Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

Light Metals 2014

ALUMINA AND BAUXITE

Process Control

SESSION CHAIR
Carlos E. Suarez
Ma'aden Aluminium Company
Alkhobar, Saudi Arabia

Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

VOTORANTIM METAIS - CBA ALUMINA REFINERY PRECIPITATION MODELING

Thiago Teixeira Franco[1], Roberto Seno Junior[1]
[1]Votorantim Metais/CBA(Companhia Brasileira de Alumínio); 347 Moraes do Rêgo St.; Alumínio, São Paulo, 18125-000, Brazil

Keywords: Alumina, Precipitation, Hydrate, Simulation.

Abstract

Precipitation is one the final Bayer Process stages in an alumina refinery and its objective is to crystallize the tri-hydrated alumina. Precipitation is influenced by liquor temperature and composition, residence time in the precipitators, seed charge and others.

Many plant indicators are directly affected by the performance of this stage, for example, productivity and production.

In order to predict the behavior of the precipitation process, a mathematical model was developed using process simulation software. This solution became an important tool in decision making and process control, in addition to operational improvement and technological developments.

The current work presents the modeling development, results, challenges and the possibility to replicate the methodology in other refinery areas.

Introduction

Companhia Brasileira de Alumínio (CBA), of Votorantim Group, is located in Alumínio, 74 km from São Paulo city, and it is the biggest integrated aluminium plant in the world. CBA started to operate in 1955 and nowadays produces 0.475 Mt of primary aluminium.

Precipitation is one of the last steps of Bayer Process in an alumina refinery. This process can be divided into two parts, popularly known as red side and white side. To briefly summarise, in red side occurs the alumina trihydrate ($Al_2O_3.3H_2O$) dissolution in caustic solution and the residue separation of bauxite ore; in white side occurs the alumina trihydrate precipitation and afterwards the removal of structural water in this hydrate (next step to Bayer Process called calcination), generating the compound known as alumina (Al_2O_3).

Precipitation process is a step of major importance in alumina production, as it has direct impact on various refinery performance indicators, for example, yield, steam consumption and plant stability. For this reason, to assist the control, the optimization and the predictability of the process variables effects, tools and mechanisms were developed to monitor precipitation, many of them through commercial spreadsheet, often of great complexity.

CBA's existent modeling presents the plant operation and show how distant of ideality it is. On the other hand, it hardly ever presents reliable ways to predict new actions effects.

Aiming better predictability and flexibility, CBA teams are utilizing Kenwalt's software SysCAD, to develop process simulations. SysCAD was applied initially in the precipitation step.

Precipitation Process at CBA's Alumina Refinery

The precipitation and classification system at CBA is represented in Figure 1.

Cold pregnant liquor from the HIDs (High Interchange Departments, stage responsible for cooling the liquor from the red side) follows to the first precipitation tank, where agglomeration occurs after adding fine seed. After this stage, the liquor and its agglomerated solids follow to the growth stage. The first growth tank receives coarse seed from the classification system and the slurry is then cooled by the ISCs (Interstage Cooling). These systems are composed by flash tanks, barometric columns and cooling towers. From the last growth tank the slurry is pumped to the classification system.

The first hydrocyclone batteries separate the final product from the seeds which, in turn, are separated between fine and coarse seed by another hydrocyclone batteries. Both product and seeds are filtrated to recover liquor; the product is then sent to calcination, the fine seed to the agglomeration tanks and the coarse seed to the growth tanks.

Agglomeration

a. Principles

The fine particle proportion, the crystal resistance and product occluded caustic are controlled during agglomeration. In this stage, it very important that the fine particle gather in bigger clusters, and that these clusters are cemented in firm agglomerates. Moreover, the generation of fine particles by nucleation is not desirable.

b. Control Philosophy

In the hydrate precipitation circuit, due to the dynamics of process conditions, the product particle size varies and, consequently, so do the fine and coarse seed introduced in the process. Therefore, the system operates in cycles of fining and coarsening.

When the system has a tendency to become finer, the following decisions are taken, either separately or altogether:

- reducing the fine seed charge.
- increasing the temperature in the beginning of agglomeration.
- increasing residence time in the agglomeration.
- increasing A/C ratio in the beginning of agglomeration.

