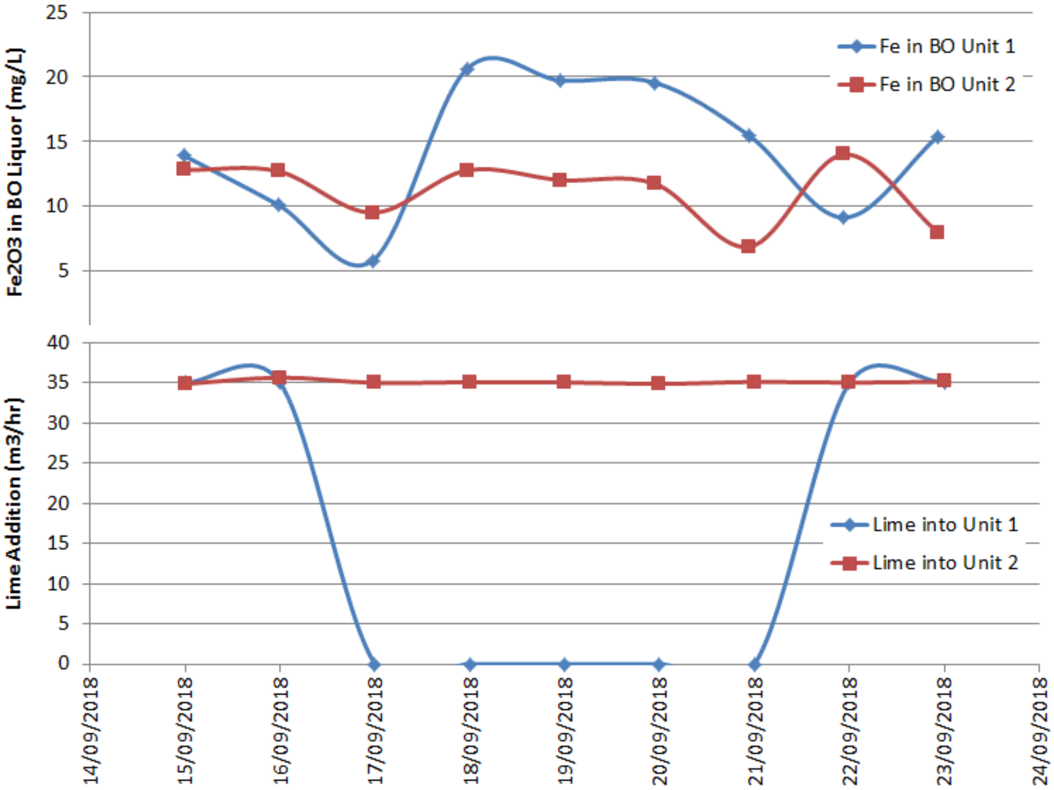


Figure 4. Impact of lime on liquor iron concentration for Digestion Units 1 and 2.

The competing mineralogical reactions that occur following the injection of lime into liquor include: 1/ TCA/katoite formation, 2/ cancrinite formation, and 3/ hydrogarnet formation. Injection of lime into bauxite slurry at 270 °C immediately forms a TCA/katoite-type compound. Increased Ca ions in liquor would appear to combine with dissolved Fe + dissolved Al + dissolved Si to form the IHG-type (iron hydro garnet) compound. The formation of only small quantities of IHG are required to lower the iron-in-liquor concentration from 20 down to 12 mg/L (Figure 2). The actual mechanism of formation of the IHG is uncertain but the compound is likely to contain only low silica concentrations [5, 6]. If the compound did contain higher concentrations the compound may have originated from cancrinite or sodalite. It is suggested that the IHG compounds formed by lime injection at elevated temperatures are different to those formed by simply adding lime to the mill feed or to predesilication and explains why lime injection is successful for iron control. Test work (U1 vs U2) to compare different lime qualities, digestion temperatures or holding times (e.g. 2 digesters vs 3 digesters) have not been able to show conclusive differences when comparing mg/L data from the two Units. Small differences in liquor compositions (± 2 mg/L) are often within sampling and analytical range.

6. Liquor Quality

The main liquor parameter that can be changed to influence iron-in-liquor is the A/C ratio, this can impact indirectly on FC and precipitation yield. FC in this instance is the amount of uncombined caustic remaining in the liquor after digestion of gibbsite and boehmite, Iron increases linearly with increased FC concentration. The desire to minimize FC and reduce iron concentrations explains why the sweetening process can guarantee iron removal.

