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ON-LINE MULTIVARIABLE CONTROL FOR DIGESTION A/C ANALYSIS

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Abstract

Better control of deviations from alumina to caustic AIM at the digester blow off can be achieved when knowing process variations and physical property characteristics. These include the test tank liquor concentrations, bauxite charge characteristics, dilutants to bauxite charge, and time through the digesters. This provides an excellent case for the use of multivariable control to set the plant flow and bauxite charge rate by taking into consideration the retention time and bauxite parameters.

This paper describes a linearized solubility relationship with real time measured variables to determine alumina and caustic concentrations. From this relationship, a feedforward set point is derived using accurate stream properties plus current plant conditions, including equipment selection and flow characteristics.

The validation of the set point is checked by the feedback trim that alters the feedforward set point for variations within the digesters which lead to deviations from the target alumina to caustic AIM. The scaling factors correlate the accuracy of the instrument's measurement with laboratory data over a long time period. Newly developed in-line instrumentation is used to increase the on-line factor.

Introduction

Achieving a better digestion target with advanced control techniques is now possible due to the introduction of new on-line instruments and improved microprocessor technology. Early applications of complex analysis for chemical compositions required laboratory and engineering calculations to predict a fixed effect of the variations. Today it is possible to characterize those effects with a linear, multivariable control model usable by standard operator actions.

Multivariable control (MVC™), as defined by Continental Controls, Inc. provides on-line optimal set points for manipulated variables based on the interaction of all relevant process variables, properties, plant configurations, and desired results. In contrast regulatory control provides single variable measurement and control action; optimized control, on the other hand, predicts the overall system behavior for a static set of process variables and equipment configurations. An MVC™ system must have controllability over a wide range of variability. The control of digestion alumina, and caustic concentration cannot be achieved without these degrees of freedom. An effective control scheme must account for the interdependence of the test tank liquor conditions and the bauxite charge rate. The bauxite charge is dependent upon the bauxite properties as well as the time delays through the system. These time delays include the time of the liquor from the test tank through the heaters to the first digester and the slurry tank retention time. This situation provides an ideal application for the use of multivariable control.

Control Approach

A regulatory solution for control might be the ratio of the test tank flow to the bauxite slurry flow. This scheme, however, does not take into consideration the interdependence of the spent liquor concentration and the bauxite properties. In addition, flow control of the test tank liquor stream does not adequately control the alumina carrying capacity of this stream. Even if a mass control solution were possible, there is not an allowance for variability of the caustic concentration in that stream. A function would have to be preprogrammed providing for the calculation of the caustic concentration, thus eliminating the variability factor.

An optimized approach to this problem might be to mass control the test tank liquor stream based upon chemical analysis and to mass control the bauxite charge. This solution fails to account for the relationship between the two streams. It also assumes constant bauxite properties and slurry tank conditions.

