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DEVELOPMENT OF AUTOMATIC CONTROL OF BAYER PLANT DIGESTION

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Supervisory computer control has been achieved in Alcan's Bayer Plants at Arvida, Quebec, Canada. The purpose of the automatic control system is to stabilize and consequently increase, the alumina/caustic ratio within the digester train and in the blow-off liquor. Measurements of the electrical conductivity of the liquor are obtained from electrodeless conductivity meters. These signals, along with several others are scanned by the computer and converted to engineering units, using specific relationships which are updated periodically for calibration purposes. On regular time intervals, values of ratio are compared to target values and adjustments are made to the bauxite flow entering the digesters. Dead time compensation included in the control algorithm enables a faster rate for corrections. Modification of production rate is achieved through careful timing of various flow changes. Calibration of the conductivity meters is achieved by sampling at intervals the liquor flowing through them, and analysing it with a thermometric titrator. Calibration of the thermometric titrator is done at intervals with a standard solution. Calculations for both calibrations are performed by computer from data entered by the analyst. The computer was used for on-line data collection, modelling of the digester system, calculation of disturbances and simulation of control strategies before implementing the most successful strategy in the Plant. Control of ratio has been improved by the integrated system, resulting in increased Plant productivity.

Introduction

The automatic control system exposed in this paper is the result of a coordinated effort in different disciplines. This work was carried out by a team of Alcan personnel for several years.

The purpose of this presentation is to analyze the interactions of the various fields of expertise including

- Process operation knowledge
- Sensors and instrumentation development
- Software engineering and control strategy design
- Human behaviour and training

and to present their unique solution to the control problem.

Process Description

Alumina trihydrate contained in Bauxite is dissolved in a caustic liquor to obtain sodium aluminate in the digested slurry. Impurities will be filtered and form red mud. Filtrate is further seeded and pure alumina trihydrate recovered by precipitation. The so-called spent liquor is then recirculated to the digestion area.

In the Alcan digestion process, as illustrated in Figure 1, ground bauxite is fed to a small amount of liquor to make up a slurry which is pumped into the digesters. The main liquor stream is injected directly into the first digester together with steam. Reaction then starts and carries on in following digesters. Digested slurry is then flashed to get back to atmospheric pressure and the recovered flashed steam is used to preheat spent liquor.

Control Problem

Extraction efficiency and stability of the digested slurry are critically dependent upon the ratio of sodium aluminate to caustic concentration. In order to maximize productivity, continuous attempts have been made to increase the "ratio" by increasing the Bauxite charge in the liquor. However following considerations are limiting.

- If ratio within the digesters is too high, extraction suffers and efficiency rapidly decreases.

- If ratio after the flashing stages (blow-off) exceeds some limits which depend upon various operating conditions, liquor becomes unstable and premature precipitation may occur prior or during mud filtration. This again decreases overall extraction efficiency and may as well cause very serious operating problems in the mud filtration area.

Objective of the Control System has been to stabilize both Digester and Blow-off ratios during continuous operation as well as during transient conditions. Monitoring, alarming and performance analysis are also integral parts of the control functions.

Disturbances which cause the process to deviate from stable operating conditions may be classified into two categories:

Disturbance inherent to process:

- Alumina content in Bauxite varies depending on Bauxite origin and moisture content.

- Alumina remaining in solution in the spent liquor fluctuates depending on precipitation performance. This is characterized by the spent liquor ratio.

- Caustic dilutions are returned in the digesters area from the mud filtration.

Disturbance introduced by the analysis method for ratios:

- Sampling procedures even when standardized may not produce representative samples.

- In Chemical analysis by titration, the analysts have to determine visually the titration end point. This is giving a large variance from analyst to analyst.

- Calculations involved to determine ratio from titration results are subject to errors when performed manually.

Engineering

In order to apply any form of control strategy three elements are required in the so-called control loop as in Figure 2:

- Precise measurement of the process variables to be controlled is essential. The performance of the overall system will be critically dependent upon this information as one will only control not the process but the measurement he gets from it. In other words control will be as good as the measure.

  This justified important developments described in the next section.

