APPLICATION AND BENEFITS OF ADVANCED CONTROL TO ALUMINA REFINING

Robert K. Jonas
Honeywell Int., 2500 W. Union Hills Dr., Phoenix, AZ, 85027, USA

Keywords: alumina, advanced control, mpc

Abstract

Substantial returns to alumina refineries can be realized through the use of control technology that utilizes existing infrastructure and requires minimal support staff. The globalization of markets and the consolidation of producers have created a more competitive environment that drives the need for optimal production and performance in alumina refineries. Throughout the Bayer process, advanced control is becoming a preferred tool to deliver return on capital employed. Primarily, this is being done using the prevailing control technology, multivariable predictive control. This paper will discuss the applications and benefits of this technology in the alumina industry.

Increases in production, yield, and quality are being realized in many areas of the Bayer cycle using multivariable predictive control, most notably in the control of the bauxite digestion area. New benefits are being achieved by applying this control technology to evaporation and heat-interchange units. The technology is also proving to be suited to grinding, precipitation, and calcination. Improvements in production or yield of up to ½ to 4% are realizable.

Introduction

Many alumina refineries are realizing substantial financial returns through the use of advanced control technology. The globalization of markets, the consolidation of producers, and emergence of substitutes has created more competitive environment that drives the need optimal production and performance in alumina refineries. Throughout the Bayer process, advanced control is becoming a preferred tool to deliver return on capital employed because it utilizes existing infrastructure and requires minimal support staff. The prevailing control technology used to achieve these results is multivariable predictive control (MPC). This paper will discuss the applications and benefits of this technology in the alumina industry.

MPC technology is used in hundreds of different processes worldwide. Much like the venerable single-loop controllers (PID), this type of control has been used throughout the world on every industrial process. However until recently, mining and metal processing industries use of MPC has been limited to a few applications. More than ever, MPC is being applied to many areas of the Bayer cycle.

Digestion

The digestion process has the most potential for MPC benefits. This is because digestion is considered by many refineries to be the key production unit and because the suitability of the process and generally good state of digestion controls. One of the first applications of MPC in digestion was in the digestion area in 1996 in Western Australia at a large refinery.

Application of MPC to Digestion

Typically digestion control manipulates liquor, bauxite, and steam flow to a unit. Primarily the MPC task is to regulate the digester's blow-off ratio (A/TC) and digestion temperature, and to maximize throughput. However, these tasks could not be achieved effectively if other crucial parameters were not also limited or controlled to the satisfaction of the operating crews. For example, test, flash, and flow-off tank levels need to be monitored and limited when necessary. Refer to Figure 1.

MPC is well suited to digestion because of the long delay times of 10 –20 minutes and multiple variables that need monitoring, and regulation or limiting. In fact, several digestion units have been controlled from a single MPC application, however for larger number of units many implementers have chosen to apply separate MPC applications to simplify use and maintenance, as well as distribute the application to reduce risk from a single point of failure.
Benefits of APC to Digestion

The primary benefits of MPC in the digestion area is by increased throughput, improved yield by better temperature and blow-off ratio control, and in some cases reduced steam consumption. Energy consumption becomes important when steam availability limits production, otherwise the optimal use of steam is necessary to achieve yield and quality targets. Typical benefits [3]:

- 0.5 to 1% throughput
- 0.5 to 1% yield

Grinding

In the last decade, several advanced control techniques have been used for grinding with a great deal success in the mining industry, and in particular there has had some limited success of advanced control in alumina industry [4,5,6].

Application of MPC to Grinding

Grinding/milling is a good area for application of MPC because of the importance of grinding on quality and throughput. Grinding is one of the first applications of MPC, as well as other supervisory control techniques. The application controls the key mill parameters such as particle sizing, mill load, and densities. The key parameter to be measured is the mill loading, which can be measured with sonic probes or inferred from mill power and feed. For example in a typical ball mill, the application controls mill loading, mill solids, cyclone feed density, particle sizing, and cyclone feed rate. In this example, MPC achieves this by manipulating ore feed rate, mill water flow, sump water flow, and recycle flow. The multitude of controller variables and small number of manipulated variables require that some monitored variables are controlled to a limit, and that the MPC control

Figure 1. Digestion MPC Diagram

Figure 2. Grinding MPC Diagram
effectively manage priorities of the controlled variables. Refer to Figure 2.