Continental Controls' solution is to mass control the test tank liquor stream based upon the analysis of its physical properties and mass control the bauxite charge while taking into account the residence time through the heaters, the deviations in the bauxite properties and current plant configurations. Because the liquor analysis uses physical properties (conductivity and density) to infer the chemical concentrations, they can be measured on-line which eliminates lag time due to the manual analysis reporting by the laboratory. It has also been found that the on-line instruments increase the precision of the liquor analysis.
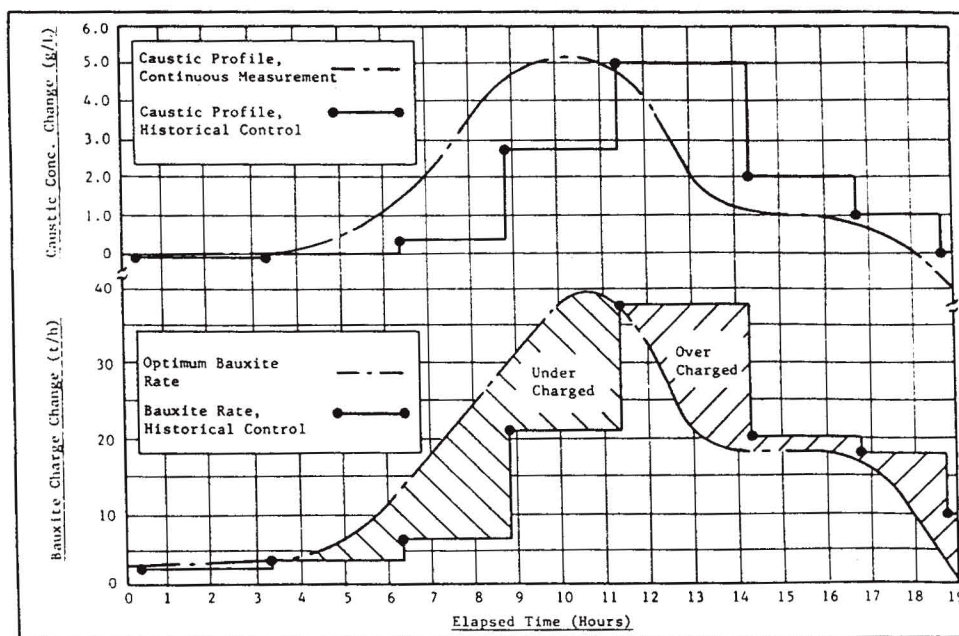
HISTORICAL VERSUS OPTIMUM BAUXITE CHARGE CONTROL SYSTEMS
Figure 1

The curve of system response as reported by Dr. P. McIntosh,[1] illustrates the advantage of quicker response time, see Figure 1.

A set of equations were developed to incorporate the variability of liquor properties into the determination relationships[2]. These experimental relationships, over the entire concentration range, are best fit by nonlinear equations. However, when considering the test tank liquor and the digestion liquor concentrations separately, the quadratic function can be linearized over a set of ranges with little error. Since these equations are generic in form, they can be modified on-line to fit the given plant conditions. Another advantage with using a linear solution is its robustness. Regardless of plant conditions, a linear solution will always converge, thus, an answer can be produced to achieve any set measurements over a wider range of process conditions. A multiple regression technique is used to linearize the determination equations.

A comparison between linear and nonlinear determination equations can be seen in Figures 2 and 3. This comparison is similar for the test tank analysis.
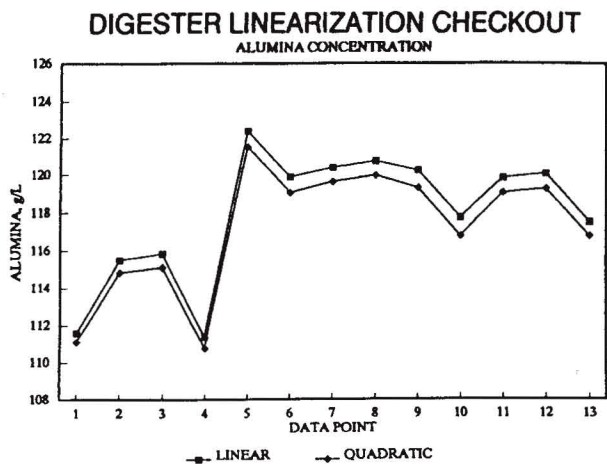