- Decision making process or controller should take advantage of all possible knowledge of process dynamic behaviour. Performance is generally improved when a reasonable dynamic model is established. This consideration is even more valid when the process contains pure time delays as it is the case here. Modelling and controller design will be described later on.

- Corrective actions should be accurate and should follow exactly what was required during the decision making stage. In this respect, process engineering was required to improve Bauxite feeding system. Bin arrangement was redesigned. A remotely controlled scale was installed and a major part of the instrumentation was renovated and centralized. A process control digital computer was leased for a 2-year period to serve as a data collecting unit and later on to perform control functions.

  Due to the success of this development program, another computer was bought to replace the original one at the end of the lease.

Sensor Development

Major breakthrough happened when on-line measurement of ratios was made possible. Alcan scientists have established operating conditions of an electrodeless conductivity meter such that electrical conductivity is a linear function of ratio. The conductivity cells are fed by small side streams of liquor. The sampling point in the digester train has been determined experimentally as that at which virtually all the soluble alumina in the bauxite has gone into solution.

Conditions for linearity include temperature of the liquor passing through the cell, frequencies of calibration and washing. Figure 3 shows such a relationship between ratio and conductivity under conditions described above. Scaling affects cell characteristics and therefore produces a shift of the operating line. Estimation of cell constant is characterized by the value of the Intercept. Typical variations as a function of time are illustrated in Figure 4.

Such Variations of the cell constant make calibration of the conductivity meter a major constraint in order to obtain accurate results.

Calibration of the sensor

After every descaling and during continuous operation, a liquor sample is analyzed with the thermometric titrator. This instrument has been described by VanDalen (1). It performs acidimetric titrations to determine concentrations of sodium aluminate and sodium hydroxide in the liquor. The titration end-points are determined via thermal effects and the apparatus automatically terminates the titrations. Calibration procedures are described in detail by Browne (2).

Trends occurring in the calibration relationships are examined and the analyst is advised if these are greater than pre-determined values. He can then decide if emergency maintenance or washing of the conductivity meter is needed.

Results

These calibration procedures improved measurement accuracies from 0.006 to 0.003 ratio units. Accuracy is defined as the standard deviation of ratios measured by thermometric titration at calibration time.

Modelling and Controller Design

Dynamic models of the process were constructed using the computer as an on-line data collection system. Pulse testing technique was used to build and identify those models. Rapid pulse changes in the input streams (bauxite, liquor to slurry mixer and digester feed) were made and the resulting ratio as measured by a conductivity cell was recorded on disk. The methods of analysis used to establish the models from these tests have been reported elsewhere (3).

The models were built to meet three specific objectives.

Estimation of perturbations: A synchronized on-line simulation is run using measured process inputs as model inputs (figure 5). Difference between process and model outputs is recorded and constitutes what we called the perturbation. Several runs were performed and a composite was established and referred to as the standard perturbation.

Digital controller design: Model was simplified to first order plus dead time while still fitting experimental frequency response in the range of interest. P.I. and Smith Controllers were studied using root locus in the Z plane (4) and (5).

Control strategy simulation and optimization: A high speed off-line simulation includes standard perturbation play back and control algorithm as illustrated in Figure 6. Such a simulation was primarily intended for comparing performance of different types of controllers, as designed by analytical procedures.

Performance criteria is the R.M.S. value of the error which, in statistical terms, is the standard deviation.

As analytical design very seldom takes advantage of the knowledge of perturbations, improvement can be obtained. Such an optimization, with respect to control parameters was performed by mapping performance criteria in the control parameter space. Optimum was visually selected. Plant tests of the control strategies have confirmed the simulation results.

Control Algorithms

The purpose of the inner control loop of digester ratio is to keep it as close as possible to the digester ratio target. The outer loop adjusts the digester ratio target so that the blow-off ratio, which differs from the digester ratio because of return streams to the flash tanks, will be kept as close as possible to the blow-off ratio target. The blow-off ratio target is set by the digester operator according to operational requirements of the rest of the plant.

Because of the long transport lags (dead time) in the system, and the mixing which occurs in the vessels, the modelling stage proved to be very useful for selection of time interval at which Bauxite flow should be modified.

