ROBUST MULTIVARIABLE PREDICTIVE CONTROL TECHNOLOGY IMPLEMENTATION IN AN ALUMINA DIGESTION UNIT

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Abstract

Significant economic savings for alumina plants can be made, through the utilisation of new control technologies, that use the existing infrastructure and require a reduced support team. The global market and suppliers consolidation has created a more competitive environment, which drives the need for production and performance optimisation. Multivariable predictive control technology becomes one of the main tools to optimise investment performande. This paper will discuss the application and benefits of this technology to alumina digestion units.

The APC philosophy for alumina digestion is based on process variability reduction, and consequently it optimises operations against the plant constraints. Since the alumina – caustic ratio (A/TC) is the key plant variable, it has a fundamental role in this variability reduction.

The project implementation took approximately 7 months and generated a 1.02% increase in production.

1. Introduction

1.1 Overview

Significant economic savings for alumina plants can be made through the utilisation of new control technologies that use the existing infrastructure and require a reduced support team. The global market and supplier consolidation has created a more competitive environment, which drives the need for production and performance optimisation. Multivariable predictive control technology becomes one of the main tools to optimise the capital investment amount. This paper will discuss the application and benefits of this technology to alumina digestion units.

The challenge for any alumina refinery is to minimise the cost of production per tonne of alumina, while meeting safety and environmental considerations. This translates to maximising the production of alumina (plant flow and yield) and minimising the energy costs per tonne of alumina.

In this scenario, the digestion process has the biggest potential for implement of robust multivariable predictive control technology (RMPCT). This is because it has thes highest potential for profit generation with the implementation of the advanced controls. Other than this, digestion is considered by most refineries as a key- unit of the production, and it is also the one that offers the best data for APC modeling.

1.2 Plant description

An alumina refinery is designed to extract alumina from bauxite. The resulting alumina is shipped to aluminum smelters, where an electrolytic process is used to turn it into pure aluminum. Four tonnes of bauxite yield approximately two tonnes of alumina, which yield approximately one tonne of aluminum.

1.3 Model predictive control

As described by Morari and Garcia (1989), Model predictive control (MPC) is sometimes defined as the family of controllers where there is a direct use of an explicit and separately identifiable model. The model provides predictions of the process response to future changes in the manipulative variables and to predicted process disturbances. In practice, MPC is characterised by its ability to handle constraints in both manipulated and controlled variables. MPC techniques provide the only methodology to handle constraints in a systematic way during the design and implementation of the controller. Moreover, in its most general form MPC is not restricted in terms of the model, the objective function and/or constraint functionality. These are the primary reasons for the success of these techniques in numerous applications in the chemical process industries. While several extension projects gradually increase the plant size and complexity, the resulting regularity, variability reduction and throughput increase challenges are met with MPC implementation. Moreover, large value creations take place, and pushing the capacity limits requires a control tool like MPC to handle the varying set of active constraints.

In the MPC philosophy, the variables that have to be maintained inside a range or in a target value are called controlled variables (CVs). In order to achieve the operational objectives for the CVs, the application adjusts the variables called manipulated variables (MVs). In a single output - single input control, there is only one CV (the process value or controller input) and one MV (process output – valve opening). With MPC technology, there are multiple MVs and CVs, rather than Disturbance Variables (DVs), which are measured disturbances that influence the process (Morari and Garcia, 1989).

1.4 Robust multivariable predictive control technology

RMPCT represents an advance of the traditional MPC technologies. Like the others, this technology models the process, makes the necessary predictions and uses multivariable control movements in order to optimise 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 ensures that the disturbances and prediction errors inherent to the process are considered in the future movement plan. The Figure 1 is a sketch of how the RCA technology works. (Qin and Badgwell, 1997).

