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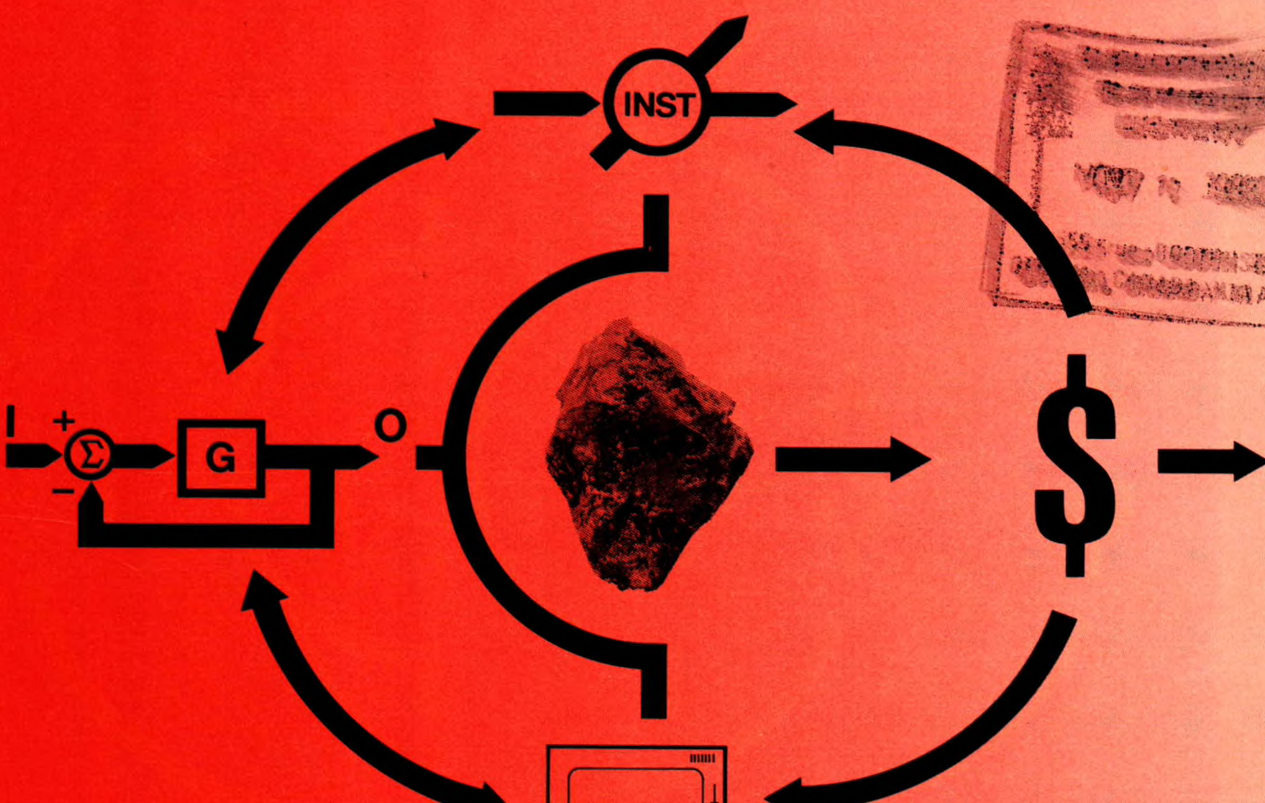
CANADIAN COAL PREPARATION PROCESS–CONTROL RESEARCH AND DEVELOPMENT DIRECTIONS

AHMED I.A. SALAMA



SP87–11E

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CANMET Special Publication
SP87-11E

Available in Canada through

Associated Bookstores
and other booksellers

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

Catalogue No. M38-15/87-11E
ISBN 0-660-13031-9

CANADIAN COAL PREPARATION PROCESS-CONTROL RESEARCH AND DEVELOPMENT DIRECTIONS

by

Ahmed I.A. Salama*

Abstract

An industry viewpoint and feedback on CANMET programs (current and planned) in coal preparation process control are presented. Results of an industry-wide survey and commentary on recent and/or continuing operational problems in process control are also detailed. Responses are summarized and analyzed to identify industry requirements and to consolidate directions for process-control R&D at the Coal Research Laboratory (CRL).

Industry requirements, as well as the medium- and long-range plans of CRL in process control, can be fulfilled by implementing a step-by-step strategy, the pace of which is dependent upon the availability of resources. R&D priorities are guided by the results of the survey. The availability and/or development of on-line ash and/or sulphur monitors can be addressed by the preparation of a state-of-the-art report and by the establishment of a joint program between CANMET, Atomic Energy Canada, and industry to evaluate and develop these monitors.

Keywords:
Coal preparation and expert systems; coal preparation automation; coal preparation process control; coal preparation process variables; coal preparation transducers; computers in coal preparation; programmable logic controller; R&D in process control and instrumentations.

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RÉGULATION DES PROCÉDÉS CANADIENS DE PRÉPARATION DU CHARBON ORIENTATIONS EN MATIÈRE DE RECHERCHE-DÉVELOPPEMENT

par

Ahmed I.A. Salama*

Résumé

Le point de vue et les réactions de l'industrie concernant les programmes (actuels et prévus) de CANMET en matière de régulation des procédés de préparation du charbon sont présentés. Les résultats d'une enquête menée à l'échelle de l'industrie et des commentaires sur les problèmes d'exploitation, récents et permanents, en matière de régulation des procédés sont aussi détaillés. Les réponses sont résumées et analysées, l'objectif étant d'identifier les exigences de l'industrie et de consolider les orientations du Laboratoire de recherche sur le charbon (LRC) en matière de R-D en régulation des procédés.