The finally selected algorithm is a digital realization of the Smith Controller to provide dead time compensation (6). In addition to changing the bauxite flow, the computer also changes the flow of liquor to the slurry mixer in such a way as to keep constant the percent solids in the slurry.

The outer blow-off loop works on a similar principle, using a different set of control parameters.

Flow Timing Algorithm

In addition to specifying the blow-off target, the digester operator specifies via a teletype, the digester feed flow target. This is changed fairly frequently as conditions in the rest of the plant dictate. A change in the digester feed flow necessitates a change in the bauxite flow and in the liquor to slurry mixer flow.

A change in any of these input flows causes a change in ratio in the digesters. However, the transport time lags are not the same for each flow. To minimize the transient change in ratio arising from the combined effects of all three flow changes, optimum timing was experimentally determined and was implemented.

Other Computer Functions

Process Surveillance

Thirty-five process variables are scanned every minute to determine if there is any indication of trouble. If so, depending upon its nature, action may be taken. Alarm messages are printed on the operator's teletype. If the computer detects interruptions in the bauxite flow through unusual behaviour of the scales, it cancels bauxite corrections for a period, so as to avoid over-compensation for consequent disturbances in the digester ratio.

Logging

Plant data obtained via the scanner is averaged every 5 minutes and stored on disk for 4 days. It is used to produce tables and graphs for the evaluation of control strategies and other tests. Shift and daily reports are printed for the digester operator, foreman and clerk.

Performance monitoring

Daily report includes information relative to productivity such as steam consumption, amount of Bauxite and liquor processed.

Operator communication routines

Process operator may ask for some specific routines to communicate with process via the computer. These routines include:

- Set point modification
- Direct access to action variables
- Information reporting

Utility programs

Some utility programs are available to assist laboratory analysts and engineers in their routine calculations.

Monthly Inventories for raw materials and product are presently in a development stage.

Implementation Phases and Training

Implementation was carried out in 4 distinct phases of increasing complexity. This was justified in order to bring operators, laboratory analyst and foremen familiar with the present control system. For each of these phases a training program has been set up to disseminate information, give enough practising opportunities and verify degree of understanding.

Phase 0 Data logging and alarming only

Reports, statistics and alarm messages were generated. Operator's communication routines were limited to information from the process. Modelling and identification of the process were performed during that phase. We also were able to debug computer system programming without affecting operations.

Phase 1 Manual control

Analysis of ratio was done by conductivity meters with proper calibration from the laboratory, decision making was still left in operator's hands but action on various flows was performed by computer. Purpose was two-fold:

- give psychological precedence of the operator over the computer so that he can feel computer was an effective and powerful tool in his hand. We then established the master slave relationship in the right direction.

- tune up the interface programs and continue work on control algorithm design.

Phase 2 Semi automatic control

Operator was relieved from the decision making, control algorithm did it, but he was asked for ratification of the automatic decision before corrections applied. This phase was intended as a transition to the next phase.

Phase 3 Automatic

Adjustments and corrections are now done without any interventions from operator. However he is informed every time about process values and correction magnitudes. He also keeps the privilege of selecting the control mode which seems more adequate to process situation.

Computer System

Original development machine was a CGE 4020 process computer. Today's production computer is a PDP-11/40. Table I compares the two configurations.

Teletypewriters are located in the operator's control room and in the plant laboratory. Flows are changed by sending pulse trains to stepping motors on the set-points of the flow and weight controllers. For both machines, operation is under a real-time multi-programming operating system, which enables off-line work such as simulation and program compilation to proceed simultaneously with on-line control. Programs have been written in Fortran and Assembler languages.

Table I. Computer Configurations

CPU	DEC PDP-11/40	GE 4020
Core memory	64K 16 bit words	16K 24 bit words
Bulk memory	3 moving head disks 1.2 M words each	2 moving head disks 1.2 M words each
Real time System	RSX-11D	RTMOS
Analog inputs	64 flying capacitor multiplexed	36 read relays multiplexed
Digital inputs	32	32
Digital outputs	32	32
Computer console	Video 900 ch/sec.	Teletype 10 ch/sec.
Line printer	Electrographic 600 line/min.	Electrostatic 100 line/min.
Card Reader	300 cards/min	300 cards/min
Card Punch	None	100 cards/min

Results

The standard deviation of blow-off ratio is one measure of success of the control scheme. This can be maintained at .008 irrespective of the uniformity of the bauxite being fed to the digesters.