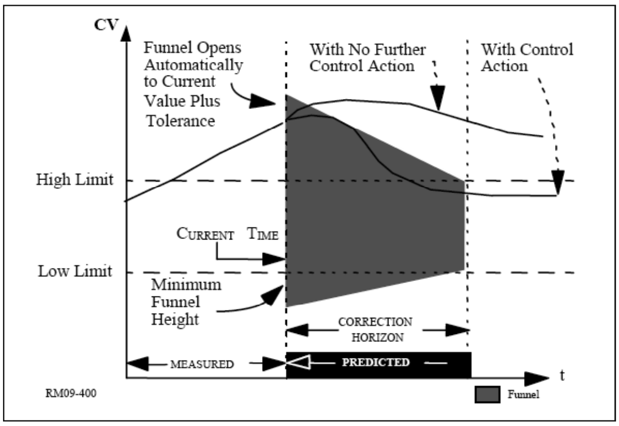

Figure 1. RCA technique controlling a CV inside limits.

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 a set point 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 further 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 drive the application to deal more smoothly and efficiently with model mismatches (gain inversion, colinearities, bigger or smaller gains than the real, dynamic errors). The tuning in this technology is based on the CV and not on MV.

2. RMPCT to Digestion

The RMPCT implementation to the digestion unit is described in this section.

2.1 Alunorte

Alunorte (Alumina do Norte do Brasil) refinery located at Barcarena, State of Para, produces approximately 4.4Mt/year of smelter grade alumina. It currently has five trains and is undergoing an expansion process due to reach a capacity of 6.3Mt/year.

2.2 Digestion process description

The digestion area is designed to meet two main requirements:

- Extraction of gibbsitic alumina from bauxite using hot spent alumina liquor.
- Removal of dissolved silica from the liquor leaving the digesters to ensure product hydrate of the desired quality.

The digesters mix the heated spent liquor and bauxite slurry to arrive at a target digestion temperature. They then maintain that temperature for a period of time sufficient to dissolve the alumina from the bauxite and to reduce the silica dissolved by the desilication reaction to a tolerable level.

The digestion of bauxite to extract alumina is carried out in a train consisting of five vertical digesters arranged in series. The digester train has two sets of small digesters, followed by a set of three large vertical digesters. Dissolution of the alumina is carried out by the small digesters, equipped with agitators, and the large digesters, without agitators, provide additional holding time to ensure liquor desilication.

The five vertical digesters are sized to provide a total of 60 minutes nominal retention time. Varying the liquor exit temperature from the second live steam heater controls the digestion temperature. On occasions when one digester is taken out of operation the temperature is increased by approximately 1°C to compensate for the reduced residence time.

2.3 Control objectives

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

- Control digestion blow off (DBO) ratio to operator specified target;
- Maximise 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

As described by Lopes and Charr (2008), the RMPCT implementation consisted of the following steps:

Data and information gathering → pre-step test → step test → mathematical modelling → installation and sustaining.

The implementation methodology is detailed bellow:

1. Historical data, operation screens, process flow diagrams, and engineer and operator information were collected by interviews.
2. Instrumentation review, control strategy setup and related loops tuning were performed.
3. After the analysis of all data, a preliminary controller design matrix was defined and discussed. This matrix drove the initial plant tests (pre-step test).
4. Prior to starting a test, the process and control systems were brought to a suitable starting condition, and allowed to settle if any changes were made. This involved ensuring that the process was away from limits or "wind-up" conditions, and making sure that all control loops were in the correct modes.
5. Pre-step testing was necessary to determine the steady state gain and settling times in order to conduct precise step testing. After analysis of the collected data, final decisions about controller structure and step size were issued in a report that acted as the basis for the formal step testing.
6. After the pre-step test, the step test was performed, applying steps to the considered MVs. The steps were applied over varying times and in varying amounts, in order to identify the actual interactions that would build the definitive multivariable control matrix.

Using the data gathered in the step test, the models were constructed and the RMPCT was built. The matrix was validated, analysing the predictions and controller *offline* simulation.

After the matrix and control construction, the software connections with DCS were configured and an inital software tuning was performed.