Les exigences de l'industrie, ainsi que les plans à moyen et long termes du LRC en matière de régulation des procédés, peuvent être satisfaits par la mise en oeuvre d'une stratégie étapiste dont la cadence sera dictée par la disponibilité des ressources. Les priorités en matière de R-D sont dégagées des résultats de l'enquête. La disponibilité et(ou) la mise au point de contrôleurs de cendres et(ou) de soufre en circuit peuvent être abordées dans un rapport sur la technologie de pointe et dans le cadre d'un programme conjoint CANMET-ÉACL-industrie visant à évaluer et à mettre au point ces contrôleurs.

Mots clés :
Préparation du charbon et systèmes experts; automatisation de la préparation du charbon; régulation des procédés de préparation du charbon; variables des procédés de préparation du charbon; transducteurs pour la préparation du charbon; les ordinateurs dans la préparation du charbon; contrôleur logique programmable; R-D en matière de régulation des procédés et d'instrumentation.

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INTRODUCTION

In 1985, Canadian coal production was 60 million tonnes of which 27 million tonnes (45%) were cleaned prior to use. This prepared coal is destined primarily for international metallurgical and thermal coal markets. Western Canadian mines provide 95% of the production capacity in Canada.

During the past three years, the demand for coal has decreased which, coupled with an increase in production capacity, has resulted in an oversupply on the world market. To overcome reduced prices and a shrinking market, the coal industry is challenged to optimize its operations to reduce the cost of production. The cost of cleaning coal can be reduced by improving the recovery of fine coal and in general by maximizing plant yield. These approaches can be helped by the use of process control and by new developments in computer technology.

Application of process-control techniques and schemes in coal preparation can achieve flexibility in operation, improved plant performance and product yield, better use of personnel, tighter quality control, and minimization of production cost. Successful implementation of process-control techniques and schemes is expected to improve coal preparation plant recovery by as much as 5% (1).

The mandate of CANMET (Canada Centre for Mineral and Energy Technology) is to address needs and provide new technologies to industry to enhance the role and contribution of minerals and energy to the Canadian economy by means of mission-oriented R&D, which is supportive of R&D performed by industry. As part of the close interaction and contacts required by this mandate, an industry survey was conducted recently (1986) in conjunction with field visits. Discussions were held with plant operational management to determine coal industry interest in process-control development and priorities regarding specific plant circuits.

This document evaluates results of the survey, focuses on the on-line process-control and instrumentation applications, presents research and development directions for coal preparation process control, and outlines a long-term (5-year) strategy for the Coal Research Laboratory (CRL) of CANMET.

CANADIAN COAL PREPARATION PROCESS-CONTROL DEVELOPMENT

Most Canadian coal preparation plants were commissioned during the past two decades with minimal provision for making use of process control. Most of these plants include manual sequential start-up and shut-down with analog instrumentation for some process variables (2). The fast-growing development of computer technology in the 1970's and 1980's had a considerable effect on the use of process control in industrial applications. Consequently, the technology of a programmable logic controller (PLC) found its way into plants built recently.

In 1981, CRL began development of a distributed process-control scheme for various circuits in its comprehensive pilot plant facilities at Devon, Alberta (3). The pilot plant is being used to develop, test, and evaluate various process-control strategies and on-line instrumentation before recommending them for industrial use. Part of process-control R&D at CRL is carried out through research contracts, two of which were on control systems for heavy-medium and froth flotation circuits. The heavy-medium control system is designed to regulate the medium density at a prescribed set value (4). The developed system was installed in the pilot plant and was successfully completed. This system will be the focus of further development and improvement. The design of a computerized process control for the flotation cells has been completed. At present, in-house expertise is being used to implement the sequential start-up and shut-down of the pilot plant.

CANADIAN INDUSTRY PROCESS-CONTROL SURVEY

To maintain the relevance of CRL's process-control development program, an industry-wide survey was conducted, with two main objectives:

- to identify industry needs and problem areas; and
- to generate industry feedback as an input to CRL's planning and overall strategy.

A questionnaire aimed at fulfilling the above objectives was prepared and hand-delivered or mailed to 12 coal washeries across Canada; 7 responses were received. The questionnaire format is shown in Appendix A. A summary of industry response "as received" to the questionnaire is outlined in Tables 1-7, where the respondents are designated as plants A to G.

QUESTIONNAIRE DISCUSSION

A careful and thorough analysis of the responses received indicates that six out of the seven respondents are in favour of more process-control R&D activities. However, one operator noted that present economic restraints are creating an unfavourable atmosphere for any new developments or changes in his plant. The following is the interpretation and discussion of the questionnaire's main points.

CIRCUIT PRIORITIES

Examination of Table 1 reveals the following circuit priorities:

Circuit	Flotation	HMB/HMC	Thermal Dryer	Thickener	Spiral	Jig
Response	5/7	3/7	3/7	2/7	1/7	1/7

this result indicates that the froth flotation circuit is a top priority in reference to plant benefits, followed by HMB/HMC and the thermal dryer.

PROBLEMATICAL CIRCUITS

Examination of Table 2 reveals the following circuits as areas requiring effective control to improve performance:

Circuit	Flotation	Thermal Dryer	Spiral	Jig
Response	4/7	3/7	1/7	1/7

Froth flotation is the most problematical circuit in the plant, which is in agreement with the previous findings.

