Essential Readings in Light Metals: Alumina and Bauxite.
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10. PROCESS CONTROL/SIMULATION

Today it is essential that the process design of a new refinery or the change of process for a new source of bauxite will require the use of a complex and rigorous process computer model. Such models will either be proprietary to a company in the alumina industry or to an engineering firm that specializes in the alumina industry.

The 1986 *Light Metals* paper "Modeling of the Bayer Process" (Aspen) describes the difficulty and complexity of developing a rigorous simulation of the Bayer process adequate for design of refinery process areas. A number of heat and materials balance models were developed during the 1980s, some better than others and some more costly to develop than others. Today it is probably better to audit and negotiate for the use of a good proprietary model than it will be to undertake the development of a model, especially if time is a factor.

The importance of the paper by Scandrett on countercurrent decantation washing for clarification may not be obvious. The paper develops use of a "mixing factor" for each stage which may be a misleading name for its use. The factor can be used to account for inefficiencies in multistage washing of red mud. A guess at the value of the factor is applied until the model soda loss nearly matches actual performance. Presumably the factor is a way to account for inefficiencies such as the mismatching of underflow and overflow, the periodic addition of extraneous caustic solutions of variable concentration, etc. A very low factor would indicate that something needs to be fixed.

The other papers have to do with process control in process sections of the refinery, such as digestion, clarification, and precipitation. One continuing difficulty of improving process control is the development of accurate and reliable online measurement of liquor chemical and solids concentrations, temperatures, pressures, and flow rates in an environment of slurries and scale formation.

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MODERN CONTROL INSTRUMENTATION AND PROCESS MANAGEMENT IN BAYER PLANTS

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Summary

Successful implementation of modern microprocessor based control instrumentation and process management systems offers the potential for significant raw material and energy cost savings in Bayer Plants. These benefits can be achieved in new plants or from modernization of existing plants.

This paper reviews the hierarchical control available with modern systems. The management, hardware selection, system design, maintenance and support requirements for successful implementation are covered.

Introduction

Many of the Bayer plants operating today were designed and constructed in the 1960's when the industry was characterized by:

- High rate of demand growth and tight alumina supply.
- Low raw material, energy and capital costs.
- Relatively low concern for efficiency, with all plants making money by producing at maximum rates.

The industry has experienced massive change since the mid 1970's and is now characterized by:

- Low growth rate in demand, accentuated by excess world capacity and low selling prices.
- High raw material, energy and capital costs.
- Highly competitive market place.

This situation is likely to continue beyond 1990.

To remain competitive, older plants need to be modernized, employing "state-of-the-art" technology available in the newer plants.

Properly engineered and supported microprocessor control instrumentation and computer based process management systems offer the potential for large raw material and energy cost savings. Application to the Bayer plant is fraught with difficulties not experienced in other chemical processing plants. The Bayer process, with its combinations of high flow, temperatures, high solids content slurries, erosive, corrosive scaling services, and with varying time lags from seconds to days, is unique and presents special challenges in providing accurate and repeatable process measurement and control.

The systems, however, permit many economically attractive control methods heretofore not feasible. The economically attractive features center around advanced control and optimizations can be applied on-line with direct feedback to process control and off-line via computer-based management information programs.

An important part of this new technology is that all parts of the process must communicate, via digital data links, with each other and to a central information and control system. Therefore, local area systems must all be compatible with the overall plant system. Since the data gathering and handling systems are electronic, a switch from pneumatic to electronic instruments in existing plants is reasonable.

Successful implementation requires a step-wise process, with full understanding of the requirements and capabilities of vendor supplied hardware, careful specification and design of each installation, building on initial successes, with subsequent projects being justified economically and conforming with an overall concept.

Kaiser Aluminum and Queensland Alumina have developed a systematic approach to computer-based control resulting from 10 years experience, not all of it successful. Our approach, while predominately concerned with modernization of existing plants, is equally applicable to new installations.

Historical Background

Use of digital computers for on-line monitoring and control of industrial processes has progressively developed since the early 1960's. Initial applications were limited to the oil and power industries, spreading to the mining and mineral processing industries in the late 1960's. Application of the new technology in Bayer plants began in the early 1970's.

The early pioneering projects were characterized by high costs and high risk. Each installation, custom engineered to the specific installation, was limited to data acquisition and control of a few loops. Standard process control hardware and software packages had not been developed. Reliability problems necessitated complex and highly costly back-up facilities to ensure acceptable availability of the system for process control.

