Advanced Process Control Wide Implementation in Alunorte Digestion Unit

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Abstract: The most competitive environment generated the need of process performance optimization. Performance optimization means produce the same amount of product, more effectively and spending less money. On the alumina market, that's fundamental in this economy scenario. Robust Multivariable Predictive Control Technology becomes one of the main tools to optimize this class of plants. This paper will discuss the application and benefits of this technology to alumina digestion units, implemented in 5 interconnected digesters. This digestion interconnection is a whole digestion train, and the plant has 5 of those. The APC philosophy is based on process variability reduction, and consequently operations optimization, against plant constraints. Since alumina – caustic ratio (A/C) is the key plant variable, it has a fundamental role in this variability reduction. The main challenge in this project was to coordinate the use of 5 bauxite grinders and 2 more grinder bauxite flows to the 5 digesters. The implementation was made in 3 phases and the project length was approximately 18 months, generating more than 1.00% increase in overall production, rather than A/C variability reduction.

Keywords: Advanced Process Control, Alumina, Alunorte, Honeywell, Multivariable, RMPCT

1. INTRODUCTION

Significant economic savings can be generated to alumina plants, through the utilization of new control technologies that uses the existing infrastructure and require a reduced support team. The global market and supplier consolidation created a more competitive environment, which drives the need of production and performance optimization. The multivariable predictive control becomes one of the main tools in this scenario. This paper will discuss the application and benefits of this technology to the alumina digestion units.

The challenge to any alumina refinery is to minimize the cost of production per tonne of alumina, consistently with safety and environmental considerations. It is translated into alumina production maximization (plant flow and yield) and energy costs per tonne of alumina minimization.

In this scenario, the digestion process is the one that has the biggest potential to the robust multivariable predictive control technology (RMPCT) implementation. Rather than this, the digestion is considered by most of refineries as a key-unit to the production and also is the one that offers the best data for an APC modelling.

1.1 Process Description

The process for obtaining alumina from bauxite ore was developed and patented by Karl Josef Bayer in 1888. Typically, depending on the quality of the ore, between 1.9 and 3.6 tonnes of bauxite are required to produce 1 tonne of alumina.. Bayer process is cyclical and involves many unit operations, like digestion, solid – liquid separation and crystallization.

Overall, bauxite ore is digested in caustic solution concentrate in temperatures ranging from 145 to 270°C, depending on the nature of the ore. Under these conditions, most mineral species that contains aluminum is dissolved, forming sodium aluminate, soluble, as shown in equations (1) and (2).

$$Al(OH)_3 + NaOH \rightarrow NaAlO_2 + 2H_2O \quad (1)$$

$$AlO(OH) + NaOH \rightarrow NaAlO_2 + H_2O \quad (2)$$

The portion of the ore that is insoluble in caustic solution after digestion (red mud) is removed by sedimentation and filtration process. The pregnant liquor in alumina is send to the precipitation, which is almost pure crystals of $Al(OH)_3$. The hydrate precipitate is removed, washed and sorted. Alumina is then obtained by their calcination.

1.2 RMPCT (Robust Multivariable Predictive Control Technology)

RMPCT technology represents an advance of the traditional MPC technologies. Like the others, this technology models the process, calculate the necessary predictions and use multivariable control movements in order to: optimize the process, maintain the variables inside operational limits and respect the process and plant constraints. The performance gain and robustness is due to a feature called "range control algorithm" (RCA), which makes that the disturbances and prediction errors inherent to the process are considered in the future movement plan. Figure 1 sketches how the RCA technology works.

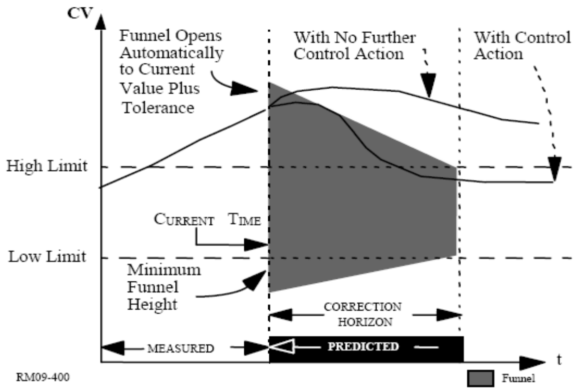

Figure 1 - RCA Technique Controlling a CV Inside Limits

The correction horizon concept is that CV errors are reduced to zero at the correction horizon in the future. Prior to the correction horizon, the controller is free to determine any trajectory for the CV as long as the CV is brought within limits or to setpoint at the correction horizon. Because no trajectory is imposed on the controller, the controller has the freedom to determine a trajectory that requires minimum MV movement and is least sensitive to model error.