DIGESTER LINEARIZATION CHECKOUT
CAUSTIC CONCENTRATION

Figure 3

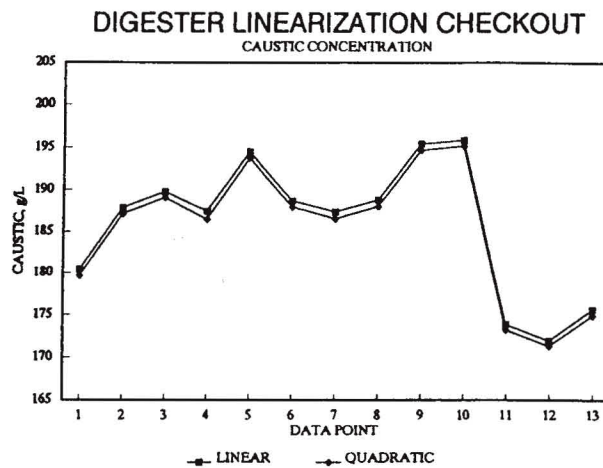DIGESTER LINEARIZATION CHECKOUT
ALUMINA CONCENTRATION

Figure 2

The range over which the test tank equations were linearized is 160-200 gpl for caustic and 50-65 gpl for alumina. Over that range, the difference between the two types of equations was 0.11 gpl in the alumina terms and 0.05 gpl in the caustic terms. This is more than adequate for control purposes.
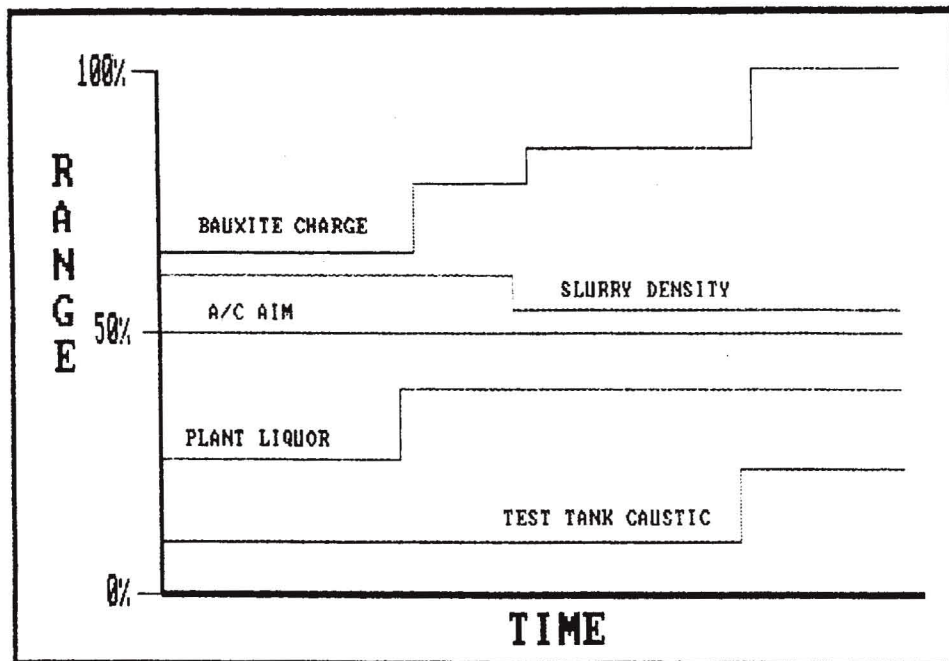
BAUXITE CHARGE VERSUS INDEPENDENT VARIABLES

Figure 4

The interaction between the test tank A/C calcu-lation and the bauxite charge rate can also be seen. An increase in the plant flow caustic concentration results in an increase in bauxite charge.

Measurement

The measurement of the physical properties for the solubility control scheme is feasible with newly developed instrumentation. The abrasiveness of the conditions in the digesters makes it impossible to use many instruments that have elements protruding into the stream. Scaling of instruments reduces the instrument's accuracy. A special Coriolis meter was fabricated for the density measurement. For the conductivity measurement, a probeless sensor was chosen. These instruments are designed for high temperature and high pressure conditions so that the measurements can be made as close as possible to the point where digestion is nearly complete. This allows for the shorter dead time used in the feed-back trim. In order to keep from scaling, the flow is controlled using a control valve. All measure-ments are converted into the signals that are used by a personal computer, where the MVC™ is programed. The SCADA package is a multitasking shell which allows for data base access and execution of the application programs which monitor and control the process conditions including the bauxite charge.

