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Bayer plant digester charging control by computer using on-line ratio sensors

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On-line computer control of digester charging has been achieved in Alcan's Bayer Plants at Arvida, Quebec, Canada. The purpose of the automatic control system is to stabilize the alumina/caustic ratio in the blow-off liquor. Measurements of the electrical conductivity of the liquor at this point and within the digester train are made using conductivity meters. These signals are read by the computer, converted to ratio using calibration data stored within it, compared with target values, and adjustments are made by the computer to the bauxite flow entering the digesters. Dead-time compensation is used within the control algorithm. Flow changes of liquor and bauxite are timed so as to reduce disturbances in the ratio. The computer monitors the bauxite feed equipment, detects interruptions in the bauxite flow and avoids overcompensation for consequent disturbances in the ratio.

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.

1. INTRODUCTION

The automatic control system presented in this paper is the result of several years work by a team of Alcan personnel. The objective has been to maximize liquor productivity by stabilizing digester and blow-off ratios (1). They have developed:

— Method of using conductivity meter for on-line ratio sensing;
— thermometric titrator for ratio analysis;
— calibration procedures;

(1) $\text{Ratio} = \dfrac{Al_2O_3 \text{ (gpl)}}{\text{NaOH (expressed as gpl } NA_2CO_3)}$

— accurate dynamic models of the digestion process;
— optimum control algorithms;
— flow timing algorithm;
— an automatic control system centered around a computer, incorporating these elements;
— superior control performance, with standard deviation of .004 for digester ratio and .008 for blow-off ratio.

Figure 1 shows the inter-relationship of the elements.

2. CONDUCTIVITY METER

Alcan scientists have established operating conditions to give electrical conductivity proportional to ratio. These conditions include temperature control of the liquor passing through the cell, temperature compensation of the signal from the meter, regular calibration and frequent washing. The intervals for washing have been established by observing the rate at which the cell characteristics change under plant operating conditions.

The conductivity cells are fed by small side streams of liquor from two sampling points, one in the digester train, the other at blow-off. 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.

3. THERMOMETRIC TITRATOR

This instrument has been described in Reference 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. It is used in this control scheme for calibration of the conductivity meters.

4. CALIBRATION RELATIONSHIPS

Both conductivity meters are calibrated after every wash and at intervals between. Since the ratio at blow-off is the critical operating constant for the process, the conductivity meter at this point is calibrated more frequently than the one in the digester train.

The method of calibration after a wash is as follows. A small number of samples of the liquor passing through the cell is taken at intervals, and the conductivity reading noted at the same instant the samples are taken. The samples are analysed repeatedly by the thermometric titrator. The analyst enters the date obtained into the computer via a teletype. The computer then determines mathematically the relationship between conductivity and ratio and stores this for calculating ratios from conductivity signals until the next calibration.

The computer examines for consistency the data entered by the analyst and challenges any unusual divergence.