However, the correction horizon by itself does not say anything about what happens to the CV prior to the horizon. It is important that the controller does not transiently move a CV farther outside a limit while correcting other CV errors, even though all CVs are brought to zero error by their correction horizons. Limit funnels are used to prevent the controller from introducing transient errors prior to the correction horizons, by defining constraints on the CVs that are imposed at intervals from the current interval out to the horizon.

These features drives the application to deal smoother and more efficiently with model mismatches (gain inversion, colinearities, bigger or smaller gains than the real, dynamic errors). Rather than this, the tuning in this technology is based on the controlled variables and not in the manipulated variables.

2. APPLICATION OF RMPCT IN ALUNORTE DIGESTION UNIT

2.1 Digestion Process Description

The digestion unit is designed to extraction alumina from bauxite using caustic solution in high temperature and remove dissolved silica from the liquor leaving the digesters to ensure product hydrate of the desired quality.

The alumina extraction is carried out in a train consisting of five vertical digesters arranged in series. The first step is to dissolve a most part of alumina in ore mixing slurry bauxite and heater spent liquor, in small digesters, equipped with agitators. The large digesters, without agitators, in series are to keep the residence time to reduce the silica dissolved by desilication reaction to a tolerable level.

The five vertical digesters are sized to provide a total of 60 minutes nominal retention time. Varying the liquor outlet temperature from the second live steam heater controls the digestion temperature. In occasion when one digester is taken out of operation the temperature is increased approx 1°C to compensate.

2.2 General Control Strategies

The Advanced control strategies of the Bayer plant are used to control blow off ratio, caustic concentration and to keep productivity and quality.

Alumina refineries generally operates with advanced A/C ratio control systems, involving feed forward with feedback trim and utilizing on-line measurement of liquor properties, such as electrical conductivity and density.

In 2006, ALUNORTE concluded the project of expansion 2 with five lines, in operate, with total liquor flow of 5610 m3/hr and installed capacity of 4.3 Mt/year.
The project to implement RMPCT control is divided in three phases:

- Phase I : Implementation of control on digestion 3.
- Phase II : Implementation of control on digestions 1 and 2.
- Phase III: Implementation of control on digestions 4 and 5.

2.3 Controller Objectives

The advanced control objectives for the digestion section are described below:

- Control A/C ratio to operator specified target
- Maximize productivity (bauxite and liquor flows), subject to process constraints
- Provide safe and stable operation
- Protect the unit when possible from defined, measurable constraints such as hydraulic, mechanical and environmental constraints.

2.4 Application Methodology

The RMPCT implementation consisted on the following steps:
Data and information gathering → Pre-Step Test → Step Test → Mathematical Modeling → Installation and sustaining

The implementation methodology is detailed bellow:

- Collection of: historical data, operation screens, process flow diagrams, engineers and operators information by interviews;
- Instrumentation review, control strategy setup and related loops tuning;
- After the analysis of all data, a preliminary controller design matrix is defined and discussed. This matrix will drive the initial plant tests (Pre-Step test);
- Prior to starting a test, the process and control system must be brought to a suitable starting condition, and allowed to settle if any changes were made. This will involve ensuring that the process is away from limits or "wind-up" conditions, and making sure that all control loops are in the correct modes.
- Pre-Step Testing is necessary to determine the steady state gain and settling times to be able to conduct precise Step Testing. After analyze of the collected data, final decisions of controller structure and step size will be issued in a report that acts as the basis for the formal step testing
- After the Pre-Step test, the Step Test is performed, applying steps to the considered manipulated variables. The steps are applied with variable time and amount, in order to indentify the actual interactions that will build the definitive multivariable control matrix.
- Using the data gathered on the Step Test, the models are constructed and the RMPCT is built. The matrix is validated, analyzing the predictions and controller offline simulation.
- After the matrix and control construction, the software connections with DCS are configured and an initial software tuning is performed.

2.5 Basic Controller Structure

The main manipulated variables are:
- Bauxite slurry flow
- Liquor flow
- Steam flows of relevant plant heat exchangers

The main controlled variables are:
- Alumina/Caustic Amount Ratio
- Digestion Conditions (temperatures, pressures and volume controls)
- Feed to digestion conditions.