Software

The MVC™ system as discussed so far provides a ratio which is close to target. However, to maintain the true values of your target, a set of calibration factors are installed to make the various instrument sensors produce the same values for identical process conditions. The first set of factors are used in the linearized equations and include offset factors and fouling factors. Offset factors are implemented during commissioning of the system and after cleaning any of the analyzing instruments. They correct the field measurements to the same caustic and alumina concentrations for the same conditions, i.e., the same flow through each unit should read the same conductivity and density measurement. The fouling factors are used to cali-brate the A/C concentration determined from the MVC™ system from a laboratory reading. Deviations between laboratory and analyzer concentrations could be a result of changes in the liquor conditions or scaling of the field instruments. This on-line calibration procedure extends the time for field recalibration of the instruments. The factors, implemented on-line by the operator, are time stamped so that the laboratory analysis is compared against the instrument value at the grab sample time. Due to deviations in laboratory analysis, a weighted average or exponential smoothing is used in the calculation of these factors.

An off-line spreadsheet is used to solve the multiple regression matrix which in turn gives the constants for the linearized equations. This spreadsheet allows the engineer to relinearize the existing algorithm off line for changes in liquor properties. Data is entered into the spreadsheet and new constants can be entered, tested and saved without the current linear program which is being run on-line.

Control algorithm for the bauxite charge uses process conditions as well as bauxite properties analyzed by the laboratory. The alumina to caustic (A/C) ratio in the digesters can be controlled closer to the target without fear of overcharge. The bauxite charge calculations are divided into two sections, feedforward and feedback trim. The feedforward portion is divided into two portions, the amount of alumina currently entering the digesters and the capacity of the liquor flow streams. The first division of the feedforward section uses mass balances which incorporate bauxite properties as determined in the last laboratory analysis, current field conditions, retention times, and the liquor concentrations. The bauxite properties include the net extractable alumina, solids in the slurry tank, and any significant nonmeasured densities such as density of lime when added to the slurry stream. The field instrument measurements include the flows and densities for significant streams which are needed for the mass balance equations. The final element required by the mass balance equations is the caustic and alumina concentrations in the slurry tank. These concentrations are not necessarily the same concentrations as those which are currently being calculated by the linearized equations. They need correction for the time through the heaters and the retention time in the slurry tanks themselves. All of the aforementioned factors are combined to determine first, the mass rate of alumina currently entering the digesters including the mass of alumina which has dissolved into the liquor portion of the slurry. Second, the alumina carrying capacity of the stream is determined by the linearized relationships, again corrected for the residence time through the equipment. These two feedforward portions are compared with an A/C ratio provisional target, which can be modified on-line by an operator and a new bauxite charge set point(s) is delivered.

The feedback section incorporates the alumina and caustic concentrations of the digesters as calculated from the readings of the digestion A/C analyzers and the MVC™ equation. It compares these concentrations with the target ratio and produces a trim multiplier. This will not only account for offsets between target and the inferred ratio, produced from the feedforward calculation, but also for varying conditions within the digesters. A typical set of equations for this solution is:

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MAP   = (XSOLST-XSOLBM)*FLSL*DBSL
MAB   = (FLSL*DBSL*XSOLST)*NEA
MAL   = ATT*FLIQD + ASLURR*XLIQSLURR*FLSL
MWS   = ACAIM*(CTT*FLIQD+CSLURR*XLIQSLURR*FLSL)
DELTA = MWS - MAP - MAB - MAL
NVF   = (MAB+DELTA)/(DCOR*XBX*NEA)
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WHERE

MAP = mass of alumina in slurry tank dissolved into spent liquor

XSOLST = fraction of solids in the last slurry tank

XSOLBM = fraction of solids entering the first slurry tank

FLSL = flow of slurry immediately leaving the slurry tank

DBSL = density of slurry immediately leaving the slurry tank

MAB = mass of alumina in the slurry

NEA = net extractable alumina

MAL = mass of alumina in the liquor streams

ATT = concentration of alumina in the test tank liquor stream corrected for the time through the heaters calculated from linearized equations

FLIQD = flow of liquor to the digesters

ASLURR = concentration of alumina in the slurry tank

XLIQSLURR = fraction of slurry that is liquor

MWS = capacity of the liquor stream

ACAIM = target ratio

CTT = caustic concentration in test tank liquor corrected for the time through the heaters calculated from the linearized equations

CSLURR = caustic concentration in the slurry tank

DELTA = difference between the alumina in solution and the capacity of the liquor stream

NVF = new bauxite charge volumetric set point

DCOR = density of slurry corrected for the addition of lime and steam.