With the previous manual control methods, such a standard deviation was occasionally obtained when the bauxite was very uniform and well mixed, but it normally ranges from .010 to .013. The standard deviation of digester ratio about the target has been controlled at about .004 by the inner digester control loop.

Liquor productivity has been increased by 1.5% as a direct result of greater stabilization of blow-off ratio.

Performance of computer reflects in the uptime figure which is now at 95%, this only six months after conversion from GE 4020 to PDP-11. Most of computer down time is preventive maintenance and operating system minor troubles. However on the complete system, conductivity cells still affect uptime as their regular and emergency maintenance represents major cause of complete control system downtime.

Conclusions and Future

As a result of special attention being paid to training, acceptance has been very good. New applications are now connected to the system or are in the engineering stage.

The extra effort which was spent in modelling, simulation and control strategy design proved to be paying for itself. Experience gained in these domains has also helped increasing process control performance and operational knowledge in other areas. Close cooperation between various disciplines was achieved through coordination of a steering committee acting as a project leader.

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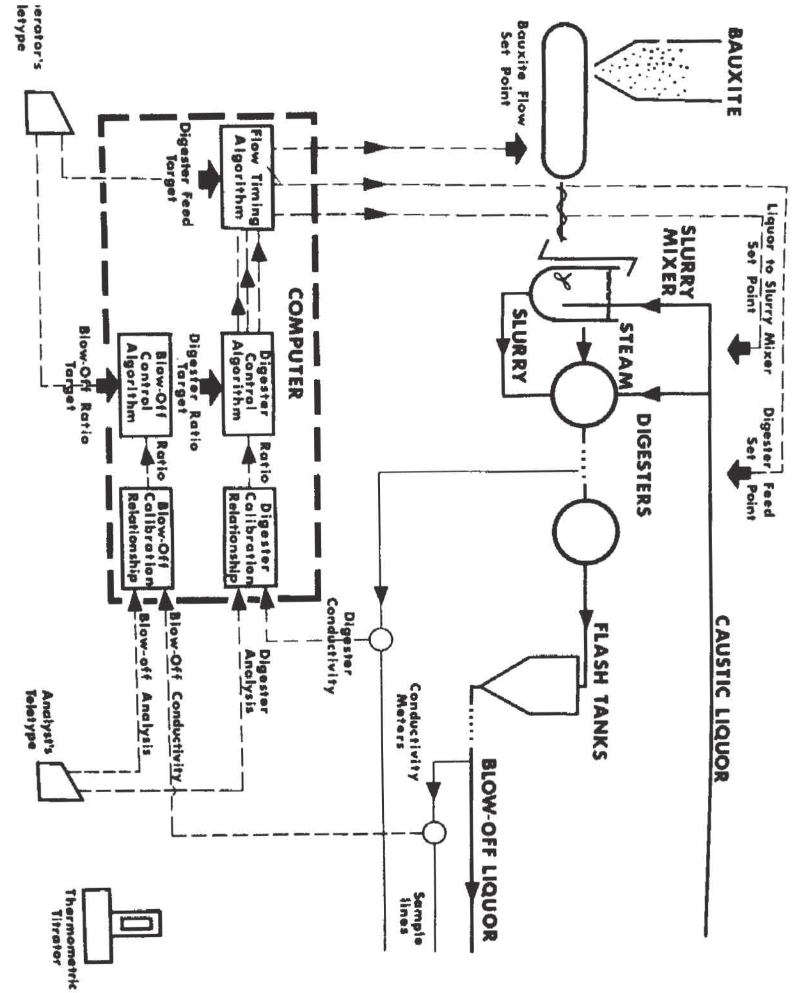