The following table represents the controller gain matrix. MVs 1 to 4 refer to the unit mass balance variables. MVs from 5 to 7 refer to the unit energy balance variables. CVs from 3 to 6 refer to the unit energy balance variables. Other CVs are related to the unit mass balance parameters.

Table 1 – RMPCT Gain Matrix to the Digestion

	MV1	MV2	MV3	MV4	MV5	MV6	MV7
CV1	+	+	-	-			
CV2	-	-	-	-			
CV3	-	-	-	-	+	+	
CV4	-	-	-	-	+	+	
CV5	-	-	-	-	+	+	
CV6	+						
CV7		+					
CV8			+				
CV9				+			
CV10					+		
CV11							
CV12							
CV13						+	
CV14							-
CV15	+	+					

For example, MV1 is the bauxite flow and CV1 is the Alumina – Total Caustic ratio. If the bauxite flow is increased, the A/TC ratio is increased, after a dead time. CV2 is the residence time and the CV's 3, 4 and 5 are digestion temperatures. It can be noticed that, if the bauxite flow is increased, the residence time on the digestion system decreases and the digestion temperature decreases, too. In this controller, the A/TC ratio is controlled on a target, not inside operational limits.

MV3 is the liquor flow to the digestion system. This variable has a significant influence on the A/TC ratio as is one of the main handles for it. For the digestion temperature and residence time, it can be expected the same behaviour as on the interaction between the bauxite MV and the same controlled variables.

CV's from 6 to 13 are valves and they are controlled as constraints on the controller.

3. MODELLING RESULTS

*3.1 Modelling Achievemen*t

The historical data gathered was enough to get good models to build the control matrix. To the mass balance variables, around 10 steps were used and to the energy balance variables, around 6 steps were used. This difference is due to the bigger relevancy of the mass balance, since the main variable (A/C) is influenced by this group of variables.

The following figure represents one of the models between the manipulated and controlled variables. In this case, the model represents the behaviour of the Alumina – Caustic Concentration ratio, against on of the mass balance manipulated variables.

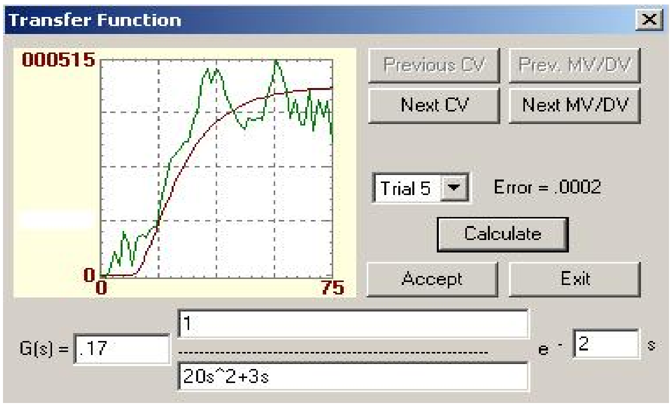

Figure 2 – Model Between Bauxite and the Alumina-Caustic Concentration Ratio (CV)

The unit studied has some valve opening problems on the liquor and pulp heating section. These problems are due plugging, caused by the material that goes inside the heat exchanger tubes. In order to minimize this problem, the valves were modelled, against their steam flows. A model example is showed on the Figure 3.

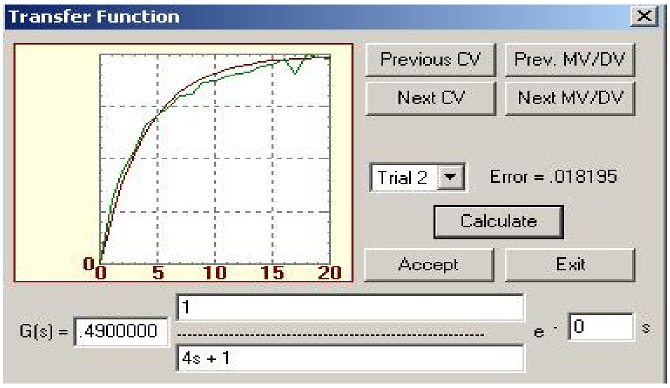

Figure 3 – Valve modelling against the steam flow

3.2 Model Validation

After the modelling, the predictions were analyzed, in order to check if the model is coherent with the real process data, found on the plant test. This validation is one of the last steps, before the controller implementation. The following pictures show the prediction results.