ON-LINE ANALYZERS

An area that is important for successful and effective implementation of process-control schemes is the development and availability of reliable on-line analyzers (ash and/or sulphur). From Tables 1 and 2, we obtain:

On-line analyzer	Ash	Sulphur
Response	4/7	1/7

These results reflect regional needs (i.e., eastern Canada needs sulphur analyzers whereas western Canada needs ash analyzers). One operator indicated that he has already installed an ash monitor which is being tested. A critical study on the evaluation and availability of on-line monitors will be carried out by the author in the near future and the findings will form a separate report.

PROGRAMMABLE LOGIC CONTROLLERS

Six out of the seven plants are using PLC's and the response is summarized as follows (see Table 6):

PLC	Allen Bradley	Modicon
Response	4/7	2/7

This result indicates good support for the use of programmable logic controllers among Canadian coal preparation plants and reflects the effectiveness and reliability of PLC's in monitoring and control.

DIGITAL AND ANALOG INSTRUMENTATION

The survey reflects the rapid development of computer technology as indicated by the gradual shift to digital control in plants built before 1982 (see Table 5). However, recently-built plants include some digital instrumentation. Future coal preparation instrumentation is expected to be digital.

CANADIAN COAL PREPARATION PROCESS-CONTROL R&D: FUTURE DIRECTIONS

This section summarizes the main directions and circuit priorities for R&D activities in process control as applied to Canadian coal preparation.

Appendices B and C present brief summaries of "Coal Preparation and Computer Applications" and "Coal Preparation and Process Control", respectively; details of these subjects can be gathered from the listed references.

PLANT AUTOMATION

Distributed Process Control

A Direct Digital Control (DDC) system uses a central process-control computer to perform most of the functions of local controllers (Fig. 1). DDC thus offers a means of simplifying many of the analog controls: complex analog control loops are replaced by simple DDC loops and control calculations are handled digitally. One serious disadvantage that limits the usefulness of DDC systems in industry relates to overall system backup. For example, if the central control computation should fail, the central control function is lost and no backup remains.

The disadvantage that the control functions of all local controllers are handled by a central process computer can be eliminated by introducing the concept of a distributed system (Fig. 2). In the distributed system, control functions are spread among two, three, or more control computers or microprocessors (5-11), which are easily interfaced with a supervisory digital computer. The various distributed microprocessors are interconnected by data highways and can talk to the supervisory computer. The distributed system is, in a sense, the digital version of analog control but it uses microprocessors instead of analog control elements. The distributed microprocessor supervisory control has the backup feature and the communication advantage of DDC. Moreover, this system offers greater reliability, more flexibility, greater ease in service, and simpler operation. Other advantages are that it has an alarm capability e.g., blinking lights, flashing CRT displays, and bells ringing, and that multiple levels of alarm are possible. These advantages indicate that microprocessor-based, distributed, process-control systems will be used for coal preparation process-control applications in the future. A comparison between the different process-control systems (existing on the market) is presented in Appendix D. This information is extracted from the final design document of the computer control of coal flotation research contract submitted to CANMET (12).

Table 1 - Quality control, on-line monitors, and circuit priorities

Plant	Methods of quality and process control	On-line monitors and applications	Circuit priorities for process control
A	Automatic sampler Reagents control Moisture control Belt scales Relative density (RD) RD controllers	Reagents control Moisture control On-line RD control Ash analyzer under testing Feed rate monitors	HMC Spirals Thickener/filter
B	Hourly samples Improvements planned	Centrifuge (torque monitor) HMC/HMB (RD Monitor) Thickener (bed depth, torque monitor) Dryer (temperature control & monitor)	HMC Flotation/ash analyzer
C	Hand sampling Process-control programs		Dryer Jig Thickener
D	Belt samples (hourly)	Monitor (RD, level, % solids, flow rate etc.)	Sulphur analyzer Streams (mass balance measure) Flotation
E	Timed sampling Process control (typical controllers)	Monitor process variables	Flotation products ash analyzers
F	Different monitors used	Simple control loops (not computerized)	Dryer control Flotation RD control Quality control of products
G	Hourly samples Process variables control	Monitor process variables Process variables control	Dryer control Flotation (froth %S) HMB/HMC (on-line analyzers)

Table 2 - Circuits requiring process control and process-control previous experience

Plant	Circuits requiring process control	Previous experience
A	Spirals (product quality) Dryer (narrow range and require fine tuning)	Study was carried out in the past (cost not justified)
B	Flotation / ash analyzer	None
C	Dryer control Jig control using on-line ash monitor	Enviroclear thickener (stabilization problem)
D	Optimization of yield and sulphur level Dryer control (future) On-line sulphur analyzer	Various on-line systems looked at (design drawbacks: sample presentation or reproducibility of results)
E	Flotation (concentrate ash and reagent addition control)	None
F	Dryer (gas consumption optimization) Flotation (stream analyzers)	None
G	Flotation control	RD nuclear gauges replaced by dip tube system Silo level indication unreliable Moisture analyzers scrapped (levelling problem)

Table 3 - On-line process-control activities

Plant	Monitoring	Sequential start-up & shut-down	Control loops	Process optimization	Adaptive control
A	Yes	No	No	Yes	No
B	Yes	Yes	Yes	Yes	No
C	Yes	Yes	Yes	No	No
D	Yes	No	No	Yes	No
E	Yes	Yes	Yes	No	No
F	N/A	N/A	N/A	N/A	N/A
G	Yes	Yes	Yes	Yes	Yes

