

Relationship Between Liquor Yield, Plant Capacity Increases, and Energy Savings in Alumina Refining

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The mechanisms of alumina trihydrate precipitation and controlling parameters, and the methods and technologies affecting liquor yield/productivity in alumina refining, have been described in several publications [e.g., Refs. Alamdari et al. (*Light Metals 1998*, pp. 133–137, 1998), Moretto and Power (*Proc. 1990 Alumina Quality Workshop*, Perth, Australia, pp. 154–165, 1990)]. However, the relationship between increasing liquor yield, on the one hand, and plant production capacity increases and related energy savings, on the other, has been under-emphasized. This article addresses this issue and provides estimates of plant production capacity increases and steam and power energy savings as a function of precipitation yield increases resulting from the implementation of plant adaptations. Conclusions are that increasing precipitation yield in an alumina refinery results overall in a significant improvement of project economics and interestingly improves a refinery's direct and indirect environmental performance, thus, addressing two of the three “pillars” of sustainable development (economic, environmental, and social).

LIQUOR YIELD/PRODUCTIVITY AND HEAT RECOVERY IN ALUMINA REFINING

Alumina hydrate precipitation (crystallization) from caustic soda liquor is one of the main process unit operations of an alumina refinery. Its mechanisms, controlling parameters, and the methods and technologies affecting this area have been the subject of many publications (e.g., Refs. ¹ and ²). The relationship between enhancing liquor yield, plant production capacity increases, and related energy savings, however, has been neglected. The following discussion explores this aspect in more detail.

Figure 1 shows a schematic of the alumina refining process. Caustic soda (NaOH) liquor is used on one end of the process (digestion) to dissolve alumina from bauxite at a relatively high temperature—typically 145°C to 150°C for so-called low-temperature (LT) digestion alumina refineries processing Gibbsite bauxite, and 240°C to 250°C for high-temperature (HT) plants using Boehmitic bauxite. The dissolved alumina is crystallized from the solution at a relatively low temperature on the other end (precipitation). The solution is recycled to

the front end. Process areas forming part of this loop are often referred to as belonging to the Bayer loop.

In other words, the higher the productivity/yield of the liquor that is being pumped around, the more cost effective the use of installed equipment. An important design objective of an alumina refinery is therefore to maximize liquor yield (defined as kg alumina produced per cubic meter of circulated liquor). The main advantages are as follows:

- Plant production capacity increases with more or less the same equipment (at least within a certain production range); i.e., the capital cost per annual ton production capacity drops for several process areas (e.g., digestion, decantation, precipitation, and steam and power station).
- Lower consumption per tonne Alumina (tA) of energy required for steam and power generation (e.g., digestion steam and overall pumping power); labor; maintenance materials; and overheads and other fixed costs.
- Alumina product quality control. Although not straightforward, some aspects of product quality control improve when the conditions for yield increase improve (e.g., increasing the alumina