2.5 Basic Controller Structure

As designed by Lopes and Charr (2008), the main MVs are:

- Bauxite pulp flow;
- Liquor flow;
- Steam flows of relevant plant heat exchangers.

The main CVs are:

- Alumina/Caustic Ratio.
- Digestion Conditions (temperatures, pressures and volume controls).
- Feed to digestion conditions.

Table 1 represents the controller gain matrix. MVs 1 to 4 refer to the unit mass balance variables. MVs 5 to 9 refer to the unit energy balance variables. CVs 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*	*MV8*	*MV9*
CV1	+	+	-	-					
CV2	-	-	-	-					
CV3	-	-	-	-	+	+	+	+	
CV4	-	-	-	-	+	+	+	+	
CV5	-	-	-	-	+	+	+	+	
CV6	+								
CV7		+							
CV8			+						
CV9				+					
CV10					+				
CV11						+			
CV12							+		
CV13								+	
CV14									-
CV15	+	+							

3. Modelling Results

3.1 Modelling achievement

The historical data gathered was enough to provide good models to build the control matrix. For the mass balance variables, around 10 steps were used and for the energy balance variables, around 6 steps were used. This difference is due to the higher relevance of mass balance, since the main variable (A/TC) is influenced by this group of variables (Lopes and Charr, 2007).

Figure 2 represents one of the models of the MVs and CVs. In this, the model represents the behaviour of the alumina and caustic concentration ratio against the mass balance MVs.

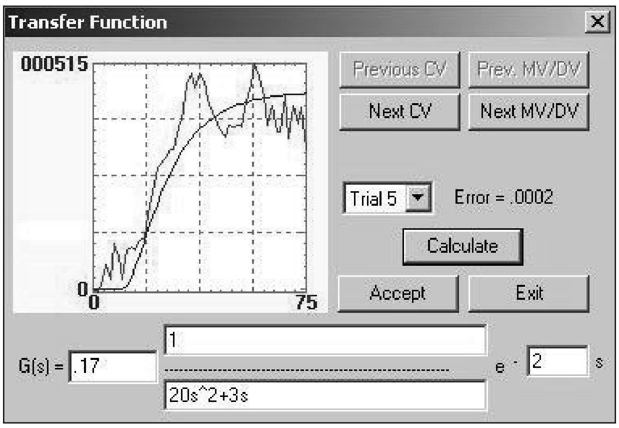

Figure 2. Model of one of the mass balance variables (MV) and the alumina-caustic concentration Ratio (CV).

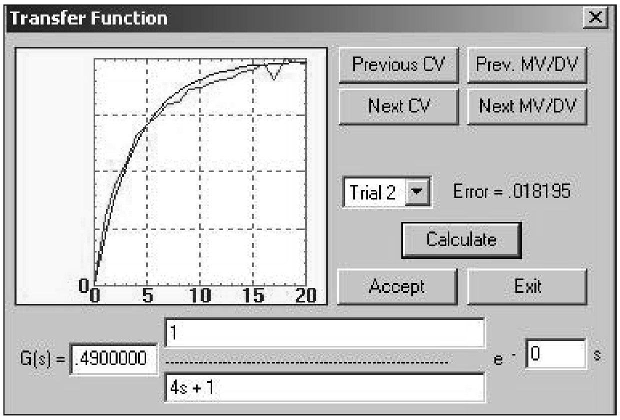

Figure 3. Valve modeling against the steam flow.

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

3.2 Model validation

After the modelling, the predictions were analysed in order to check if the model was coherent with the real process data obtained by the plant test. This validation was one of the last steps before the controller implementation. Figure 4 – 7 show the prediction results.