7. Reagent Addition Opportunities

Any reagents added to settler O/F to reduce iron concentrations in liquor need to either 1/ help grow the colloidal particles or, 2/ chemically combine with the iron colloids or 3/ act as a super flocculant and settle out the ultrafine colloidal particles. Adding a ferrous compound to grow the iron colloid particles in the liquor is an interesting approach which could allow the coarser iron colloids to be recovered through existing flocculation and security filtration [10]. The effectiveness of these steps will be dependent on the size of the colloids in the liquor, but has not shown to be viable.

Test work using a reagent developed by Ma'aden and using a pretreatment using conventional flocculants has consistently led to a reduction of iron of less than 1 mg/L (<8 % of the total soluble Fe_2O_3). In the creation of a suitable filter bed the addition of gibbsite, or increased g/L of TCA can help improve filtration and remove some of the finer iron colloids. Induced gibbsite precipitation in the filter bed can also help extract a small percentage of the colloidal iron. Laboratory tests by adding gibbsite to the filter bed usually removed a maximum of 5 to 8% of the soluble iron component.

The addition of a high surface area hematite by Fulford [8, 9] has shown some promise but has not been adopted by the Alumina Industry for iron control. It is also difficult to visualize iron oxide being used as a filter aid as any filter material short-circuiting the Kelly or Diastar filters would be deleterious and easily contaminate the liquor stream. Suggestions for a 2-stage filtration process on PGL would also be cost prohibitive.

Particulate solids in the settler O/F stream should be at a minimum to reduce any particulates accumulating on the security filter cloth. Any solids passing through the filter with the PGL stream would otherwise contaminate the precipitated gibbsite. The chemical characteristics of the SGA will indicate the type of solids that have migrated through the filters.

e.g. TCA → high Ca, DSP → high Na + Si, Goethite → high Fe.

8. Magnetic Particle Removal

Magnets placed on the outside of launders can incrementally remove any metallic particles that may have originated from the wear of pumps, pipes, valves and tanks. Also, the magnets can act as security removal of any other metallic object that may have entered the liquor stream within the precipitation circuit. Similarly, in the calcination area, metallic particles can be removed from product at minimal cost. Other iron containing particulates are most likely to be iron oxyhydroxides from metal oxidation but are non-magnetic.

9. Iron-Rich Mud Recycling

Recycling refinery mud enriched in hematite appears to be an attractive proposition to enrich the Fe_2O_3 in low-iron bauxites. However, the muds at Ma'aden are only 20 to 25 % Fe_2O_3. To achieve an Fe_2O_3 enrichment of 2 % would require the addition of ~ 15 dry mass % (see Figure 5). The inert material would also have the effect of diluting the alumina grade (~ 7 mass %). Also, while the iron content of mud can be upgraded the impact on iron-in-liquor may not reach the predicted removal owing to possible deactivation of hematite surfaces. Convincing experimental data showing that mud addition makes a significant benefit have not been published. As an alternative suggestion the addition of iron in the form of an iron ore could deliver an improved iron content to the bauxite with minimal dilution. The finely milled iron ore (~ 65 % Fe_2O_3) should be hematite-rich or a thermally treated goethitic ore which retains its high micro-porosity [9].