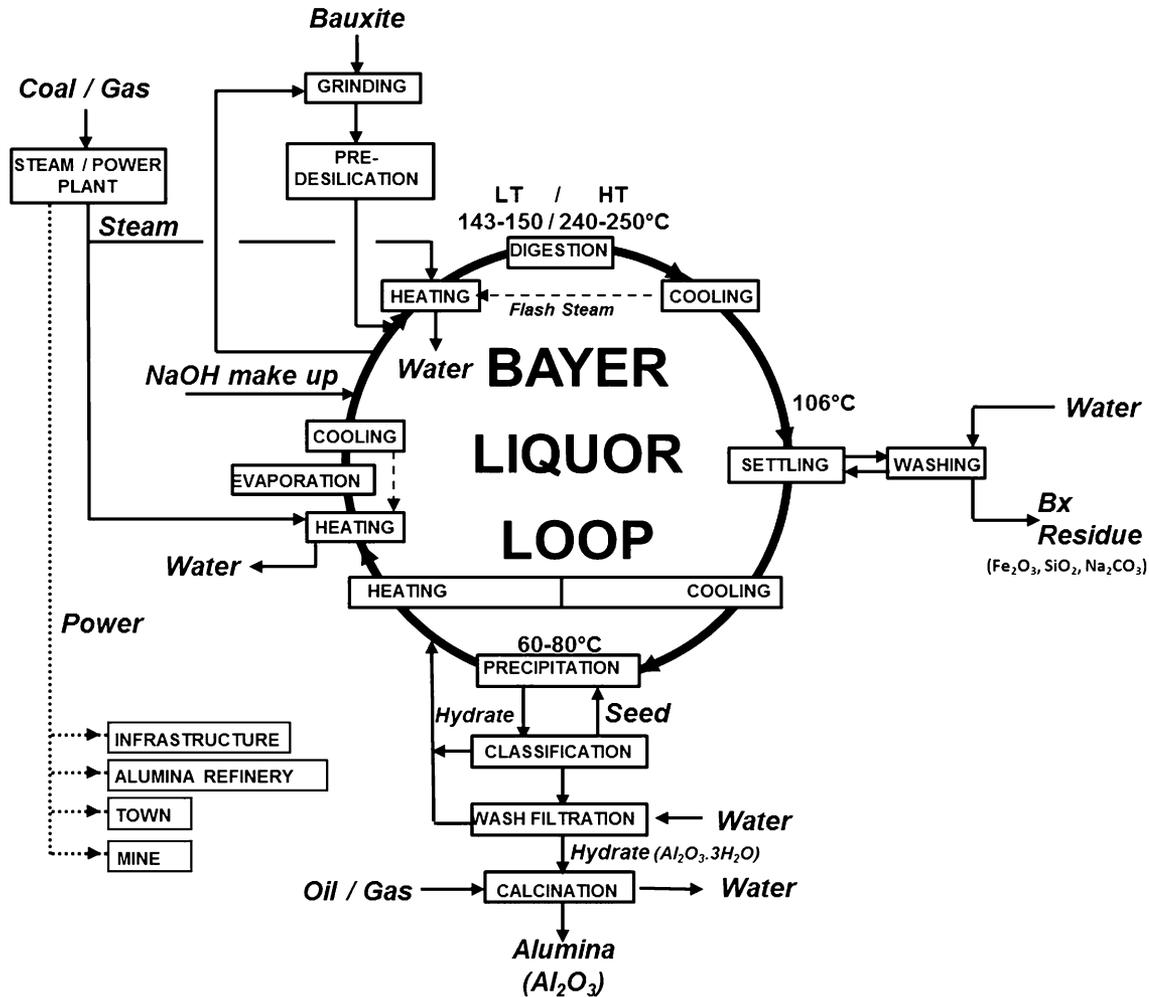


Fig. 1. Alumina refinery process schematic (Sources: this study and Ref. 3).

super-saturation of the mixture of green liquor and spent liquor recycled with the seed charge feeding precipitation).

The focus for maximizing liquor productivity in an alumina refinery is on precipitation yield because the reaction kinetics of the precipitation process (alumina trihydrate crystallization) are more difficult to control and enhance than those of the digestion process (dissolution of alumina from bauxite).

Figure 1 also illustrates that heat recovery occurs extensively throughout an alumina refinery by recovering heat from streams requiring cooling to streams that require heating. Examples are heat exchanger-flash vessel combinations in digestion and evaporation, and the heat exchanged between “pregnant” liquor to precipitation and “spent” liquor ex precipitation returning to digestion. Another example is if wash water for the bauxite residue wash circuit is first used for cooling purposes in a barometric condenser, for instance, in the evapora-

tion area, thus, recovering heat and optimizing energy consumption.

YIELD INCREASE OPTIONS

Several options exist to increase precipitation yield through plant adaptations, with proven technology and by introducing proposed new technologies as described for instance in a 2007 publication by Den Hond, Hiralal, and Rijkeboer.⁴ Although most options in this publication are applicable to both LT and HT plants, one option (“Sweetening Digestion”) is applicable only to HT plants. In addition, the typical current precipitation yield for LT plants is $\sim 65\text{--}75\text{ kg/m}^3$, and for HT plants $\sim 65\text{ kg/m}^3$, while benchmark yield is at $\sim 90^+\text{ kg/m}^3$.