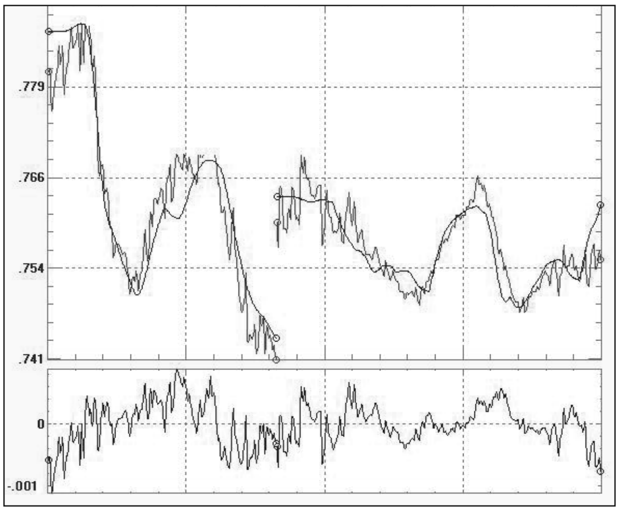

Figure 4. A/TC Prediction.

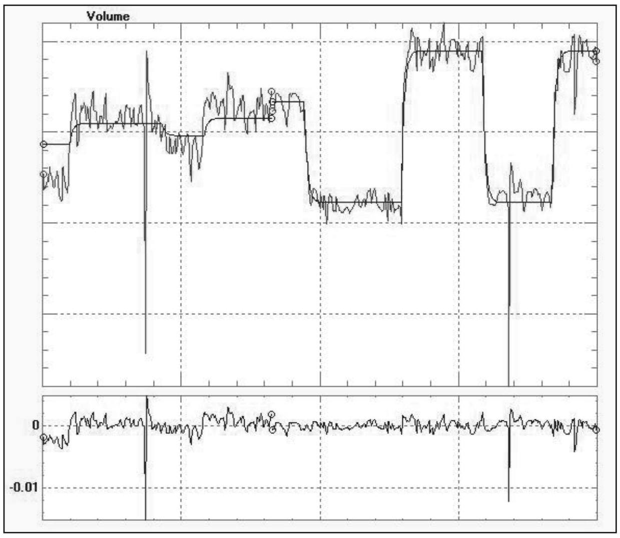

Figure 5. Digestion Volume Prediction.

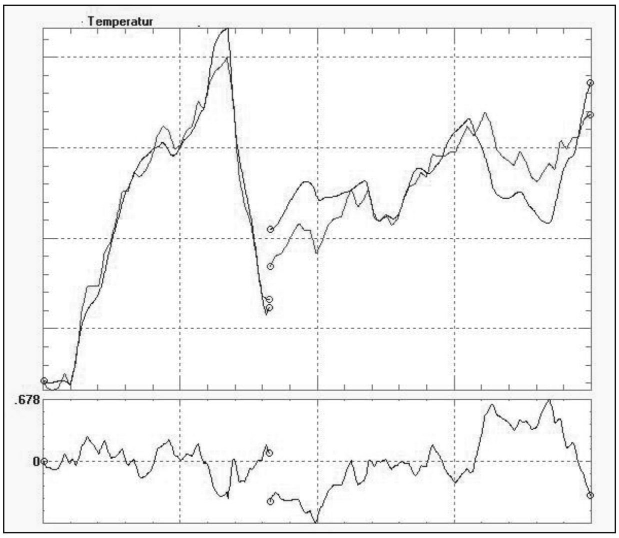

Figure 6. Temperature Prediction.