XBX = mass of bauxite ore in slurry tank

A variation in the independent variables in the mass balance equations will cause a variation in the bauxite charge set point (Figure 4). An increase in plant liquor flow would cause an increase in bauxite charge. An increase in the dilution streams, added to the slurry, can be seen by the varying slurry tank density.

The bauxite charge set point is tuned through the feedback trim. Before the feedback multiplier is used, a dampening factor is incorporated. The dampening factor or feedback gain takes into account the calculated residence time from the first digester to the sample system. By increasing the dampening factor, the bauxite charge rate modifier is increased. A dampening factor of zero would result in no feedback action. These feedback actions correct the bauxite charge and caustic and alumina concentrations for inaccuracies that might be unaccounted for within the MVC™ equations.

Installation

The installation of the MVC™ system is made easy through the use of operator screens. The system is comprised of both high resolution graphic screens and character graphics screens. The high resolution screens are process diagrams, which show location and status of the A/C analyzers, as well as the final outputs for bauxite charge, A/C linear control schemes, and trend information. The trend screens include field input measurements from the analyzers as well as the concentrations produced from the algorithms. The character screens are for control purposes. They contain the face plates for the control of the process flow through the instrument racks. All bauxite properties are entered off-line are from these screens. In addition, they contain significant flow and density field measurements used in the bauxite charge algorithms and the tuning factors. From these screens the tuning and drift factors are initiated and the results are printed.

As with any new control application, it is important to provide a training class to aid in the understanding of the system. The class has several parts: one, the multitasking environment; two, the MVC™ system; three, maintenance; and four, operator training.

Conclusions

Besides the significant economic advantages to the user, a key benefit of this MVC™ system is its adaptability. The control scheme could be reversed, and the capacity of the stream could be varied to meet the current bauxite charge flow. The target AIM is reached more frequently because there is no lag time between the laboratory analysis and the subsequent control changes. The plant liquor concentrations can be monitored on-line. This on-line analysis has led to a reduced number of laboratory samples. The on-line instruments have proved to be more consistent and repeatable in their analysis. Typical laboratory analyses are subject to human variability. However, when statistically plotting a curve of continuous laboratory results, the instrument values (as modified by the fouling factors) were more often closer to the laboratory statistical curve. Figure 5 is a representation of the on-line caustic concentration calculation versus the laboratory analysis. The fouling factors eliminate the need to constantly recalibrate the instruments in the field.
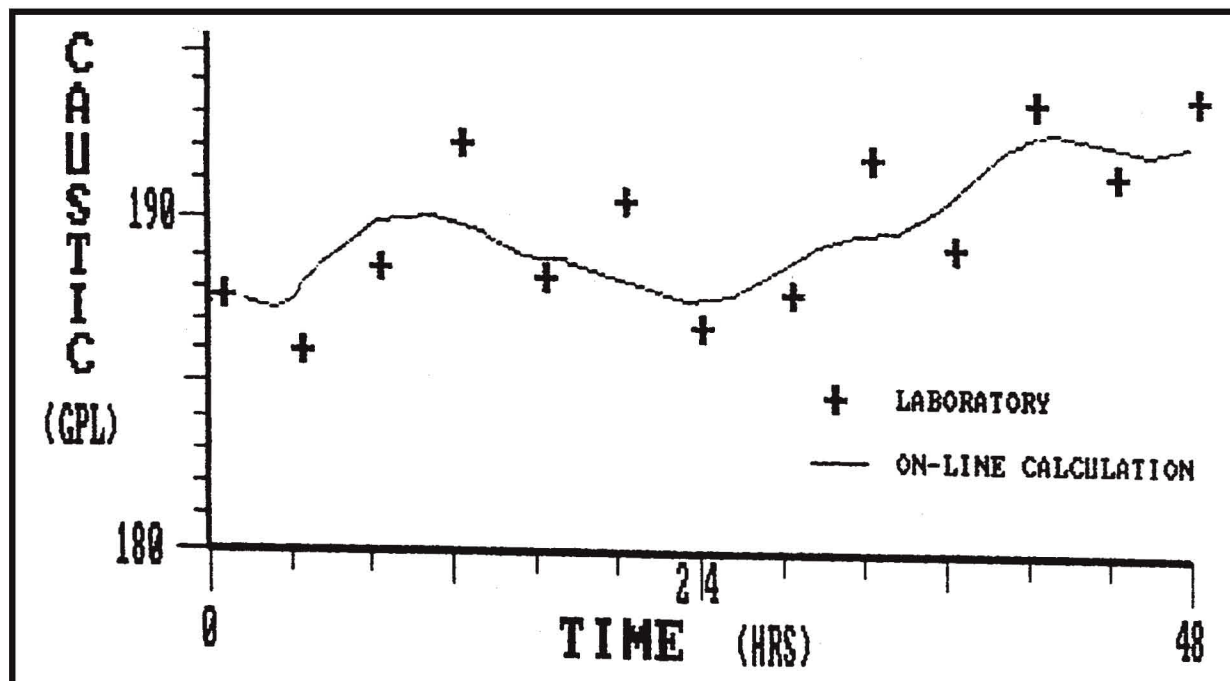