FIGURE 1
PROCESS AND CONTROL FLOW CHART

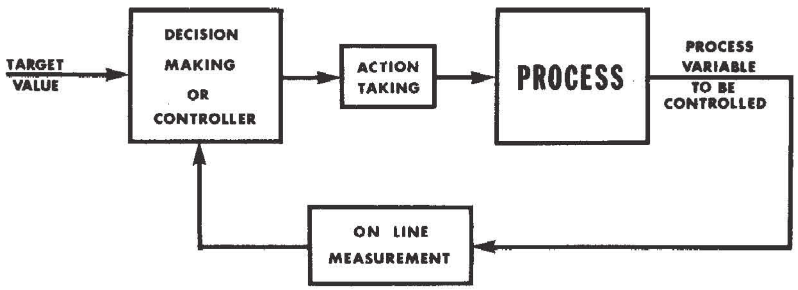

FIGURE 2

BASIC FEED BACK CONTROL CONCEPT

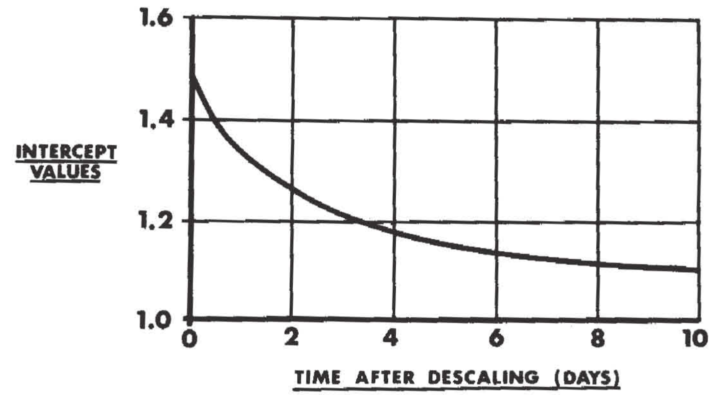

FIGURE 4

INTERCEPT AS A FUNCTION OF TIME

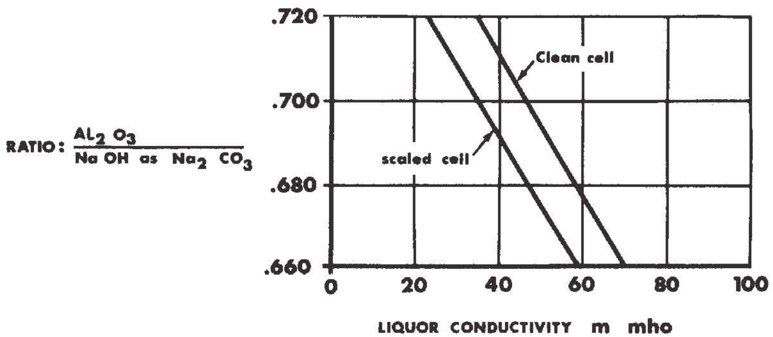

FIGURE 3

RATIO – CONDUCTIVITY RELATION

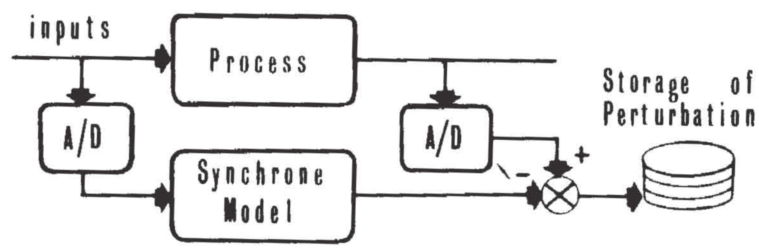

FIGURE 5

IDENTIFICATION OF PERTURBATION

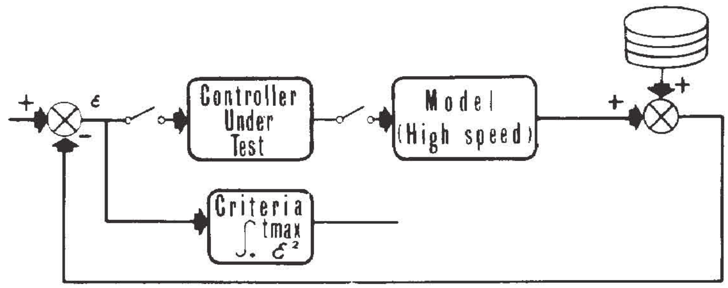

FIGURE 6

OPTIMIZATION OF CONTROL ALGORITHM