Grinding/Milling is well suited to advanced control because of the high degree of interaction in the mill that are well managed by multivariable type controls. For example, a change in any one of manipulated variables such as ore feed rate, mill water flow, or sump water flow effects every monitored variable. Thus, adjustments to the mill become a careful orchestration that is easily handled by MPC. Furthermore, in some grinding systems the moderate response time of the grinding circuit minimizes the need for good predictive control, thus this application has proven suited to other advanced control methods that can suitable control and prioritize multiple variables.

Benefits of APC to Grinding

The benefits from advanced control of grinding are from improved throughput (loading), particle size distribution that effects digestion recovery, and reduced energy consumption. Typical benefits are [4, 5, 6]:

- 1.0 to 4.0% throughput or
- 0.5 to 2.0% energy reduction

One dramatic illustration the increased throughput capability of MPC can be seen in Figure 3. This is Data from over 2 months turning the MPC application on and off for 12 hour period. The data shows a higher average with MPC [4].

![Figure 3. Trials of MPC for Bauxite Grinding](image)

**Evaporation and Heat Interchange**

**Application of MPC to Evaporation and Heat Interchange**

Advanced control of the evaporation and heat interchange has been applied with good results. In many cases it is desirable to run the units to their equipment limits, thus MPC provides a means to monitor the limitations and optimize the flows to provide the best operation considering the need to increase throughput, overall efficiency and liquor temperatures. The application manipulates the flows to each of the evaporation or heat interchange units, as well as bypass and recirculation flows in order to regulate or maximize flows, temperatures and evaporation rates. Refer to Figure 4.

MPC is ideally situated for control of these units because of it's ability to monitor the multiple limitations in each unit and make the appropriate flow decisions to achieve the optimization and control objectives for each unit and the overall evaporation or heat interchange process. For example, the MPC can push feed flows to the limits of flash tank or effect levels in order to maximize recycle flow and hence the evaporation rates. In this example, liquor temperatures can be monitored as well as controlled to run to a temperature limit or optimized to a temperature. Also, for those evaporation units that feed oxalate removal plants it is usually desirable to maintain constant flows, thus MPC can be set to move these units last (only when needed).

Benefits of APC to Evaporation and Heat Interchange

The advantages of evaporation MPC are the stability in evaporation rates and temperature control, and increased throughput. Because of MPC multivariable ability it can manage flows through the evaporation units to insure adequate spent liquor flow, but in a way that maintains or maximized evaporation rates. Stable and optimized evaporation rates allow digestion bauxite additions to be applied at the best ratios for maximum production and maintainable scaling rates. Similarly, MPC for heat interchange maintains desired green (pregnant) fill temperatures to improve precipitation yields in manner that uses the most efficient heat interchange units and minimizes bypass flows. By adjust targets and limits, several modes or combinations of operation can be selected, such as:

- Maximize evaporation rate (maintain throughput and tank inventories, and limit liquor temperatures)
- Maintain constant evaporation rates (maintain throughput and tank inventories, and limit liquor temperatures)
- Maintains desired green liquor fill temperature (maintain throughput and precipitation yield).

The is a new application of MPC and the benefits are not as well documented as digestion and grinding, but the benefits have been estimated at [3]:

- 0.25 to 0.5% throughput increase (digestion yield)
- 0.25 to 0.5% decrease in soda losses due to increased washing ability.
- 0.25 to 0.5°C temperature decrease due to reduced variability.
Mud Washing

Application of MPC to Mud Washing

Presently mud washers and thickeners (a.k.a. decanting) are extensively controlled by supervisory programs in the industry. The first MPC applications in mud washing and thickening circuit will most likely occur in this year, or the succeeding year. This absence of MPC is most likely because other MPC opportunities have taken priority and that the benefits are slightly less than other opportunities in the Bayer circuit. Nonetheless, control and optimization of the mud washing circuit is well matched to MPC, given that sufficient instrumentation is available, namely mud and interface levels and underflow density measurement. The application controls the underflow density, mud levels and mud interface levels, and limits rake torque. This is achieved by manipulation of underflow, flocculent addition, and in some cases by underflow pump injection. In addition, overall washing circuits control & optimization can be included for regulation of net dilution and overflow solids control.