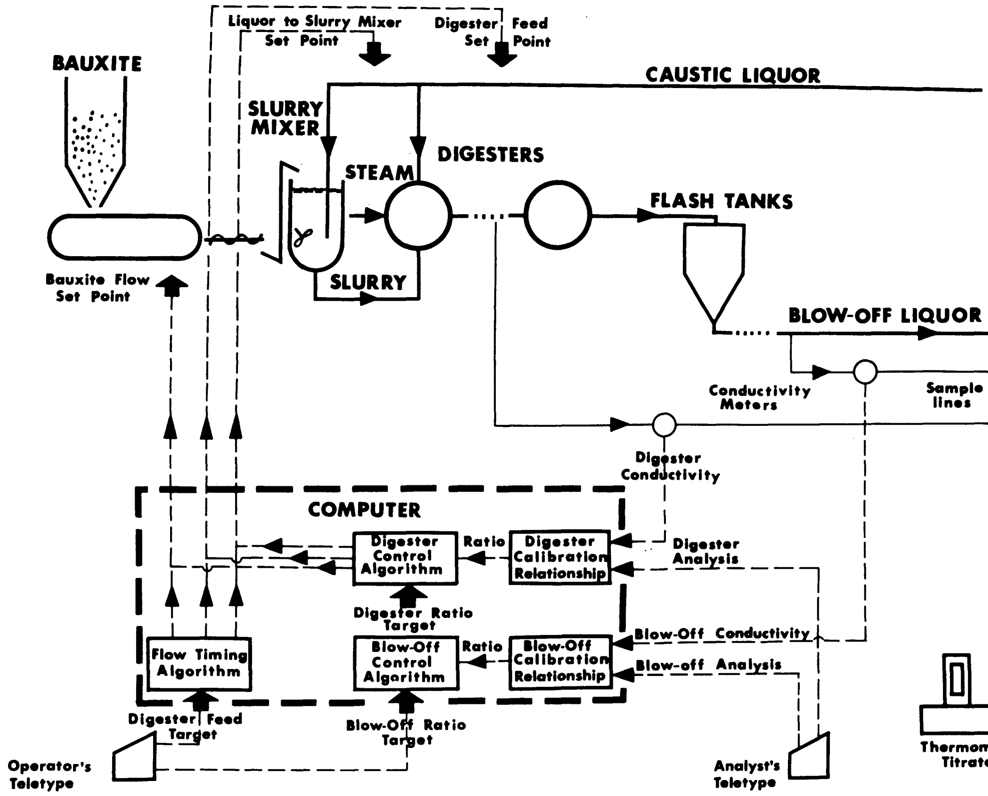

Fig. 1. — Process and control flow chart

The frequent calibrations of the blow-off conductivity meter between washes is performed in a different way. The analyst takes a series of samples of liquor passing through the cell between certain pre-determined times of the day, makes a composite sample, analyses it on the thermometric titrator and enters the ratio found into the computer. The computer has meanwhile stored the conductivity signals during the same period. It adjusts the previous calibration relationship in accordance with this most recent information.

The computer also examines the trends occurring in the calibration relationship and advises the analyst if these are greater than predetermined values. He can then decide if emergency maintenance or washing of the conductivity meter is needed.

5. 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, ratio at any point in the digester train following a change in bauxite flow occurs in the way shown in Figure 2. Similar but even longer delays occur before the ratio change reaches blow-off.