Table 4 - Off-line process-control activities

Plant	Density separator modelling	Size separator modelling	Flotation modelling	Crusher modelling	Thickener modelling
A	Yes	Yes	No	No	No
B	Yes	Yes	Yes	No	No
C	No	No	No	No	No
D	No	Yes	Yes	No	No
E	No response	No response	No response	No response	No response
F	N/A	N/A	N/A	N/A	N/A
G	Yes	Yes	Yes	No	Yes

Table 5 - Simple control loop scheme & type and circuit level strategy

Plant	Simple control loop scheme	Simple control loop type	Circuit level strategy
A	HMC (RD control)	Analog	HMC
B	HMC (RD control-PID) (prop-integr-deriv) Dryer (temperature control-PID	Dryer control (digital)	HMC (RD control) Flotation (re-agent control)
C	PI (prop-integr)	Digital	Jig (set point) Thickener (floc. control) Dryer (tempera-ture control)
D	PI PID	Digital and analog Digital in future	HMC (RD control)
E	PI PID	Analog	HMC (RD control) Flotation (level control)
F	PI	Analog	Flotation (monitor level & RD) HMC (RD control)
G	PI PID	Mostly analog Digital in future	HMC (RD control) Flotation (level, reagent, and assays control) Spirals (splitter gates)

Table 6 - Plant level control strategy, computer system used, and previous experience

Plant	Plant level control strategy	Computer system used	Previous experience
A	No response	PLC (Allen Bradley)	No response
B	Seam blending		
	Flotation (yield optimization)	PLC (Modicon 584)	Generally very good
C	Distributed micro-processor with supervisor	PLC (Allen Bradley) Mini computer (HP-1000) (monitor and control)	Good (minor problems)
D		Distributed control (Fisher-Provox)	Very good (PLC)
	Distributed control interfaced with PLC	PLC 2/30 & 3 (Allen Bradley)	Human interface (controlled environment)
E	Manual supervision & co-ordination	PLC 3 (Allen Bradley)	Reliable & flexible
F	N/A	None	None
G	Swanson interlock	Foxboro 3	Excellent
	Controllers (analog)	PLC's (Modicon)	Computer room (maintenance important)

Table 7 - Off-line computer models used

Plant	Models
A	No response
B	Semi-empirical simulator (yield prediction and product quality) Seam blending
C	None
D	None
E	None
F	None
G	Matbal program Statistics (data collection)