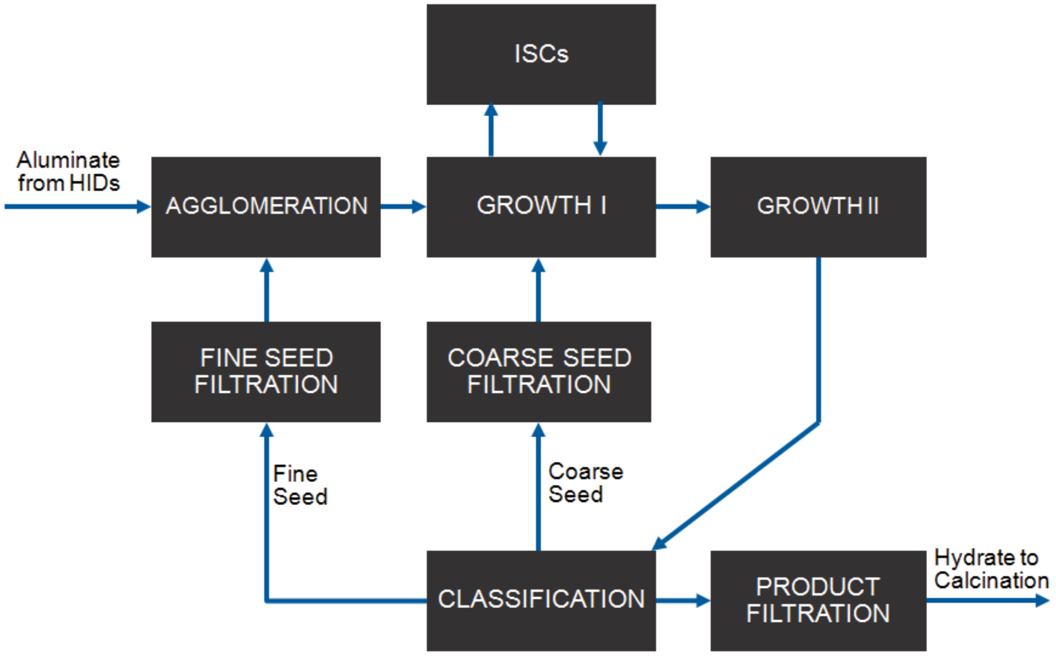


Figure 1 - Block diagram for CBA's precipitation and classification system.

The first option is more immediate and the others may require longer planning.

Fine seed charge can be adjusted as described bellow.

CBA's classification system has three by-passes which allow the passage of precipitation product straight to seed classification (1); to the seed cyclones overflow tank (2); or to the seed cyclones underflow tank (3), as seen in Figure 2 below:

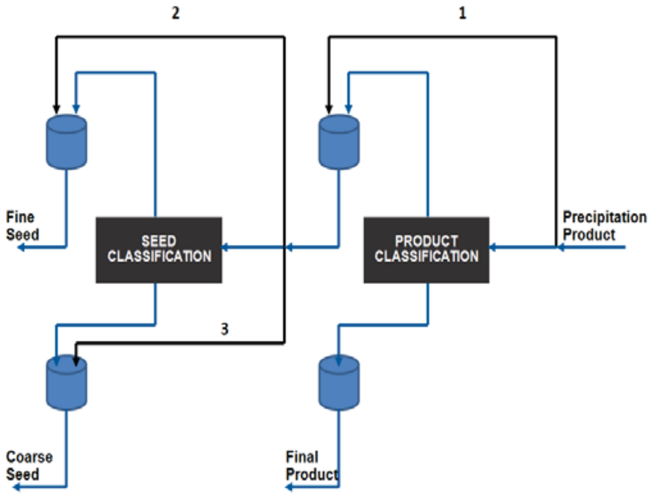


Figure 2 - CBA's hydrate classification schematic diagram.

Growth

a. Principles

During Growth, the main objective is to maximize yield. The linear growth of crystal by means of hydrate deposition occurs, favored by relatively lower temperatures in comparison with agglomeration.

b. Control Philosophy

At CBA's refinery, the temperature decrease is assisted by ISCs. The temperature drop is balanced to achieve the maximum supersaturation to increase the precipitation yield and improve the resistance of the crystal and also to avoid excessive nucleation.