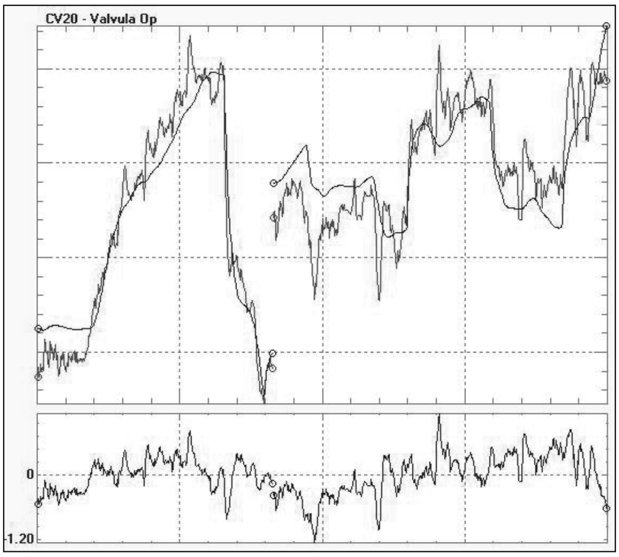

Figure 7. Valve Opening Prediction.

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

4. Implementation Results (Ribeiro, 2007)

To evaluate digester operation with RMPCT, it is necessary to take into consideration two parameters:

1. Productivity.
2. DBO ratio.

To compare digester performance using RMPCT and without it, two specific periods were analysed:

- June 2006 up to August 2006 without RMPCT (base line)
- September 2007 up to November 2007 with RMPCT (RMPCT performance)

4.1 Digestion blow off ratio

DBO ratio means:

$$DBO\ ratio = A/C = \frac{Al_2O_3\ g/L}{NaOH\ g/L}$$, called in the process pregnant liquor, because it has high alumina concentration in a caustic solution. In the train which operates with RMPCT control the DBO ratio target is 0,750.

The DBO ratio is the main parameter to determinate digestion productivity. Good control of the DBO ratio on the specified target means a small variability of this parameter, which makes it possible to achieve high productivity.

Figure 8 shows the behaviour of the DBO ratio standard deviation (δ_{DBO}) with RMPCT operation and without it.

In digester operation without RMPCT, the average δ_{DBO} (0.005) is higher compared to digester operation with RMPCT (0.002).

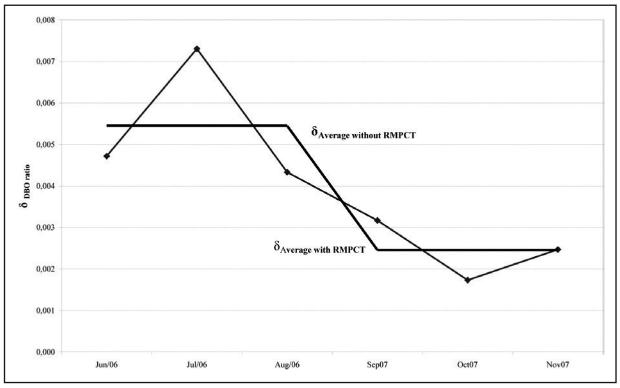

Figure 8. Behaviour of DBO ratio standard deviation (δ_{DBO}) with and without RMPCT operation.

Table 2 shows DBO ratio performance with and without RMPCT operation.

Table 2. DBO ratio performance

RMPCT Operation	Average DOB Ratio	Average δ_{DBO}
Without	0,748	0,005
With	0,751	0,002

4.2 Productivity

To calculate digestion productivity, equation 1 is used:

$$Y = (((C_{SL} - S_l)\cdot A/C_{DBO}) - (C_{SL}\cdot A/C_{SL})) - C_{STT}\cdot 0{,}654 \quad (1)$$

where:

C_{SL} = Spent liquor caustic concentration (g/L)
S_L = Loss due to Silica
A/C_{DBO} = Digestion blow off ratio
A/C_{SL} = Spent liquor ratio
C_{STT} = Spent liquor solids concentration

Other improvements were made in the plant to increase productivity, for this reason, the productivity parameter takes into consideration only the DBO ratio and keeps other parameters in equation 1 constant. Table 3 shows the values of parameters that were used in equation 1.

Table 3. Constant parameters in productivity equation

A/C_{SL}	0.3996
S_L g/L	9.074
C_{STT} g/L	2.003

Figure 9 shows the behaviour of productivity in the digestion system. A productivity gain to Alunorte of 1.02% is shown from the average base line.