The advent of standard, "off-the-shelf" computer-based systems began to standardize the approach to digital control in the mid 1970's, although centralization within a single computer facility was still the norm.

More recently, development of microprocessor based control systems by the established instrumentation suppliers has enabled digital control and monitoring functions to be distributed throughout the process areas, rather than concentrated in centralized computers. System security has been improved by distributing control system intelligence via a number of plant area controllers, each of which handles the control requirements of single plant areas or geographically associated processes. In the Bayer plant, this means that control can be distributed at the Digestion, Evaporation, Precipitation etc. levels.

Distributed Control Hierarchy

Distributing regulatory process control functions in multiple controllers, with the associated operator interface centralized at CRT screens, creates the need for a communications network to transfer information between these controllers, their video based workstations and associated supervisory control or central process computer systems. The resulting three levels of control hierarchy are:

Regulatory Control. Incorporating single loop analog or digital controllers, distributed microprocessor based multiloop controllers, process input/output modules.

Video based consoles provide all the display, command, alarm and trending functions previously available on analog control panels. Video consoles are incorporated into operator workstations which also incorporate alarm annunciators, motor stop/start controls and computer consoles.

Supervisory Control. Typically incorporating dedicated mini-computers providing reports, custom video displays, coordination between distributed regulatory controllers and complex calculations in a plant area. Data acquisition, monitoring, control and man/machine communication are implemented using standard vendor supplied software packages. Color consoles, incorporated into operator workstations, provide all command, alarm and graphic functions for supervisory control.

Plant Management. Incorporating more powerful computers with bulk storage capability and sophisticated application packages for long-term historical data reporting, plant optimization, plant scheduling functions and on-line production rate, energy and raw material usage calculation.

Implementing Distributed Control Systems

It would be unwise to begin with high level optimizing computers as the primary means for plant operation. Computers and their advanced control programs are data hungry devices. Not only do they require data but they require accurate data. Next, they are high quality manpower intensive projects. These expensive and valuable resources must not be wasted.

The order of progression to a computer-based control system must bring together the following functions:

- Measurement
- Front-Line Regulatory Control
- Advanced Supervisory Control
- Optimal Control and Management Information

First, it is necessary to correctly and accurately measure the process. This may require replacing old instruments, upgrading by relocating or reinstalling existing instruments to meet good measurement practices, or developing new measurement devices.

After measurement, the front-line regulatory instrumentation for flow, temperature, pressure and level controls etc. must be able to attenuate disturbances and serve as slaves to optimization and advanced control systems.

Finally, addition of plant wide communication and computer systems enables implementation of advanced supervisory control and management information systems. Table I lists examples which are known to have been successfully implemented in Bayer plants, or are proven in other industries and readily applicable to the Bayer plant. The list is obviously not exhaustive.

Table I. Known or Potential Applications for Advanced Supervisory Control

Digestion	Bauxite charge control Heat recovery and energy related items Digester temperature and flow control Monitoring of heat exchanger performance Blow-off dilution control utilizing on-line measurement of caustic concentration
Clarification	Mud inventory control (pumping rates) Flocculant addition (optimize settling rates) Wash water balance and control across washer trains Filter aid control related to settler overflow and/or filtrate solids Settler auto precipitation monitoring
Precipitation	Seed charge, surface area and holding time control Seed and product inventory and trends Classification controls Tray overflow solids monitoring and flocculant addition
Calcination	Rotary kiln control Comparative heat balances and kiln efficiencies Automated LOI control utilizing on-line measurement of LOI
Powerhouse	Overall energy management and distribution control Tie line demand control Turbine dispatch control Heat/work balancing Performance monitoring and accounting

Uniform Project Control

To ensure proper control and coordination of projects, we have developed an Instrumentation and Control Systems Master Plan. The plan states overall objectives and aims to implement an engineering procedure to ensure installation of a well designed, secure system, and on-going maintenance and development to achieve its full potential.

The Master Plan is part of an overall program to achieve maximum economic benefit from process control and management information as shown in Table II.