Yield increases and the resulting production capacity increases and energy savings in this article are therefore subdivided into those relating to LT plants processing Gibbsite (trihydrate) bauxite and HT plants processing Boehmite (monohydrate) bauxite.

The following yield increase options using proven technology have been included (refer to Ref. ⁴ for further details):

- Seed filtration in precipitation: Installing seed filters drastically reduces spent liquor recycle, increasing the so-called precipitation A/C fill ratio (effectively its alumina super-saturation) and, thus, the driving force for precipitation and precipitation yield. The liquor A/C ratio signifies to what extent a caustic liquor is saturated with alumina, the ratio being that of the alumina concentration in solution (in g/L, expressed as Al_2O_3) and the caustic soda concentration (in g/L, expressed as Na_2CO_3). In addition, an increased fill ratio increases the capacity to agglomerate fines, enabling a finer hydrate seed, increasing the specific surface area of the in-tank solids, also resulting in an increased yield.
- Interstage cooling in precipitation: The optimum temperature in precipitation associated with the highest crystallization rate depends on the A/C ratio and caustic concentration of the liquor in a precipitation tank. By increasing the number of cooling steps between the tanks, it is possible to operate the precipitation area more closely to the optimum temperature profile.
- Direct cooling in the heat interchange area: Heat transfer in the heat interchange area is accomplished after digestion by direct means such as plate heat exchangers rather than by indirect means (flash steam), thus, avoiding the concentrating effect of liquor flashing. As a result, the digestion area can operate at a higher liquor caustic concentration without changing the caustic concentration of the liquor to precipitation, enabling an increased precipitation fill liquor A/C ratio.
- High rate thickeners in decantation: High rate decanters/settlers and washers reduce the liquor-to-mud contact time and hence the potential of premature Gibbsite crystallization (so-called reversion) in the liquor coming from digestion (which is super-saturated with alumina) onto unextracted Gibbsite in the bauxite residue.
- Sweetening in HT digestion: The HT Boehmitic bauxite digest is used to increase the digestion liquor A/C ratio with a first increment. As the HT digester discharge slurry progresses through flash cooling, gibbsitic bauxite is added when the slurry reaches a temperature of $\sim 180^\circ\text{C}$, thus, raising the A/C ratio of the digestion discharge liquor to a level that is more typical for Gibbsitic bauxite digestion.

Also considered are the following yield increase options for proposed new technologies (refer to Ref. ⁴ for details):

- Fines destruction in precipitation (refer to the patent by Hiralal⁵): Dissolving excess fines controls the amount of fine seed to match the capacity of classification and agglomeration systems in precipitation, and the high A/C ratio liquor

obtained after dissolution of fines is used to increase the precipitation fill ratio.

- Bauxite residue re-digestion at high solids density (refer to the patent by Den Hond⁶): Inclusion of a second low-temperature digestion step of the decanter underflow with additional spent liquor, with the objective to maximize alumina extraction from the bauxite residue of the main digestion step.

Increasing precipitation yield through extra liquor dilution (instead of or in addition to the plant adaptations indicated above) requires additional evaporation, i.e., additional energy consumption. The overall economic and environmental gains are not clear-cut especially for LT digestion plants. A similar argument applies to increasing precipitation yield by just increasing the liquor holding time in precipitation. These options have therefore not been included. Maximum achievable yield may be constrained by liquor impurities originating from the bauxite feed such as oxalate, carbonate and sulphate. Various liquor removal options may be considered to offset their effects.