Nucleation

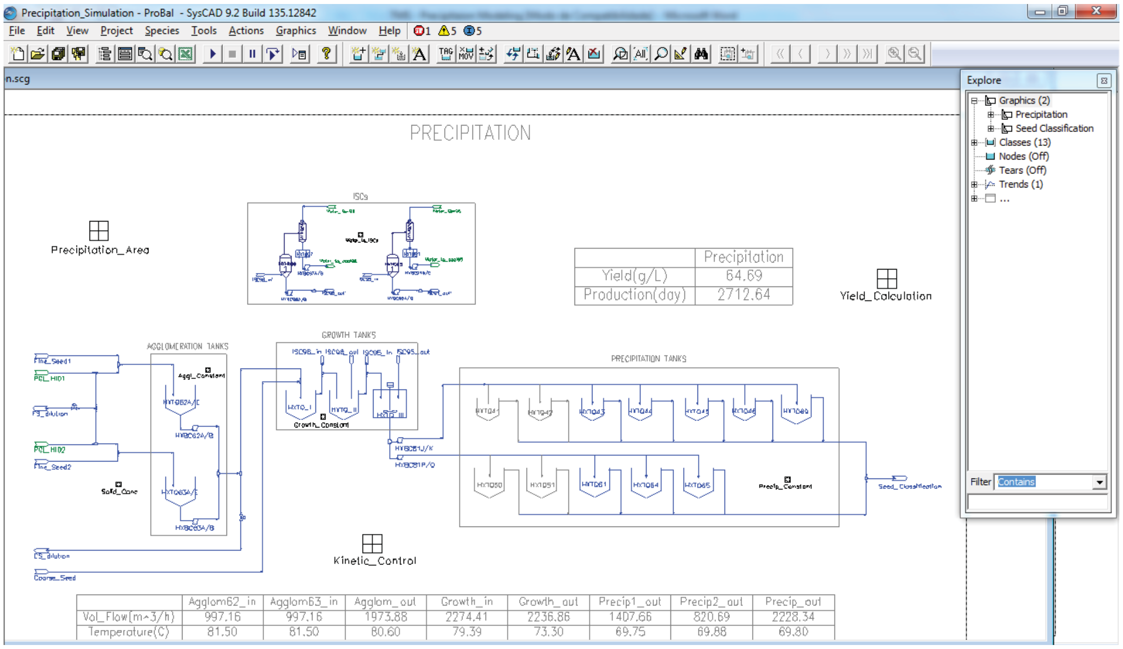
a. Principles

New hydrate particles are formed during nucleation. This stage occurs in highly supersaturated liquors. Caustic concentration, A/C ratio, temperature and lack of surface area can affect this process.

The nucleation of new crystals must happen to compensate the removal of final product from the particle size control system, in order to reduce the risk of explosive nucleation and guarantee a good cementation during the agglomeration stage.

b. Control Philosophy

The precipitation temperature profile is adjusted in the ISC to increase or decrease the nucleation rate.



	Precipitation
Yield(g/L)	64.69
Production(day)	2712.64

	Agglom62_in	Agglom63_in	Agglom_out	Growth_in	Growth_out	Precip1_out	Precip2_out	Precip_out
Vol_Flow(m^3/h)	997.16	997.16	1973.88	2274.41	2236.86	1407.66	820.69	2228.34
Temperature(C)	81.50	81.50	80.60	79.39	73.30	69.75	69.88	69.80

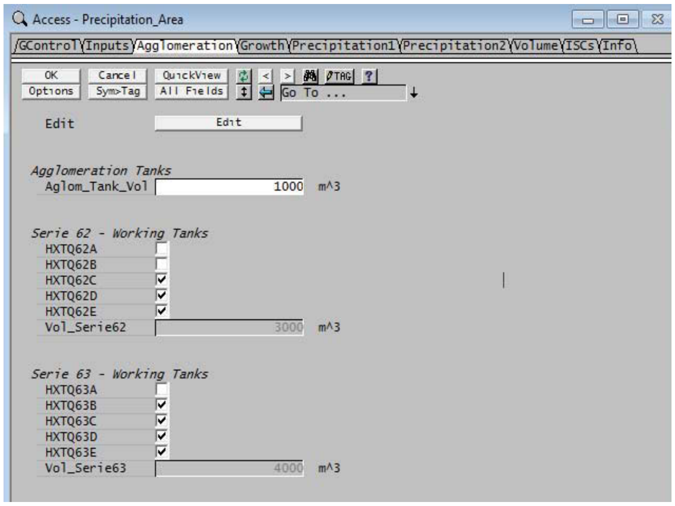
Figure 3 – CBA's Precipitation system on SysCAD interface.

Developments

Input Data System

CBA's precipitation is composed by ten 1000 m^3 agglomeration tanks, a first stage growth with five 3300 m^3 tanks and two 4400 m^3 tanks, and a second growth stage with fifty eight tanks varying from 470 to 1000 m^3. The ISC systems are located in the first growth stage.

The modeling was created as simple as possible, attending the dynamic plant routine of inserting and removing tanks from operation and changing ISCs position in first growth stage tanks. A system was programmed that inserts or removes tank by tank by selecting checkboxes and also chooses ISCs position.