Figure 5

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With the improved performance, the plant can optimize the consumption of caustic and extract the maximum alumina without fear of overcharge and its resultant problems. Better control of digestion makes the overall plant stability achievable, regardless of plant flow. Digester energy consumption can also be reduced using a similar MVC™ on the control of digester temperature.

Acknowledgment

Early discussions on linearization of the quadratic equations were held between Dr. Jean-Pierre Riffaud, Alcan International Limited and P. N. Berkowitz, Continental Controls, Inc. We are grateful for Dr. Riffaud's contribution in exploring this opportunity.

References

1. P. McIntosh, "Optimum Control of Bauxite Charge to High Temperature Digestion Units at QAL.Light Metals 1984 (New York, NY: American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. 1984) 31.

2. Pierre Cousineau, Alcan International Limited, Personal Communication.

Recommended Reading

Csoke, B., G. Mucsi, and K. Solymar. Optimization of bauxite grinding by means of empirical model (2005, pp. 53–58).

Hilfiker, K.F. Application of fluid-dynamic principles on flashing of liquid and slurry in evaporation and digestion plants (1978, pp. 39–50).

Jamialahmadi, M., and H. Muller-Steinhagen. Forced convective and subcooled flow boiling heat transfer to spent Bayer liquor (1992, pp. 141–150).

Kumar, R., et al. Mechanochemistry and the Bayer process of alumina production (2004, pp. 31–34).

Kumar, S. Indirect bauxite slurry heating system for the Bayer process (1989, pp. 137–140).

Ma, C., et al. Selection of Bayer digestion technology and equipment for Chinese bauxite (1996, pp. 187–191).

Maltz, N.S., V.M Sizyakov, and N.S Shmorgunenko. Digestion kinetics of monohydrate bauxite (1983, pp. 99–107).

Pawlek, F., M.J. Kheiri, and R. Kammel. The leaching behavior of bauxite during mechano-chemical treatment (1992, pp. 91–95).

Schooler, L.N. Comminution of Caribbean bauxites in rod mills (1980, pp. 19–37).

Singhoffer, E., and J. Steiner. Experiences for the reconstruction of traditional digestion lines with the application of tube digestion elements in the Hungarian Alumina plants (1990, pp. 27–33).

Solymar, K., T. Ferenczi, and D. Papanastassiou. Digestion alternatives of the Greek diasporic bauxite (2002, pp. 75–81).

Songqing, C., et al. Improvements of the processes to produce alumina from Chinese diasporic bauxite (2003, pp. 153–158).

Van Den Broek, B. The third generation of autoclave feed pumps (2004, pp. 121–125).