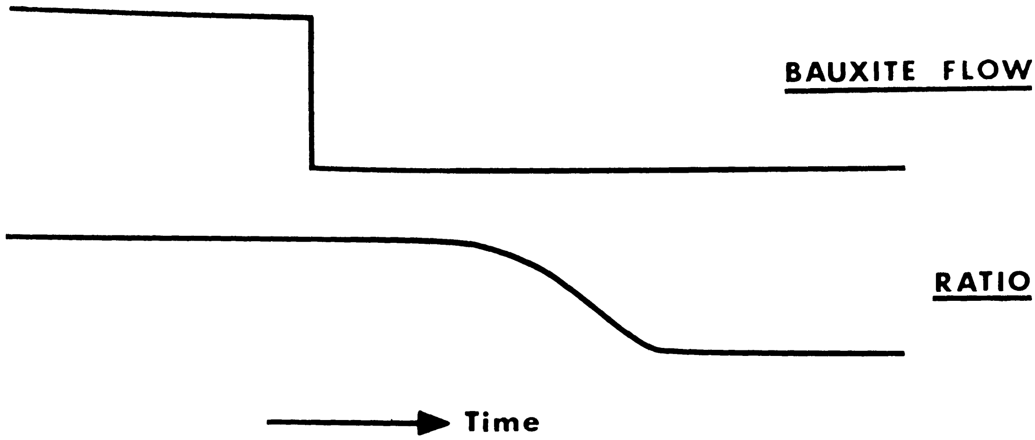

Fig. 2. — Change of ratio following bauxite flow change

The computer control algorithm causes changes in bauxite flow to occur at intervals, not continuously as would be the case for an analog control device. The change in bauxite flow is calculated as sufficient to restore the ratio to its target value. The intervals between changes are so timed for the digester control loop that part, but not all, of the resulting change in ratio will have reached the conductivity cell by the time the next change is due. In order to decide if a further adjustment is necessary at this time, the computer calculates from a dynamic model of the process, the ratio which should occur at this time if no other change has occurred since the previous bauxite flow adjustment. Any deviation between the measured ratio and the ratio calculated from the model indicates that a further change has occurred, and the magnitude of the deviation allows the size of further adjustment to be determinated (Fig. 3). This algorithm is a digital realization of the Smith Controller to provide dead time compensation (Reference 3). 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 model.

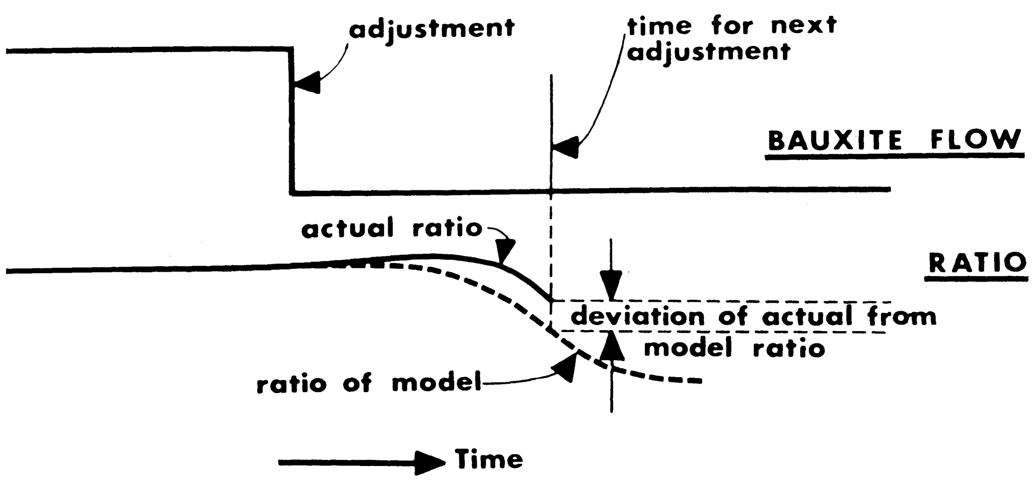

Fig. 3. — Use of model in control algorithm

6. MODELLING

Dynamic models of the process were constructed using the computer as an on-line data collection system. 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 the computer disk. The methods of analysis used to establish the models from these tests have been described in Reference 2.

7. OPTIMIZATION OF CONTROL ALGORITHMS

Before the control algorithm described above was put into routine use, other control strategies including digital P.I. and integral controllers were designed and their performance measured by off-line simulation. They were tested under a standard perturbation which was itself calculated from the deviations between actual ratios and those indicated by an on-line model, in a similar schema to that shown in Figure 3. Reference 2 gives further details.

8. FLOW TIMING ALGORITHM

In addition to specifying the blow-off target, the digester operator specifies to the computer (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 those 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, the computer has been programmed to effect the flow changes at certain experimentally determined intervals.

9. OTHER COMPUTER FUNCTIONS

9.1. Process Surveillance

The computer scans 35 process variables 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.

9.2. Logging

Plant data obtained via the scanner is averaged every 5 minutes and stored on disk for one week. 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.

10. COMPUTER SYSTEM

The machine used is a CGE 4020 process computer (16K words core, 2.4 million word disks, 24 bit word) with a teletype console, a card reader, card punch, line printer and Vidar scanner for analog input. Teletypes 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. The computer operates 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.

11. RESULTS

The standard deviation of blow-off ratio is one measure of success of the control scheme. We have found that 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 as a direct result of greater stabilization of blow-off atio.

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