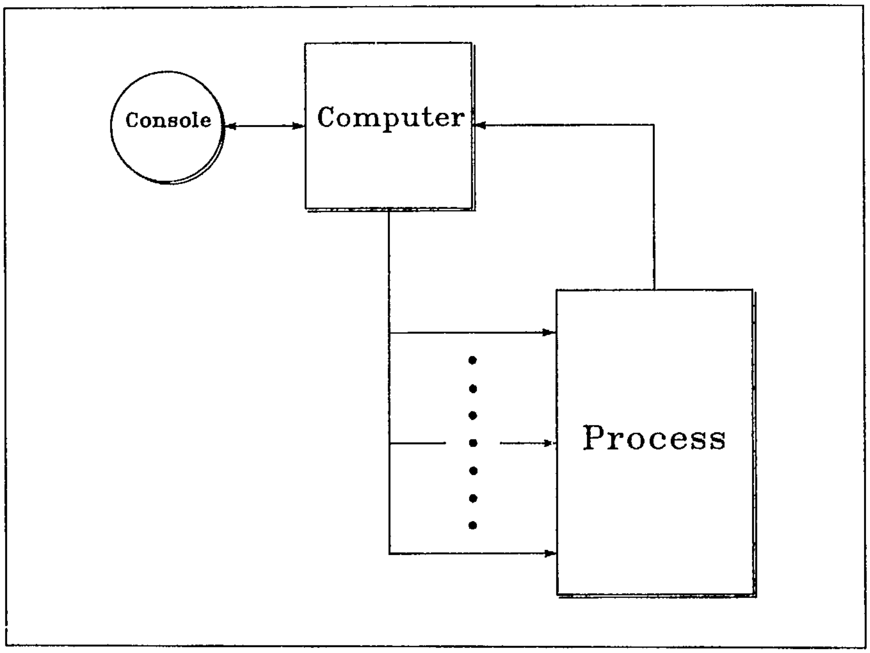

Fig. 1 – Direct digital control

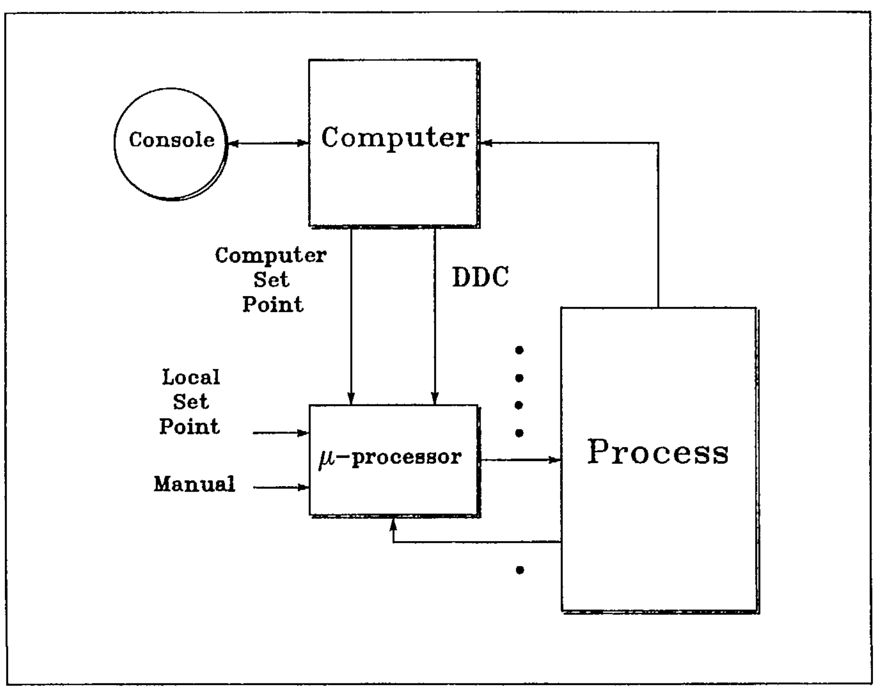

Fig. 2 – Distributed process control

Programmable Logic Controller

In general, the control commands of the process are generated by the computer but some control units such as programmable logic controllers (PLC's) are used instead of, or in conjunction with, the computer (13-17). The PLC has proved to be reliable and robust, and it gives the system the following capabilities for control: sequential start-up and shut-down, interlocking of plant (i.e., failure in a unit of equipment will cause the up-stream flow to be halted), emergency shut-down, detection of alarm conditions, and monitoring ability. Also, software is available for these devices to be interfaced with existing and known minicomputers and personal computers (16). The versatile CRL pilot plant at Devon, Alberta, was redesigned in 1983 with the installation of some new equipment. The flexibility in operation covers 15 flowsheet options to serve research and industrial needs. This large number of flowsheet options needed the use of PLC's. As a result, CRL installed a medium-sized Allen Bradley AB PLC 2/30 system to handle the sequential start-up and shut-down, alarm, and monitoring features. The next stage is to install an Allen Bradley AB-Advisor colorgraphic system to display the status of all motors and all analog quantities of any particular option.

The availability of PLC's with enlarged capabilities (computation and storage), and at reasonable prices compared to computers provides an extra advantage of operating in a standby mode that provides reliability and flexibility.

Use of Modern Control Theory

After World War II, control system design was viewed as an art. Subsequently, a concentrated effort by control system theoreticians resulted in an enormous amount of theoretical and applied work in terms of problem formulation, analysis techniques, system stability, and optimization. These foundations, along with the rapid development in computer technology (software and hardware) and the extensive use made of computers in system control, have resulted in the emergence of modern control formulation (i.e., ease of implementing on computer).

From a coal preparation process-control perspective, limited control has been implemented; a concentrated effort is required to make use of full potential of the results reported in modern control theory. Most coal preparation circuits are accessible for formulation in the frame of the modern control theory, which will facilitate the use of computers (18-21). Any control system requires identification of the relevant process variables. An attempt is made in Appendix E to identify the process variables in coal preparation circuits.

Optimization and Adaptive Techniques

Modern control theory provides the vehicle for the analysis and optimization of most physical processes by use of a digital computer. The level of optimization is governed by the hierarchy of the coal preparation facility (18). We can classify the optimization levels as:

Level 1 - Simple regulation: this improvement can be viewed on the single loop level and deals with local regulation involving simple, physical phenomena, such as level control, flow control, and speed control.

Level 2 - Micro optimization: this improvement is on the circuit (such as HMC, jig, WOC, or thickener) level and concerns optimizing the efficiency of an elementary circuit, in relation to technical production criteria (e.g., yield maximization) or to internal or economic considerations (e.g., reduction of energy consumption).

Level 3 - Macro optimization: the optimization is viewed here in a wider context where the elementary circuits are considered to be included in the whole production operation. It is necessary, therefore, to optimize the process operation in relation to an internal criterion (production quality) that depends on external factors such as competition and the laws of supply and demand.

In most situations, these levels can be achieved by using dynamic, static, linear, nonlinear, distributed parameter system formulation. Problems can be solved using the existing techniques (linear, nonlinear, quadratic, mathematical programming and maximum principle and dynamic programming approaches) which lead to improved performance and, as a result, economic benefits.

Modern control theory can handle very effectively the situation where process dynamics and process parameters (such as time constants and residence time, etc.) are known. In many practical situations, some of the process parameters are unknown. Moreover, many coal preparation circuits, such as flotation or HMC, have inherent process delays (time elapsed between the initiation of a control signal and circuit response). In these situations, the adaptive control approach provides an effective means of dealing with unknown parameters and system delays. This type of control can be achieved by using a microprocessor-based controller to review the performance of the control loop, to determine the quality of control achieved against a predetermined standard, and to calculate the new tuning parameters needed to maintain specified performance. In this way, without creating process upsets, the controller maintains loop performance in an "expert" manner, i.e., in the same way as would an instrumentation engineer when "tuning the loop." This type of self-tuning control adapts not only to load-dependent dynamic gain changes, but also to variations in time - related and/or random dynamic characteristics. Such applications include: (a) pH - control, (b) level - dynamics changes with plant throughput, and (c) flow - pump and valve wear, pipe foul-up and so on. Experience with these controllers indicates savings of thousands of dollars per year in reagent costs and in energy expended. In the future, more emphasis will be placed on, and more use made of, these controllers in coal preparation process control.