The mud washing circuits are well suited to MPC because of the considerable amount of interaction and long delay times. For example, changing the addition of fresh dilution to a washer train may take several hours before the effects are seen. MPC can make more accurate and prompt control moves, while for controls that are not predictive must be tuned slower or suffer from cycling. Also, most MPC solutions have movement minimization function that should be used to prevent fast underflow changes that will upset downstream mud washers. In addition, the MPC can be made to adjust responses based upon the number of washers in the circuit (through model adaptation techniques like gain scheduling).

Benefits of APC to Mud Washing

The advantage of MPC on mud washing and thickening is reduced soda losses and flocculent consumption. In addition, upsets are reduced because the multivariable nature of MPC allows rake torque to be monitored and corrected, and that control manipulations will be made in a manner conducive to good settling. The estimates have been estimated at [3]:

- 0.5 to 1.0% caustic losses
- reduction in incidents and digester flow cuts
Calcination

Application of MPC to Calcination

The calcination process is area of opportunity for MPC. In similar processes for lime kilns in pulp and paper industry MPC has been very successfully applied [7], and supervisory controls have been applied for alumina calciners [8] and extensively for cement kilns. The MPC application varies with calciners type, either rotary kiln or fluidized bed. For the rotary kiln case, the MPC application would manipulate the combustion fuel, air flows, rotational speed, feed flow and regulates or limits product temperature, discharge-end temperature, feed-end temperature, and O2. In the case of the fluidized-bed calciners, the MPC application would manipulate the combustion fuel, air flows, feed flow, hot valve, and regulates or limits product temperature, furnace top temperature, pre-heat temperature, holding vessel residence time, and O2.

The use of advanced control of kilns is fairly extensive because of the long delay time in product qualities and the high degree on interaction among the kiln variables. These same conditions are also true for alumina calciners. The product flow in the calciners can take several hours which is a control problem well suited to predictive controls. The interaction among air and fuel flows with product qualities and energy efficiency are well managed by multivariable controls, and as stated earlier, improved due to the predictive control of these interactions.

Benefits of APC to Calcination

The primary benefits of calcination advanced control are the reduction of energy, improved hydrate quality and throughput. Other advanced control techniques (fuzzy logic) have been used in alumina calciners [8] and MPC control has been applied on similar processes (lime kilns) [7], and these have yielded the benefits in the range of:

- 1.0 to 10.0% throughput increase
- 1.0 to 8.0% energy reduction
- 30 to 50% reduction in product quality standard deviation (specific surface area)

Precipitation

Application of MPC to Precipitation

It is feasible to apply MPC to control of flow through continuous precipitators, however many of the key parameters are not continuously measured which limits the effectiveness of applying MPC. This is not to say MPC has no use in precipitation, as it has been used to manage flow through parallel units to control tank levels in a way that minimizes flow changes, limits unit flow to unit limitations (like maximum bank flow due to weir overflow), and could be extended to manage seed rates.

The multivariable control features of MPC allow flows through the precipitation buildings to be optimized for best throughput, head pumping capacity, and surge inventory. In addition, the movement minimization features of MPC stabilize flows while maintaining liquor surge inventories.

Benefits of APC to Precipitation

The advantages of MPC in precipitation is improved throughput of liquor, the management of GL feed tank and SL tank levels, and stability of GL flows to the precipitators.

Benefits Summary

The financial returns of the benefits discussed previously are significant. For a typical alumina refinery, these are summarized in Table I.

### Table I. Typical Benefits of MPC

<table>
<thead>
<tr>
<th>Area</th>
<th>Description 1</th>
<th>Benefits</th>
<th>Benefits Low-High</th>
<th>$K per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestion</td>
<td>Yield</td>
<td>0.5-1%</td>
<td>$250K-500K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throughput</td>
<td>0.5-1%</td>
<td>$250K-500K</td>
<td></td>
</tr>
<tr>
<td>Milling</td>
<td>Throughput</td>
<td>1-4%</td>
<td>$500K-2000K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>0.5-2%</td>
<td>$10K-40K</td>
<td></td>
</tr>
<tr>
<td>Evaporation</td>
<td>Yield</td>
<td>0.25-0.5%</td>
<td>$125K-250K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throughput</td>
<td>0.25-0.5%</td>
<td>$250K-500K</td>
<td></td>
</tr>
<tr>
<td>Heat Exchange</td>
<td>Caustic loss</td>
<td>0.5-1%</td>
<td>$40K-80K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throughput</td>
<td>1-8%</td>
<td>$120K-100K</td>
<td></td>
</tr>
<tr>
<td>Mud Washing</td>
<td>Throughput</td>
<td>1-10%</td>
<td>$500K-5000K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total (Conservative)</td>
<td>0.25-1%</td>
<td>$125K-500K</td>
<td>$2170K</td>
</tr>
</tbody>
</table>