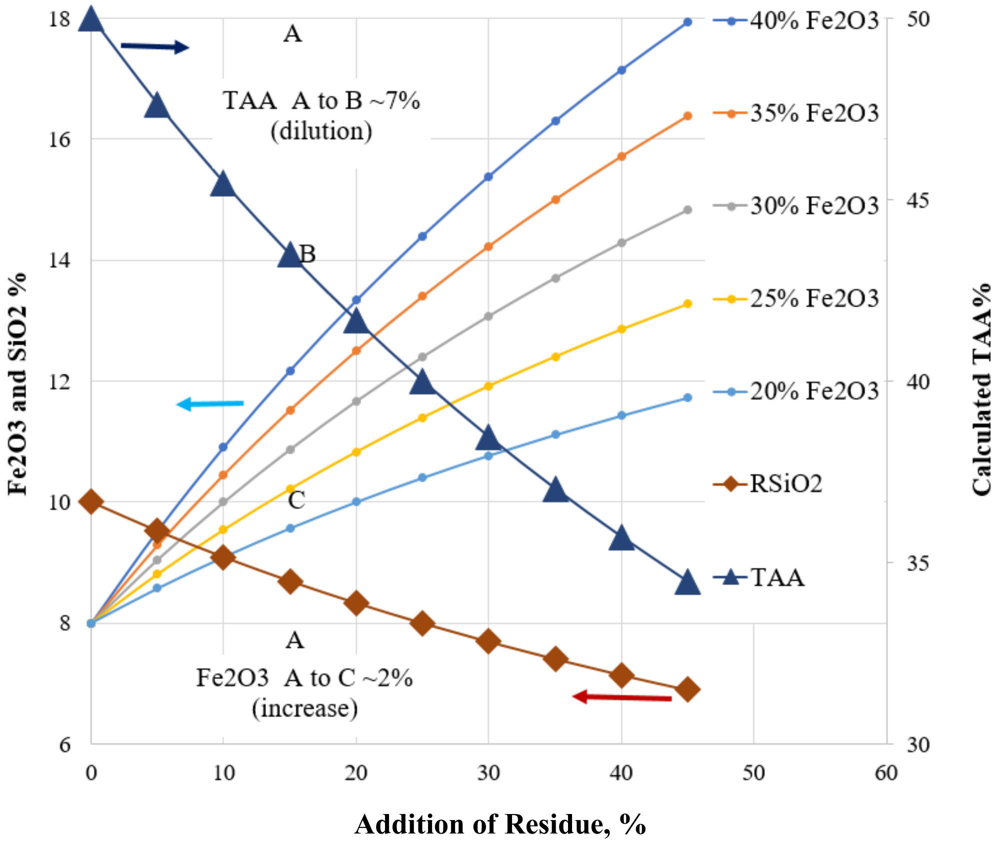


Figure 5. Model to illustrate impact of residue addition on bauxite quality.

10. Process Targets

The potential controlling factors for soluble Fe removal are reviewed in Table 3 and estimates are made on the potential contribution made by each factor. This table allows iron-reduction possibilities to be identified and helps target the most cost-effective options to be targeted and prioritised (Figure 6). All potential iron reduction opportunities should be pursued no matter how small the contribution. An iron control bridge (Figure 7) illustrates the Current and Target condition and helps communicate and simplify the major control levers that can influence iron-in-liquor concentrations (Table 3). Grade control and lime addition are considered to be the most important control parameters.

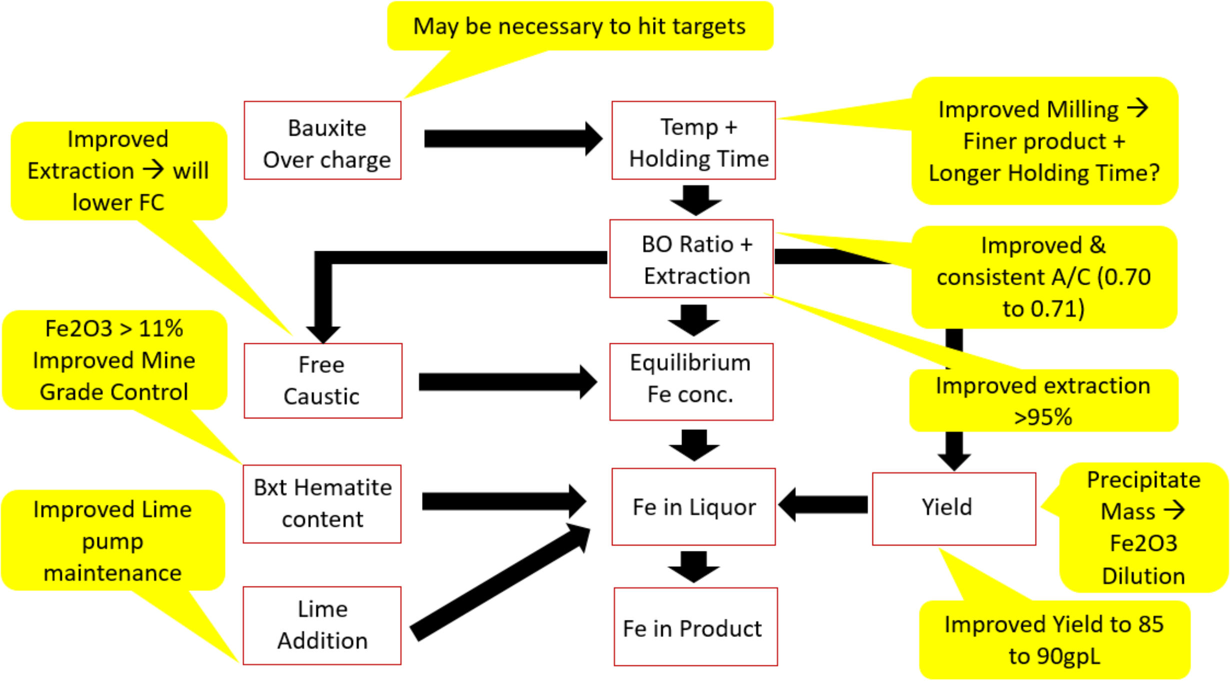


Figure 6. Incremental iron improvement target areas to help improve liquor quality.