PRODUCTION CAPACITY INCREASE AND ENERGY SAVINGS AS A FUNCTION OF YIELD INCREASE

Estimates have been made in terms of plant production capacity increases and of steam and power energy savings as a function of precipitation yield increments resulting from the implementation of the plant adaptations discussed above. The main assumptions made in this study are as follows:

- Refinery base production capacity of 2 million t/year.
- Base case precipitation yield of $65\text{--}75\text{ kg/m}^3$ for LT plants and of 65 kg/m^3 for HT plants.
- Base case steam and power energy requirement of 7.6 GJ/tA for LT plants (all required power generated in a co-generation facility) and of 9.7 GJ/tA for HT plants (part of the power required generated in a co-gen facility, and 0.5 GJ/tA of imported power required to meet remaining power needs). In other words, in both cases, alumina calcination energy is not included.
- Heat of Gibbsite dissolution of 0.7 GJ/tA for LT digestion and of 1.0 GJ/tA for HT digestion.
- Yield increases for the various plant adaptations as indicated in Ref. ⁴ and an energy efficiency improvement of 85% of theoretical (as a result of increased number of on-line equipment and other inefficiencies).

Results are presented in Table I that shows that by implementing the above-discussed plant adaptations, precipitation yield increases are feasible to a benchmark level of $\sim 90\text{ kg/m}^3$ (or g/L) and beyond: for LT digestion plants by $\sim 9\text{--}20\text{ kg/m}^3$ and for HT digestion plants by $\sim 15\text{--}30\text{ kg/m}^3$. Note that these numbers include proven technologies only.

These yield increases are equivalent to $\sim 13\text{--}31\%$ production capacity increases for LT, respectively,

Table I. Precipitation yield improvement options versus capacity increases and energy savings (Sources: Ref. 4 and this study)

Plant adaptation^a	Yield increase^a (kg/m³)	Capacity increase^b (%)	Energy savings^c (GJ/tA)
LT Plants using Gibbsitic bauxite	5–10	7–15	0.4–0.9
Seed filtration in precipitation	2–5	3–8	0.2–0.5
I stage cooling in precipitation—add 5 units	1–3	1.3–5	0.1–0.3
Direct cooling in heat interchange	1–2	1.3–3	0.1–0.2
High rate thickeners in decantation	~9–20	~13–31	~0.8–1.9
Total (proven technology)			
HT plants using Boehmitic bauxite	6–10	9–15	0.7–1.1
Sweetening in digestion	5–10	8–15	0.6–1.1
Seed filtration in precipitation	2–5	3–8	0.3–0.6
I stage cooling in precipitation—add 5 units	1–3	1.5–5	0.1–0.4
Direct cooling in heat interchange	1–2	1.5–3	0.1–0.3
High rate thickeners in decantation	~15–30	~23–46	~1.8–3.5
Total (proven technology)			
Proposed new technologies^d	Yield increase^d (kg/m³)	Capac. increase^b (%)	Energy savings^c (GJ/tA)
LT plants using Gibbsitic bauxite			
Fines destruction in precipitation	4–8	5–12	0.3–0.7
Bauxite residue re-digestion at high solids density	4–5	5–8	0.3–0.5
HT plants using Boehmitic bauxite			
Fines destruction in precipitation	4–8	6–12	0.5–0.9
Bauxite residue re-digestion at high solids density	Not applicable	n. a.	n. a.

^aBased on proven technology; refer to Ref. 4. for further details. ^bUsing a base case precipitation yield range of 65–75 kg/m³ for LT plants (digestion typically 143°C to 150°C) using Gibbsitic bauxite; and a precipitation yield of 65 kg/m³ for HT plants (digestion typically 240°C to 250°C) using Boehmitic bauxite. ^cUsing a steam and power energy requirement of 7.6 GJ/tA for plants using Gibbsitic bauxite (all required power generated in a co-generation facility) and of 9.7 GJ/tA for plants using Boehmitic bauxite (part of the power required generated in a co-gen facility, and 0.5 GJ/tA of imported power required to meet remaining power needs). In other words, in both cases, alumina calcination energy is not included. ^dRefer to Ref. 4 for further details.