On-line Ash and/or Sulphur Analyzers

On-line ash and/or sulphur analyzers are essential monitors for effective product quality control and process-control schemes. A summary of the international manufacturers of on-line ash analyzers is presented in Tables 8 and 9. A critical review of the available ash and/or sulphur monitors is in preparation by the author.

Expert Systems

In the last two decades, dramatic developments have taken place in computer technology with respect to reduced size, increased computation speed, and efficient computer algorithms. These developments, coupled with people's fascination with the prospect of intelligent machines, have speeded up the introduction of artificial intelligence (AI) technology. AI technology is in its infancy because information and knowledge of how the human brain functions and processes information is incomplete; however, some success has been reported in the areas of medicine, chemistry, and mining. Based on the current rate of advancement of computer technology, it is anticipated that AI will find its way into many technical and industrial applications (e.g., robotics). It is worthwhile to discuss briefly some basics of the subject and the feasibility of applying this new technology to coal preparation process control. The presentation is best illustrated by reviewing some of the definitions and concepts used (23,24).

AI has two different products: models of human cognition and intelligent artifacts. Expert systems (ES) belong to the latter. They are created not so much to model how experts solve problems or to understand how an expert's mind works, but for the practical purpose of reaping the benefits from the expert thoughts embedded in a computer system (Fig. 3). However, the two areas are interrelated with beneficial side effects. Building ES is, in a sense, creating a model of expert thoughts that allows us to develop better models of cognition. Also, better models of cognition obtained from different disciplines allow us to build ES better. Therefore, ES can be defined as a knowledge-based system that emulates expert thoughts to solve significant problems in a particular domain of expertise (23).

Intelligent artifacts are produced to solve problems which is the main reason for building ES. Artifacts can be classified as general or domain-dependent or as special or domain-specific. ES's are domain-specific (see Fig. 3).

An ES is composed essentially of a knowledge base, a data base, an inference engine, and some support software (Fig. 4). The central part is the inference engine. The knowledge base holds whatever information we have found appropriate to solving problems in our chosen domain. It is specific to the particular application and can be built in a number of ways:

- by observing the process-control operators at work;
- by interviewing the operators;
- by the operators themselves programming their control strategies as rules; and
- by the controller acquiring strategy on-line.

The data base is the work area of the system. The support software provides the interface to the environment. The inference engine provides the motive power to the system. Its functions determine what data it needs to solve the problem at hand, to get these data via the support software, to lodge them in the data base, to employ the contents of the knowledge base to draw inferences, and to record these in the data base. It exercises these functions repeatedly until it can do, or need do, no more (23). However, others call the unit which receives the process data, uses the inference engine to compare the process data with the knowledge base, and advises the operator accordingly as the shell.

The main desirable characteristics of ES's are the following:

- to perform well on difficult problems;
- to be easy to implement;
- to interact well with humans;
- to be able to explain themselves;
- to work at real-time pace;
- to be easy to modify and augment the knowledge base; and
- to have inference machine work irrespective of the theory.

An application of ES in process control is the area of alarm management. When an alarm or out-of-limit signal is received by the system, the inference engine uses its rules to decide which process measurements are important for an analysis of the situation. These selections can then be scanned faster than others, effectively focusing on the data needed for diagnosis. A parameter that may not normally be measured could be called up if necessary. Structuring of rules allows appropriate ones to be found without searching the entire data base. The rule altered by the data base might direct the inference to the next rule to consider or, alternatively, it could direct it to search all rules relating to a certain aspect of the system, such as a tank or temperature indicator. With the capabilities of present systems, analysis and diagnosis can be completed at a speed fast enough to prevent the development of potentially hazardous situations.

It is estimated that more than half of current development work on expert systems is in the field of alarm management. It is anticipated that, in perhaps 3 to 5 years, they will be incorporated into control systems, not just added on, in the same way that the VDU (visual display unit) has become the main operator interface.

Table 8 - International manufacturers of ash monitors (22)

Brand or manufacturer	Country	Radiation source	Manner of radiation	Ash Content range (%)
CENDREX (DSM)	Netherlands	Soft X-ray	Backscattering	3-15 <60
SIMCAR	United Kingdom	170-Tm(γ)	Backscattering	2-30
GUNSONS SORTEX (Phase 3)	United Kingdom	238-Pu(γ)	Backscattering	5-20
HUMBOLDT-WEDAG (KHD)	F.R. Germany	241-Am(γ)	Backscattering	3-10
ASHSCAN	Australia	241-Am(γ) 137-Cs(γ)	Transmission	8-12 22-35
COALSCAN (PP)	Australia	226-Ra(γ)	Transmission	-----
AMDEL	Australia	241-Am(γ) 137-Cs(γ)	Transmission	-----
NUCOALYZER	United States	252-Cf(n)	Transmission	<30
MICHIGAN I.T.	United States	109-Cd(γ)	Transmission	45-80
EMAG	Poland	241-Am(γ)	Backscattering	3-30
AZUK, EAZ	Soviet Union	90-Sr(β) 241-Am(γ) 137-Cs(γ)	--------------	-----

Table 9 - Method of application for ash monitors

Method	Brand
Dry methods	SORTEX
	BERTHOLD-HUMBOLDT-WEDAG
	COALSCAN-Thrubelt
	COALSCAN-Shaking Tube
	SAI Ash Meter
	WULTEX
Slurry meters	ASHSCAN
	AMDEL