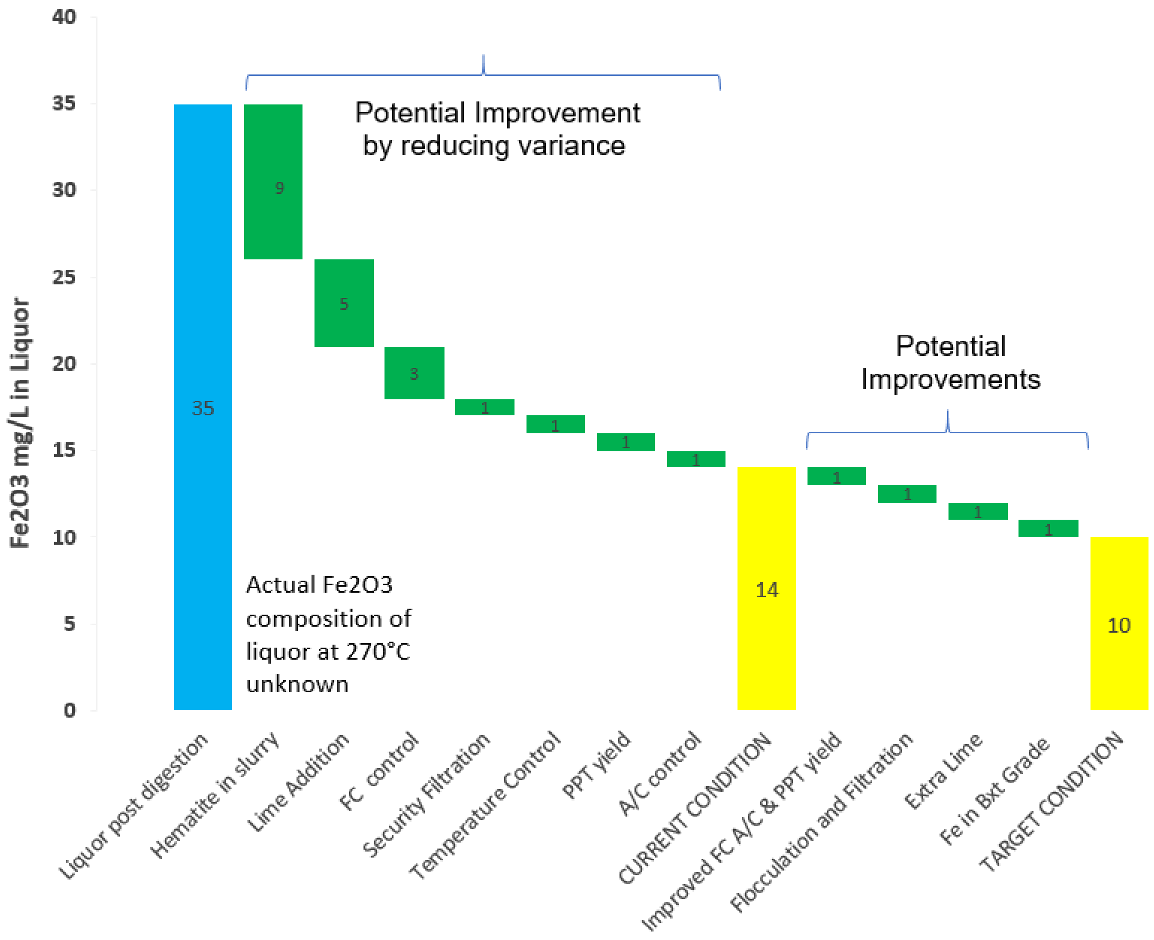


Figure 7. Iron control waterfall chart for the current and target condition at Ma'aden.

Table 3. Process targets for iron reduction in liquor.