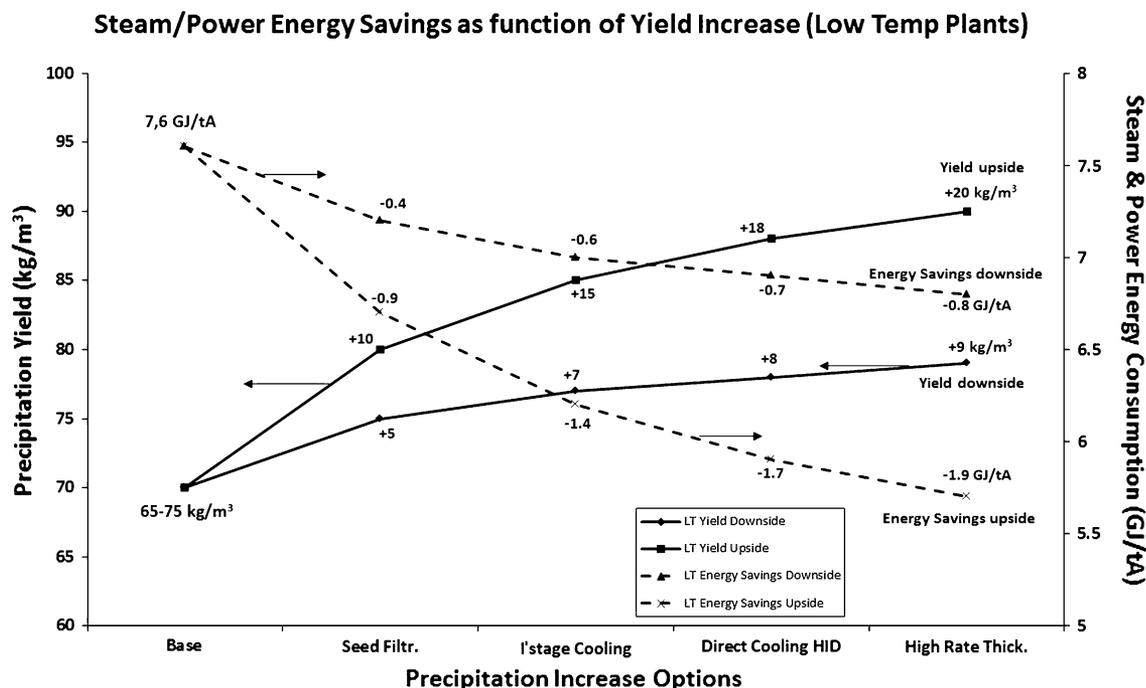


Fig. 2. Energy savings as a function of yield increase (LT plants) (Source: this study).

23–46% for HT digestion plants, and to steam and power energy savings of ~ 0.8 – 1.9 GJ/tA for LT, respectively, 1.8 – 3.5 GJ/tA for HT digestion plants (refer to Table I). These energy savings are significant compared with a typical steam and power energy consumption of ~ 6 – 9 GJ/tA for LT, respectively, 8 – 11 GJ/tA for HT plants. Note that the maximum achievable yield may be negatively affected by organic carbon impurities in the bauxite feed such as oxalate.

Figure 2 provides an illustration for LT plants of the steam and power energy savings as a function of yield increases (both cumulative) resulting from the indicated plant adaptations.

CONCLUSION

Increasing precipitation yield in an alumina refinery by implementing proven technology is a powerful tool:

- To increase production capacity: by (indic.) ~ 13 – 31% for LT, respectively, 23 – 46% for HT digestion plants.
- To lower steam and power energy consumption per tA: by (indic.) ~ 0.8 – 1.9 GJ/tA for LT, respectively, 1.8 – 3.5 GJ/tA for HT digestion plants.

The above results in an improved capital cost per annual tA of installed capacity and in an improved

operating cost per tA, i.e., overall in a significant improvement of project economics.

Interestingly the lower specific energy consumption also means a drop in greenhouse gas emissions per tA and (if applicable) coal ash residues (bottom ash/fly ash) per tA, i.e., an improvement of direct environmental performance. And the potential to improve alumina quality as a result of improved quality control in the precipitation area enables lowering alumina fines losses during transport and handling, thus, improving environmental performance indirectly.

In other words, projects to increase precipitation yield address two of the three “pillars” of sustainable development (economic, environmental, and social).

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