Assumptions:
1. Based on 1,000,00 tonne per annum production,
2. Value of alumina is $170/tonne,
3. Cost of production $120/tonne
4. 6 MW power at a cost of 3cents per KW/hr.
5. 1% per 1 C yield improvement.
6. Caustic loss shift is 200g/tonne, cost of $200/tonne.
7. Energy consumed 4GJ/tonne, cost of $3 c/GJ.

It should be noted that benefits from MPC are usually achieved by better regulation of key parameters and optimization to improve economics. Furthermore, this has can be broken into the essential components of MPC to achieve improved benefits:

- Addition of key process measurements for monitoring and limitation (control) to high or low bounds. This is essential as it allows removal of fixed limits that restrict operation that have most likely been set to assure a certain level of safe operation or reduced control-room operator effort. Without MPC, these normally monitored by control room operator and thus fixed limits may be set to avoid bothering the control room operator.
- Better regulation that reduces variability.
- Optimization function that moves key average values to improve economics, usually resulting in operations closer to constraints. Typically, this shift is around 25% of the standard deviation before MPC, once special causes are removed.

The result of these functions in MPC allows certain key operating parameters (like throughput) to be shifted as shown in Figure 5.
There are essential elements in the advanced control technology that must be satisfied in order to achieve benefits improvements. A good way to put into perspective by looking at the state of base level control and other advanced control technologies.

Regulatory Control

This control consists of the familiar single-input, single output controller that is used to regulate most loops (also known as a PID loop). This is well suited to simple first level control, regulating flow or pressure. The controller reject supplier disturbances. A good example is monitoring flow measurement and adjusting a modulating valve. Also, this may serve to linearize valve to flow, which can improve reaction of higher-level control schemes. However, the problems with this are:

- Requirement for operator to monitor other values and intervene when other limits are reached
- Account for other controller actions, not easily achieved for multiple interactions or complex dynamics.
- Slow response when the process has a long delay or lag, must tune conservatively to be stable (no cycling). Essential this type of control has limited predictive control capabilities.

Advance Regulatory Control

This control consists of either cascaded regulatory controllers (PID) with override functions, or advanced control programs. These types controllers provide some benefits in simple applications. Overall, they exhibit the following problems:

- Complex to maintain, it requires knowledge of programming or special tuning skills.
- Very difficult to include predictive features to account for other controller interactions or long process lags and delays.

Fuzzy Logic and Expert Systems

Fuzzy logic and expert systems (rule based or neural net based) provide good functionality for certain cases, where the process reaction is relatively fast and the interactions simple or small in number. Otherwise, they suffer from similar problems as outlined for advanced regulatory control, that is poor prediction capability and growing complexity with the number of variables monitored and manipulated.

Multivariable Predictive Control

This technology is generally accepted as the best control technology available for medium to large processes because of its superior capability with multiple interactions and predictive capability. The primary advantages of MPC are:

- Fast response and better control because of predictive capability.
- Better control because of knowledge of interactions.
- Less complex as interactions are handled internally, models can be easily acquired or entered empirically.
- Definable priorities when there are competing objectives (what is more important).

Many of MPC available today are 4th generation and have a good feature set that includes functionalities to improve robustness (how the controller responds to bad data, changes in plant dynamics). In fact, MPC has many of the features often touted by statistical process control and fuzzy logic. For example, only making control moves when significant changes occur, or having different control actions for different ranges of values (for example, react fast when level is high).

Conclusions

Early adopters of multivariable predictive control are seeing the benefits. Increases in production, yield, and quality are being realized in many areas of the Bayer cycle using, most notably in the control of the bauxite digestion area. Improvements in production or yield of up to ½ to 4% are realizable. New benefits are being achieved by applying this control technology to evaporation and heat-interchange units, and precipitation.

References