Table II. Uniform Project Control

Control Document	Purpose
1) Master Plan	Direction, coordination and training.
2) System Specification and Design	System functional specification and configuration.
3) Instrument Engineering Standards	Correct hardware selection and mechanical installation.
4) National Standards	Safety, accuracy, environmental and labor considerations.
5) Control System Project Coordination	Uniform documentation, instrument numbering and connection, loop drawings.
6) Control System Maintenance	Support and maintenance requirements, performance criteria.

Instrument Engineering Standards

Instrument Engineering Standards have been developed to be a ready reference for the Instrument Engineer or Technician in applying process control instrumentation in an economical and safe manner. The standards are in two parts, Standard Instrument Design and Standard Instrument Specifications, and reference relevant National Standards on safety and environmental considerations.

These standards are not always recommending the least expensive installation, but must follow good engineering practice. It is important that the standards, once developed, are periodically upgraded to reflect the best company and industry knowledge and practice.

Control Systems Project Coordination

Control Systems Project Coordination provides for documentation such as standardized instrument numbering, wiring lists and loop diagrams essential to the construction package. These are also necessary for maintenance and repair of troubled systems.

Converting plants from pneumatic control to electronic requires good circuit documentation for installation and maintenance. The problem of updating drawings can be greatly assisted by computer-based drawing systems and a continuing effort to upgrade existing instrument system drawings must be implemented. Documentation of new projects must follow a systematic procedure. Control System Project Coordination greatly assists in standardizing instrument numbering, wire lists and loop drawings.

Use of a computer-based wiring system is one mechanism for maintaining a plant-wide numbering and records system. The (IWS) Instrument Wiring System generates project documentation and supports design, installation and maintenance of instrumentation and wiring. All projects should have access to the same data base for individual project requirements.

Selection of the Control System Vendor

The need to ensure compatibility of local area systems with the plant-wide system makes selection of control system hardware a critical step. Our approach, as far as possible, is to select the vendor rather than bid the job.

The approach involves an initial evaluation of potential vendors to short list a limited number (2 or 3) best able to supply and support the required instrumentation and control systems for the particular location. Detailed negotiations are then conducted using defined criteria to assess the short listed suppliers. Table III presents a summary of the major criteria used which total 120 in all. Finally, a signed agreement is concluded with the selected supplier.

Table III. Summary of Criteria Used to Select Instrumentation and Control Systems Vendors

Instrument System
Computer System
Communications Network
Installation Requirements
Supplier Support Services
Training
Maintenance
System Documentation
Manufacturing and Delivery, including Staging
Warranty following Plant Acceptance
System Upgrade Policy
Supplier/Customer Communication Channels
Terms and Conditions
Pricing
Contact References

Design, Installation and Commissioning

This phase should be handled by a project team headed by a Senior Engineer with a proven record of project management. The individual should be at Superintendent or Manager level and accountable for all aspects of the project.

The team brings together all the disciplines necessary for successful project design, installation and commissioning, that is,

Plant Engineering, Electrical and Instruments
Process Computer Engineering, Software and Hardware
Process Engineering
Production
Maintenance, Electrical and Instruments

The team would disband on successful commissioning. Long-term support would not be provided by this team.

Implementation of new control systems in existing plants should be tackled in stages with each stage seen as advantageous by the operators. Assignment of production personnel to the team at the initial stages is considered essential for operator acceptance which will be best when the operator comes to rely heavily on the computer. There is a need for open communication between operators and process computer personnel and for direct operator involvement in the operator/machine interface design to ensure that ideas are turned into workable solutions. Many of the solutions originate from the operators.

Figure 1 illustrates a typical project information procedure. The project team first consults the Master Plan to see how the project impacts upon the plan and to use the plan as a checklist on how to proceed. Then a preliminary design, which should cover all major points, and a cost estimate are made. At this time it may become evident that the Master Plan does not cover some parts of the proposed project, requiring upgrading or adding of the Master Plan, which should be a fluid document. After management approval of the project, design can proceed. Consideration as to how this project impacts on another part of the plant, which may be scheduled for an instrument upgrade, needs to be integrated for compatibility. Designers must make use of Instrument Engineering Standards to adhere to correct mechanical construction and the Control System Project Coordination for wiring documentation necessary for the installation packages.

Finally, the path continues to the last phase where the systems must be maintained and upgraded throughout the system life. Many of these functions may require recycling of each individual part, each being cognizant of the Master Plan or restarting the entire procedure.