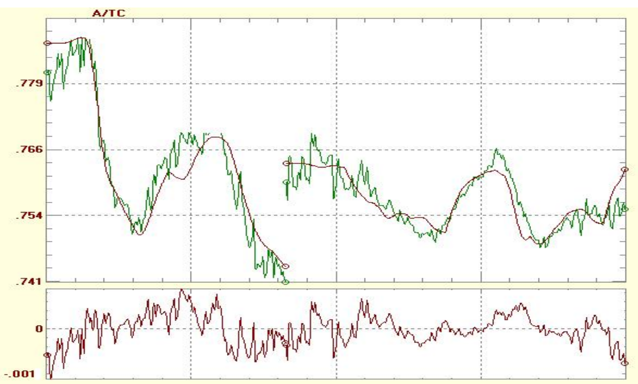

Figure 4 –A/TC Prediction

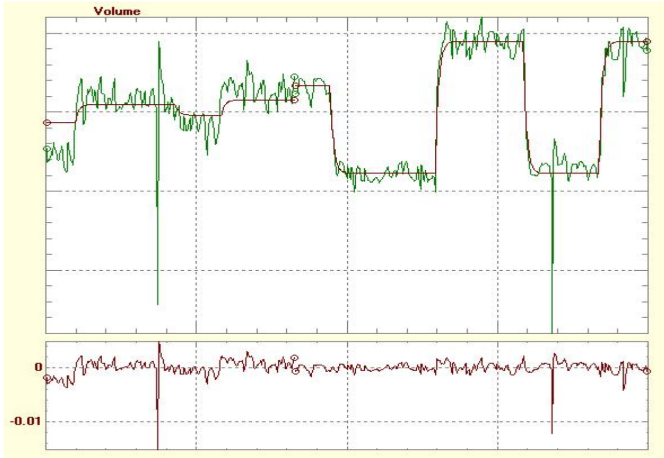

Figure 5 – Digestion Volume Prediction

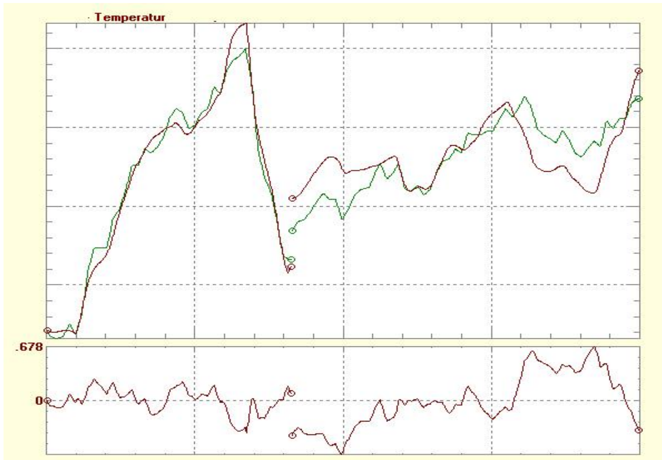

Figure 6 – Temperature Prediction

The Figures show good prediction results. Thus, the proposed and modelled matrix could be tested on the offline controller simulations. In the simulation mode, the control strategies and controller tuning are tested. Rather than this, the controller behaviour against critical situations can be validated. After this last validation, the controller was ready to be implemented on this alumina digestion unit

4. IMPLEMENTATION RESULTS

4.1 Overview

The main reason to implement RMPCT in digestion unit is to keep A/C control at the set point, decrease variability of the system, to increase digestion yield and to keep safety and stable operational conditions.

The main controllers are: DG4B_CLT (Digestion 3 controller). The others controllers are called: DG4A1_CLT, for digestion 1 and DG4A2_CLT, for digestion 2, DG4C1_CTL, for digestion 4 and DG4C2_CTL for digestion 5.

In order to evaluate digestion operation results with RMPCT, it's necessary to consider two parameters:

- Digestion Blow Off (DBO) ratio;
- Digestion Yield

4.2 Digestion Blow off (DBO) ratio

DBO ratio is the main parameter to determinate digestion yield. A good control of this parameter means smaller variability, which allows a higher yield at the digestion outlet. For digestion lines 1,2 and 3, the set point DBO ratio is 0,750. For the digestion lines 4 and 5, the set point DBO ratio is 0,759.

4.3 Digestion Yield

To calculate the digestion yield, the equation 3 is used:

$Y = (((C_{SL}-S_l) \cdot A/C_{DBO})-(C_{SL}.A/C_{SL}))-C_{STT}$ (3), where:

CSL = Spent liquor caustic concentration (g/l)
SL = Silica lost
A/CDBO = Digestion blow off ratio
A/CSL = Spent liquor ratio
CSTT = Spent liquor solids concentration

5. RMPCT PERFORMANCE

5.1 DG4B_CTL

Controller performance was evaluated through the comparison between two different periods of digestion 3 operation. Those periods represent the time when RMPCT was turned on and off.