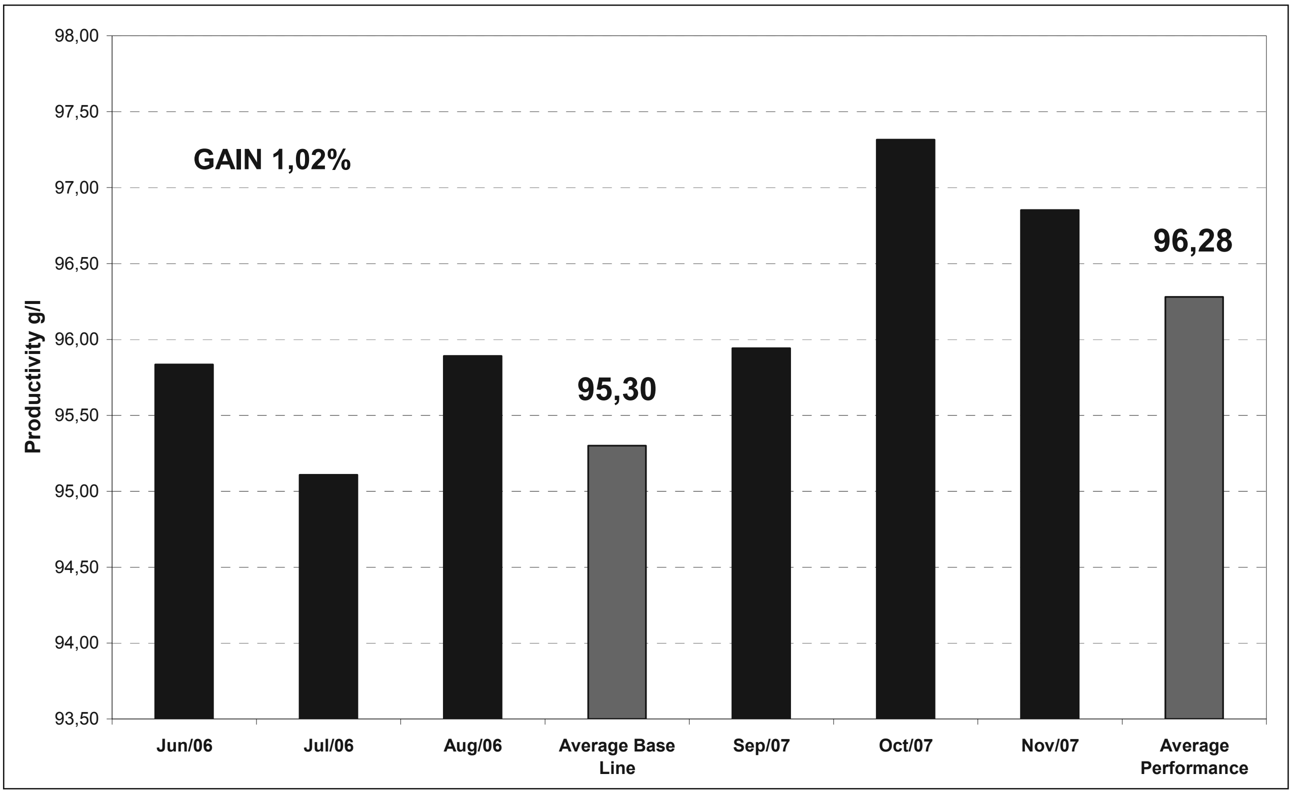

Figure 9. Behaviour of productivity in digestion system with and without RMPCT operation.

5. Conclusions

An effective RMPCT implementation in an alumina digestion unit has been described. Reduction in A/TC variability and a higher operation stability were proven. Also, the opportunity to operate the plant close to the operational constraints yielded productivity increase and helped plant debottlenecking. The steam and test tank liquor flow consumption did not change significantly, since the objective was to increase the alumina production by debottlenecking.

References

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