The Plan imposes a number of constraints on design. Among these are:

- All equipment installed is to be standard, reputable vendor "off-the-shelf" equipment, the exception being special sensors.
- Existing operations are considered the basic mode of operations except where control room consolidation and advanced computer controls are implemented.
- Requirements for space in each control house are based on equipment, as well as the maintenance and operations support requirements.
- All systems and facility criteria must be planned to accommodate future changes in operational configuration.
- A central information center to house all computer systems for advanced control and coordination of the liquor loop and the management information systems.

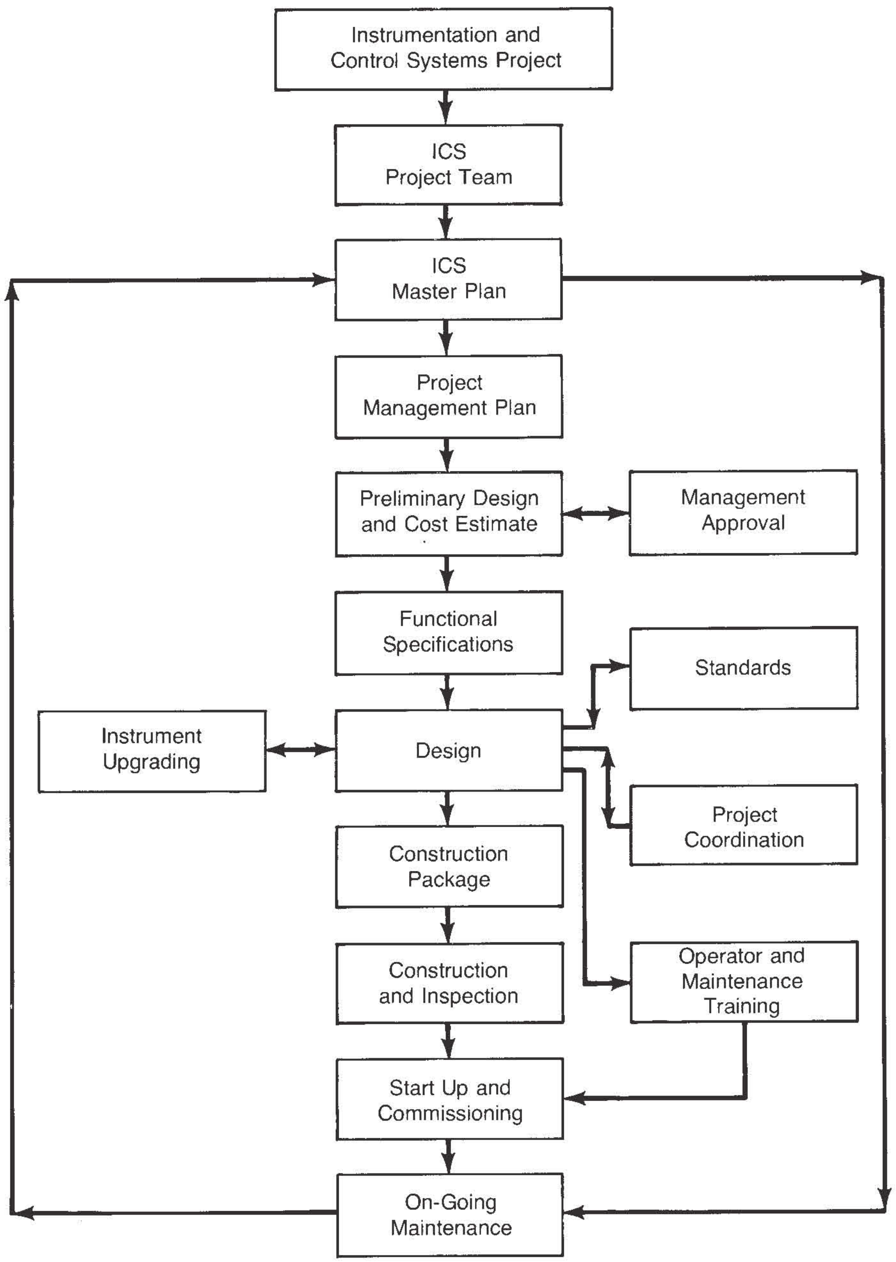

Figure 1. Typical Project Information Procedure

System Support Following Commissioning

Management commitment to dedicated, on-going hardware and software support is necessary for success.