In the digestion operation without RMPC, the average DBO standard deviation was 0,005 higher, when compared with the digester operation with RMPC (0,002). It represents that the controller performed satisfactorily. Table 2 shows draft of DBO ratio performance with and without RMPCT operation.

Table 2- Draft DBO ratio performance

RMPCT Operation	Average DBO Ratio	Average δDBO
Controller off	0,748	0,005
Controller on	0,751	0,002

This improvement on the DBO represented a gain of 1,02% on the digestion yield. The total time spent for this project phase was 8 months.

Figure 9 and 10 show DG04B_CLT performance when RMPCT was on and off. When RMPCT was on, A/C values were more stable than when the controller was off. A DBO standard deviation of 0,003 was achieved when the Profit Controller was turned on, instead of 0,006, when controller was off.

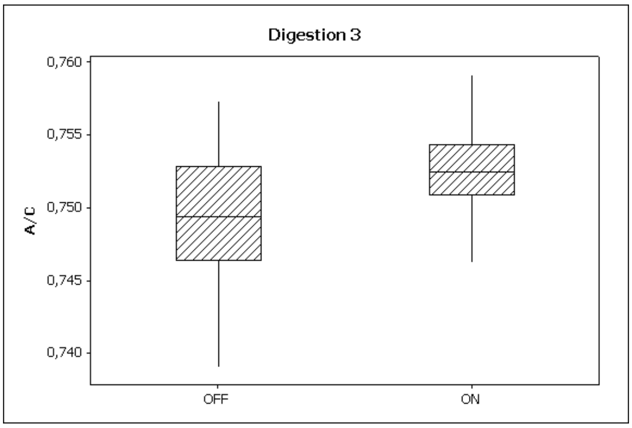

Figure 7 – Digestion 3 A/C when RMPCT on and off

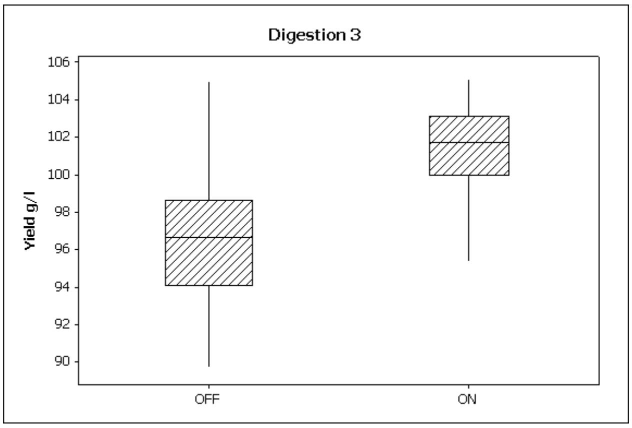

Figure 8 – Yield Digestion 3 when RMPCT on and off

5.2 DG4A1_CTL and DG4A2_CTL

RMPCT for digestion 1 and 2 was evaluated, in order to define a gain with controller in these units. The evaluation followed the same methodology as in the digestion 3.
Figure 11 shows behaviour of A/C in periods when RMPCT is off and on, with average of 0.749 and 0.753, respectively. Standard deviation of the DBO in periods where RMPCT was turned on was better than when the controller was turned off, with averages of 0,02 and 0,01, respectively.

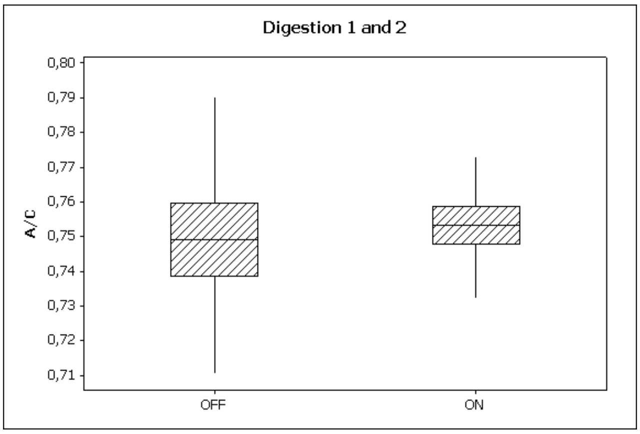

Figure 9 – Digestion 1 and 2 A/C when RMPCT on and off

Figure 12 shows an yield digestion gain of 1,85%. The yield when the controller was turned off was 98,93 g/l and when the controller was turned on was (100,77 g/l).