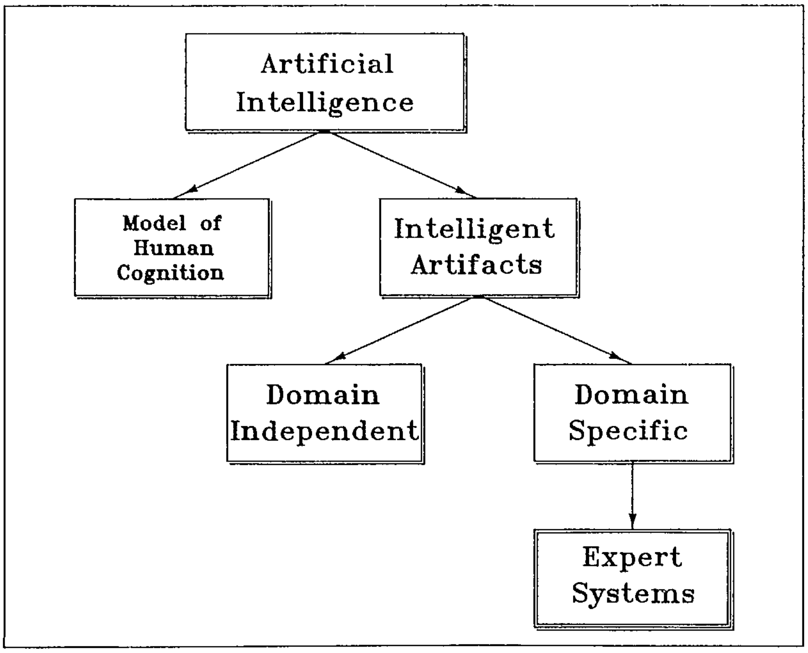

Fig. 3 – Artificial intelligence and expert systems

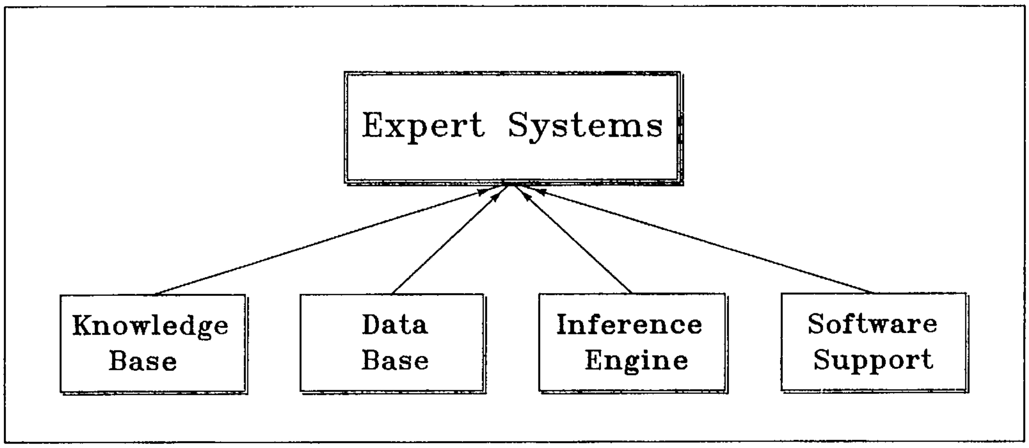

Fig. 4 – Expert system components

CIRCUIT PRIORITIES

Flotation Cell

Western Canadian coals are friable in nature and, as a result, large proportions (20-60%) of fines (<0.5 mm) are present in the run-of-mine. Efficient separation in the fines circuit is essential for an acceptable overall plant recovery. Froth flotation is the most common process used to beneficiate coal fines and is used in 10 out of 12 preparation plants in Canada.

Although simple in concept, coal flotation is a complex process that is affected by many variables, among them:

- coal rank
- flotation mechanisms (collision, attachment, detachment)
- particle size and size distribution
- size and population density of bubbles
- surface conditioners and collectors
- chemical and hydrodynamic conditions
- turbulence and fluid flow patterns in cell
- reagents dispersion state
- pH of pulp phase
- height and structure of froth layer.

Strong interactions between parameters influence the performance of flotation systems. Consequently, it is generally acknowledged that the flotation section of a coal preparation plant is the most difficult to operate and control to achieve optimum recovery. This conclusion is supported by the response obtained in the survey (see Tables 1 and 2).

Modest developments in flotation cell modelling and control from Australia, the USA, and Canada have been reported in the literature (21, 25-29). They indicate that a concentrated effort is still needed to improve coal recovery. This effort should concentrate on:

- better understanding of flotation mechanisms and development of effective, reliable, and realistic dynamic models to simulate these mechanisms;
- use of modern control theory to develop effective control strategies; and
- use of available self-tuning and adaptive control algorithms (28).

A detailed list of the process variables relevant to flotation cell circuits is given in Appendix E.

HMB/HMC

Considerable progress has been made in the development of heavy-medium circuit process control in Australia, the USA, the U.K., South Africa, France, and Canada (29-33). In all of the developed systems, the aim was to regulate the medium density and, in some cases, the viscosity. Most of the developed control systems use classical proportional-integral (PI) and proportional-integral-derivative (PID) controllers. The performance of PI and PID controllers is acceptable to some degree. However, a concentrated effort is needed in advanced digital control using:

- pulse amplitude modulation scheme
- pulse frequency modulation scheme
- pulse modulation scheme
- self-tuning and adaptive scheme

to improve the performance of the control system in terms of the response time and efficient tracking of the set points. Overseas developments could be used in Canada. A detailed list of the process variables relevant to heavy medium circuits is given in Appendix E.