Edit

Agglomeration Tanks
Aglom_Tank_Vol 1000 m^3

Serie 62 - Working Tanks
HXTQ62A ☐
HXTQ62B ☐
HXTQ62C ☑
HXTQ62D ☑
HXTQ62E ☑
Vol_Serie62 3000 m^3

Serie 63 - Working Tanks
HXTQ63A ☐
HXTQ63B ☑
HXTQ63C ☑
HXTQ63D ☑
HXTQ63E ☑
Vol_Serie63 4000 m^3

Figure 4 – Insert/remove tank system on SysCAD interface.

The data input to calibrate the modeling is done transferring historical plant data from a spreadsheet. Cold aluminate, fine seed, coarse seed and spent liquor properties are sent to software instantaneously.

Kinetic Reaction Calibration System

Alumina tri-hydrate precipitation reaction, as well as all the reactions, is influenced by countless factors. It is presented as follows:

$$2NaAlO_2\ (aq) + 4H_2O\ (l) \rightarrow Al_2O_3.3H_2O\ (s) + 2NaOH\ (aq)$$

The hydrate precipitation driving force is known as supersaturation, chemically represented by the difference between the alumina concentration at the liquor (*a*) and alumina concentration at equilibrium (*a**), which is strongly influenced by the caustic concentration in the liquor.

Precipitation kinetic can be expressed by growth linear rate (G) of hydrate crystals:

$$G = dL/dt = K_g\,.\ f(S) \qquad (1)$$

Where, L is the characteristic crystal length, K_g is the growth constant and S is the supersaturation. The growth constant is influenced by temperature (T) according with Arrhenius equation:

$$K_g = k.\exp(-E/RT) \qquad (2)$$

Where, E is the activation reaction energy of precipitation. Numerous modeling correlations were already published:

Table 1 – Kinetic models of hydrate precipitation.

Fonte	Modelo	E (kJ/mol)
White and Misra [1]	$\mathrm{K_g} . (a - a^*)^2$	60 ± 6
King [2]	$\mathrm{K_g} . \left(\frac{a-a^*}{FC}\right)^2$	53
White anda Bateman [3]	$\frac{\mathrm{K_g}}{\sqrt{\mathrm{C}}} . \left(\frac{a-a^*}{C}\right)^2$	71 ± 7
Veesler and Boistelle [4]	$\mathrm{K_g} . \left(\frac{a}{a^*} - \beta_c\right)^{\mathrm{g}}$	121

SysCAD provides some precipitation kinetic models to precipitator unit operation.

Calibration Principle

A value of activation energy (E) has to be adopted and then programmed controllers find values to the growth constant and to the environment losses. To calibrate the developed mathematical modeling, real plant data taken in stable periods of operation is utilized.

Classification System

The chosen precipitation model on SysCAD works with crystal superficial area and the available cyclone model works with particle size distribution. Therefore, it was adopted a simple statistic modeling to predict the superficial area and solids concentration in the cyclones outlet flows (underflow and overflow) as function of inlet flow variables.

Programming Controllers

To automate the use of mathematical modeling in SysCAD, several controllers have been developed in programming language:

- **a)** process data input
- **b)** kinetic reaction calibration
- **c)** tanks insertion and removal
- **d)** ISCs position in growth tanks
- **e)** density control in reslurring tanks
- **f)** statistic modeling to the classification system

Results

Mathematical Modeling

The simulation mathematical modeling achieves good results in relation to calibration with plant data in stable periods. It is possible to compare precipitation production and yield in these two situations:

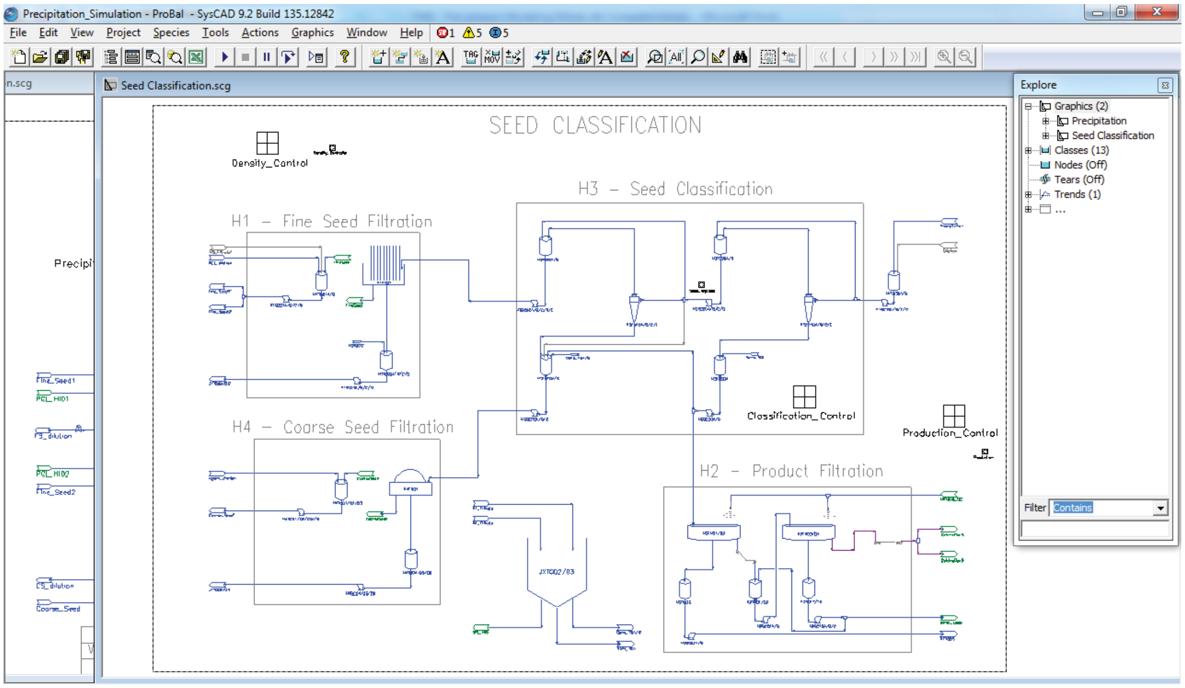


Figure 5 – CBA's classification system on SysCAD interface.

Table 2 – Comparison between calibration and simulation.

	Production (t/day)			Yield (g/L)		
Period	**Calibration**	**Simulation**	**Difference**	**Calibration**	**Simulation**	**Difference**
1	2713	2690	1%	64,7	64,2	1%
2	2035	2135	5%	60,1	62,8	4%
3	2494	2596	4%	69,5	72,1	4%
4	2297	2412	5%	66,3	69,4	5%
5	2529	2702	7%	68,0	72,4	6%
6	2398	2384	1%	65,8	65,4	1%
7	2129	2255	6%	59,3	62,6	5%
8	2657	2822	6%	67,6	71,7	6%

The observed difference between simulation and calibration, both to production and to yield, is fairly low, with values of 5% on average.

Opportunities

Through the simulation it is possible to predict effects of possible actions to be implemented in plant.

Addition of Product Filtration Filtrate to Agglomeration

This filtrate results of second stage of product filtration, which has lower caustic comparing to agglomeration liquor. The opportunity consists on adding this to fine seed reslurring tanks, that afterwards, follows to agglomeration first tanks.

The principle of this action is to decrease the resultant caustic, which in turn will result in the diminution of equilibrium alumina (a^*) and increasing the supersaturation ($a-a^*$).

It was possible to prove, in simulation modeling on SysCAD, the gain in precipitation production and yield by adding filtrate flow in the agglomeration.

Increasing Precipitation Solids Concentration

It is known that increasing solids concentration in the circuit also increases precipitation yield. On the other hand, when solids concentration increases, classification efficiency decreases due to hydraulic limitations. One way to increase solids in the precipitation without compromising the hydrocyclones efficiency is to dilute precipitation pump off with spent liquor before it enters the hydrocyclones clusters.

We can use the classification model to find the maximum solids concentration feeding the cyclones and also its mass balance to determine the maximum spent liquor flow in dilution regarding the hydraulics limitations of the system.

Replication in other Refinery Areas

The development of this present work to CBA's precipitation encouraged the use of SysCAD tool for creating mathematical modeling to other process involved in the refinery.

References

1. Misra, C. and White, E. T. "Kinetics of Crystallization of Aluminium Trihydroxide from Seeded Caustic Aluminate Solutions", Chemical Engineering Progress Series 67 1970 Vol 110 pp 53-65

2. King, W. R., "Some Studies in Alumina Precipitation Kinetics", Light Metals 1971 pp 551-563

3. White, E.T. and Bateman, S.H. "Effect of Concentration on the Growth Rate of Al(OH)3 Particles", Light Metals 1988 pp 157–162.

4. Veesler, S. and Boistelle, R., "About Supersaturation and Growth Rates of Hydragillite Al(OH)3 in Alumina Caustic Solutions", Journal of Crystal Growth 1993 Vol 130 pp 411-415