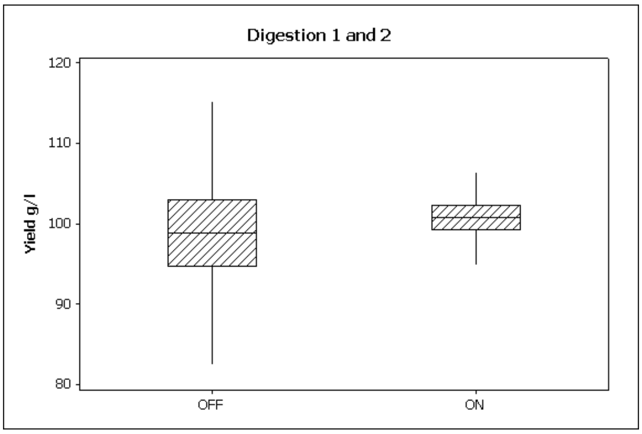

Figure 10 – Yield Digestion 1 and 2 when RMPCT on and off

5.3 DG4C1_CTL and DG4C2_CTL

RMPCT for digestion 4 and 5 was evaluated, in order to measure the gain obtained with its implementation. The evaluation follows the same methodology as in the other digestion trains.

Figure 13 shows behaviour of A/C in periods when RMPCT is off and on, with average of 0.756 and 0.759, respectively. Standard deviation δDBO in periods where RMPCT is on is better than it's off, with average of 0,02 and 0,01.

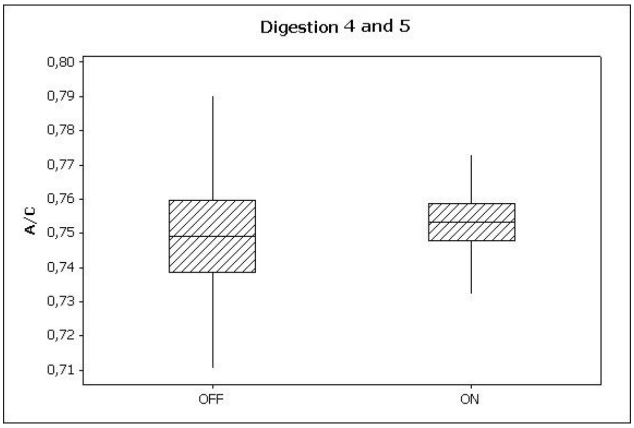

Figure 11 – Digestions 4 and 5 A/C when RMPCT on and off

Figure 14 shows yield digestion gain of 1,69%. The yield when the controller was turned off was 99,72 g/l and when the controller was turned on was 101,44 g/l.

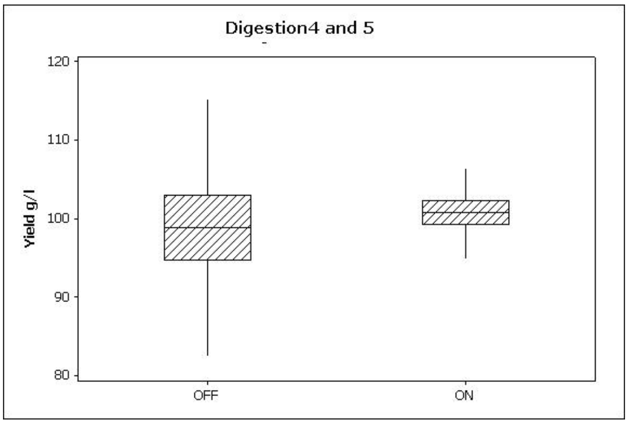

Figure 12 – Yield Digestion 4 and 5 when RMPCT on and off

6. CONCLUSION

A good RMPCT implementation on Alumina Digestion was described. The A/TC variability reduction and a bigger operation stability were proven. Also, the opportunity to operate the plant close to the operational constraints represents a productivity increase and a plant debottlenecking. The steam and liquor consumption didn't change significantly, since the objective was to use the debottlenecking to increase alumina production.

Nevertheless, in this application the liquor flow was maintained constant, due to operational restrictions. If the liquor could move, probably the results would be better than the achieved. Other source of improvement (which wasn't explored in this work) is the increase of operator training on this tool. Since the operators are the heaviest users of the system, training them to help on the optimization, pushing constraints and widening the operation limits can generate a bigger production improvement, than it was achieved.

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