There is a need to concentrate skills in a nucleus group not involved in-line functions in the plant. The latter tend to be diverted by other priorities with the result that the control system is seen as having second or low priority. In addition, organizations cannot afford sufficient numbers of specialists to dilute them in line positions.

Formation of a Process Control Group separate from the Production, Maintenance and Data process groups is common practice. This group is accountable for:

- System design, hardware selection and installation design.
- Software development.
- On-going software support for trouble-shooting, and maintenance.
- Hardware support for trouble-shooting and the actual hands-on maintenance.

Typically the group resides in the Process Engineering or Technical Services department.

Process Engineers (Chemical, Metallurgical, Electrical or Chemists) with computer aptitudes are selected from within the organization and skills developed to handle the software needs for regulatory, supervisory and plant management functions.

Instrument Engineers are selected to handle sensor selection and design, and system installation.

Maintenance is generally handled by Technicians from the Process Computer group, frequently supervised by an Engineer.

Control System Maintenance

Control system maintenance must be planned well in advance of project implementation. Computational and information systems require inputs working 100 percent of the time which means outages require more rapid attention. Computations require accurate inputs, thus there are more requests for calibration of measuring elements. Because the system is tightly interfaced to management, errors or outages are more obvious to those in command, which brings additional pressure to reduce instrument failures.

Distributed control systems are complex, requiring highly qualified engineers and mechanics to trouble-shoot and solve system problems. These types of people are difficult to find and will most likely come from in-house selection and training. Engineers and mechanics who must work closely together require training together on some aspects and separately on others. It is not abnormal to have a programmer, engineer, operator and two instrument mechanics conducting a maintenance check or trouble-shooting a problem. Outside maintenance contracts may be necessary for the most complex items.

On the other hand, frequency of repair will be reduced due to improved reliability of modern electronic instruments. Since most microprocessor based systems feature self-diagnosis of faults down to individual board or card levels, maintenance may be on a card replacement basis, with the faulty unit returned to the supplier for repair or replacement.

Training

Training should take place at both the plant and the equipment supplier's facility. Most suppliers of computer control systems provide schools for training in the use and maintenance of their equipment. With a special cadre of trained people, in-plant training programs can be organized. Training must be on-going to update skills.

To assist with hands-on training, it is advantageous to install a spare operator workstation and microprocessor based multi-loop controller, interfaced to the communication network for real time data. Operators can train with this system, looking at real plant data through the video consoles, and practice switching simulated control loops between "manual, automatic and computer." Also, planned process upsets and equipment failures can be introduced into this system, requiring the operator and mechanic to solve the problems.

Software and engineering personnel will be required to attend special schools plus permitted time on the inplant system to learn how it functions. There is no substitute for real "on-line" training where a skilled man leads a trainee through the job.

Economic Benefits

The literature increasingly cites examples of cost benefits of distributed control and process management systems over conventional analog systems. Benefits include increased production capacity, improved operational stability and product quality as well as decreased raw material and energy costs.

For utilities (power, steam, air and water) management systems, claimed savings are in the range 5-10 percent, with some cases as high as 13 percent. Presumable, the lower savings reflect plants that were initially reasonably well instrumented and controlled.

Savings of similar magnitude are cited for pulp and paper, sugar and textile plants.

At Queensland Alumina, the Digestion control system installed with the recent plant expansion has increased plant production capacity by 100,000 metric tonnes per year, or 5 percent. The supervisory control has improved operational stability and heat recovery on the 3 digestion units. Energy savings from increased yield and heat recovery exceed 700 MJ/t.

We are now developing advanced control strategies for control of evaporation and rotary kiln calciners. For the latter, studies indicate the potential for fuel savings in excess of 150 MJ/t.

Conclusions

Implementation of distributed microprocessor-based instrumentation and control systems in the Bayer plant offers the potential for significant improvement in raw material and energy costs, production rate and operational stability. To achieve the full potential requires a dedicated, systematic approach. Without this commitment, computer based control is unlikely to meet expectations, as evidenced by the following quote:

> "The process control industry has placed high hopes on a triad - plant control computer (PCC), process, control operator - to run complex and critical processes in real time. The performance of the computer, however, can only be described as disappointing. One third of the applications do not work up to expectations, one third of the planned computers are never actually built, and one third of computers work independently of their effect on plant operations....."

From "The Process Computer: Frankenstein or Genie?" Livingston and Franceschi, Mechanical Engineering, November, 1981.