Improvement Focus Area	Potential Impact on liquor Fe_2O_3 (mg/L)	Comments / Derivation
Bauxite Iron Grade Control	1.5 mg/L for every 1 % Fe_2O_3	Estimates when predominantly hematite.
Lime Injection at 270 °C	1 to 2 mg/L for every 10 kg Lime /T	Maintenance of Verti-mills other handling and pumping equipment. Ma'aden plant estimate.
Security Filtration PGL particulate solids reduction	1 mg/L (~ 10 % of the soluble iron) Ultra-fine solids reduction in PGL	Solid contaminants will always contain some iron. Could remove 50 % of the mg/L solids. Also remove minor amounts of colloidal iron. Nominal estimate only.
Increased A/C (= FC Control)	1 to 2 mg/L for every 10 g/L FC	Reduced Free caustic through more complete reaction with boehmite leading to Increased ratio and Precipitation Yield (based on laboratory test work and sweetening data). Achieved through increased digestion temperatures.
Increased A/C (=Precipitation Yield)	1 mg/L (equivalent) for 5 g/L Precipitation Yield increase	Precipitation yield impact, theoretical calculation (see Figure 2) when a starting TC is maintained.
Increase PPT Yield by increased bank solids	1 mg/L (equivalent) for 5 g/L Precipitation Yield increase	Precipitation Yield Impact, theoretical calculation (see Figure 2).
Increase PPT Yield by reduced impurities (g/L)	1 mg/L (equivalent) for 5 g/L Precipitation Yield increase	Precipitation Yield Impact, theoretical calculation (see Figure 2). Surprisingly high concentrations of impurities are required to be removed to elevate PPT yield by even 1g/L.
Holding time at temperature	1 mg/L for every 10°C increase	promote seeding onto hematite surface at elevated temperature using 3rd unused stand by digester (nominal estimate only)
Holding Time of Settler O/F slurry	1 to 2 mg/L for every 1 hr holding time at 90°C	Promote colloid particle growth. Nominal estimate only.
Improved Flocculation	Lab testwork 1 to 2 mg/L best case	Remove colloidal iron. Not additional to security filtration value.

11. Conclusions

Since commissioning of the Ma'aden Refinery in 2015 the Iron-in-product variance (SD) has been progressively reduced through improvements in: Precipitation yield, lime optimization and careful iron grade control and bauxite blending. Reducing bauxite grade variability and maintaining a consistent bauxite iron concentration in the refinery feed was an important step in controlling the iron-in-product. Iron concentration in bauxite should ideally target an SD of 1 to 2 mass %. This variability should be defined in the bauxite contract between mine, refinery and stockpile operations. A coordinated effort by several operational areas on the refinery contributed further to liquor quality improvements (yield, bank solids, settling, filtration, final FC minimisation).

Ma'aden Plant data shows that lime injection is critical for soluble iron removal. Planned maintenance of all equipment relating to lime injection is an important requirement to prevent any downtime and to help deliver a consistent lime slurry flow to digestion with minimal variability.

The iron-in-liquor composition needs to be reduced where ever possible and requires a multi-step incremental approach rather than the hope of finding a single step solution. Achieving a 10 to 20 % reduction in the liquor iron concentration should be considered a success. In laboratory test work a 5 to 8 % reduction in the iron concentration appears to be possible through improved settling and filtration. The reductions may simply be through removal of the coarser sized colloidal iron particles from the liquor stream.

As Data Scientist W. Edwards Deming has suggested for quality control "Understanding the variation is the key to success in improving the quality". From plant experience at Ma'aden a 14-step plan of action could be followed, for the delivery of an iron reduction improvement. The list details the involvement of personnel from several individual unit operations, all of which can contribute to the overall iron reduction. Success is seen where there is a clear and consistent reduction in product iron over a prolonged period. Suggested steps include:

1. Road map development + communication with mine and refinery personnel,
2. Mine grade control improvements,
3. Stockpile / blending – Target a constant bauxite Iron grade and reduce daily iron variance,
4. Lime addition - Target improved lime pumping, maintenance and operation,
5. Maximise addition of lime to digestion,
6. Ensure that purity and particle size of lime is maintained,
7. Flocculation - Improve particulate settling with improved reagent usage,
8. Minimize settler O/F solids,
9. Security filtration - Improve operation to minimize and remove particulates,
10. Precipitation yield improvements through increased bank solids and reduced impurities,
11. Reduce variance and maximise precipitation yield through increased A/C ratio targets,
12. Reduce FC in post digestion liquor through improved digestion extraction,
13. Magnetic particle removal – install permanent magnets on launders to remove metallic particles,
14. Ensure acid wash liquors from descaling of JPU's are efficiently discarded.

12. References

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