Jig

It appears that most development of process-control systems for jigs is taking place in Germany (29). The jig bed depth is continuously controlled based on the ash content of the clean product. It may be advantageous to investigate the feasibility of controlling the air pressure profile based on the yield maximization subject to ash level in the products. The German development could be used in Canada. A detailed list of the process variables relevant to jig circuit is also given in Appendix E.

Thermal Dryers

There are two categories of thermal dryers: (1) a direct heat-exchange type, where hot combustion gases from a furnace are forced through the coal, directly heating the coal and evaporating the moisture; and (2) an indirect heat-exchange type, in which hot combustion gases from a furnace warm a heat transfer medium that, in turn, heats and dries the coal. Within each of these two categories, several types of equipment are available. The direct type includes fluidized bed dryers.

The thermal dryer is an expensive component of a preparation plant, both in terms of capital and operating costs. One estimate of the capital cost of the equipment is $54 to $73 per year per tonne of water removed (32). In general, 70 to 80% of the total dried tonnage is dried using fluidized bed dryers (32). For coal dried from 14 to 5% moisture, assuming a fuel cost of $1 per million Btu and an electricity cost of 5¢ per kWh, these two components of operating cost amount to $0.61 to $0.90 per tonne of dried coal (32).

To minimize both fuel and electricity consumption in a fluidized bed dryer, the gas temperature entering the drying chamber should be as high as possible without causing the coal to burn, to lose its volatile matter, or to be oxidized appreciably. Furthermore, the moisture-laden gases must leave the drying zone at a temperature sufficiently high that they are not cooled below the dew point before they reach the scrubber. The instrumentation and control system should properly control the combustion rate and gas flow to maintain drying conditions that will result in safe, efficient, reliable operation at the desired degree of product dryness.

CRL COAL PREPARATION PROCESS-CONTROL R&D: FUTURE DIRECTIONS

In 1981, CRL began a process control program to automate its 10 t/h pilot plant facility at Devon, Alberta. At that time, it was realized that the distributed process-control scheme is superior to the direct digital control scheme, especially with regard to the backup feature and flexibility in development as was discussed earlier (Fig. 5). Moreover, the pilot plant is being used to develop, test, and evaluate process-control strategies and on-line instrumentation before recommending them for industrial use.

Part of the effort in process-control R&D at CRL is carried through research contracts, two of which were on control systems for heavy-medium and froth cell circuits. The heavy-medium cyclone project has been successfully completed. This system will be the focus of further development and improvement especially in reference to control algorithms. The design of a computerized process-control system for the flotation circuit in CRL's pilot plant is completed. A status summary of process-control developments at CRL is presented in Table 10.

Most of the circuits are controlled manually, i.e., setting of cutpoints, feed rates, and so on are adjusted manually. At present, in-house expertise is being used to implement the sequential start-up and shut-down for the 13 operating options of the pilot plant using the Allen Bradley AB PLC 2/30 programmable logic controller (existing).

Based on the analysis of responses presented in the "Questionnaire Discussion" Section and the discussion presented in "Canadian Coal Preparation Process-Control R&D: Future Developments," CRL's future efforts will concentrate on:

- sequential start-up and shut-down
- instrumentation
- monitoring and report generation
- simple control loops
- process optimization, adaptive control, and parameter identification
- process modelling
- expert systems

in relation to the following circuit priorities:

- flotation
- water recovery
- jig
- WOC
- spiral.

The sequential start-up and shut-down of the CRL pilot plant, interlocking, alarm, and monitoring are handled by an Allen Bradley AB PLC 2/30 (existing) (Fig.6). The logic programming of the different operating options has been completed. The next step in our development is the installation of an AB-Advisor colorgraphic system for flowsheet, process variables, motor status displays, and process variables trending. Storage of plant or run data, number crunching and data manipulation, report generation and higher level control are handled by a process-control minicomputer HP 1000-A700 (existing). Communication between AB PLC 2/30 and HP 1000-A700 is established via a fibre optics link.

Most of the instrumentation, except for on-line ash and/or sulphur analyzers and per cent solids, are reliable and available. During the course of development of process-control systems for different circuits in the pilot plant, the required instrumentation and control loops will be evaluated and implemented. The dedicated microprocessors designed to control and optimize a particular circuit are required to communicate with the HP 1000-A700. A list of common transducers used in coal preparation plants is given in Appendix F (34).

The major areas of process optimization, adaptive control, parameter identification, process modelling and simulation, and expert systems in coal preparation are necessary to achieve better and effective control. However, little effort in these areas has been reported. From research carried out at CRL, process-control expertise and the use of international developments could complement each other in achieving a comprehensive and efficient process-control scheme (35-49). To plan a future strategy for CRL development in coal preparation process control, it is useful to present the areas of development together with such available methodology and technology (national and/or international) related to them. This information is given in Table 11.

CONCLUSIONS AND RECOMMENDATIONS

As a result of preparation plant visits, discussions, and survey responses, the following main directions for R&D emerge:

- to continue developing accurate and reliable process monitors, particularly on-line ash and/or sulphur monitors;
- to pursue process-control strategies for coal preparation circuits, especially to maximize the recovery of flotation circuits;
- to stabilize and improve the moisture control on plant products; and
- to develop effective computer models (dynamic) which can be used as a reference for the process operation.

Regarding on-line ash and/or sulphur monitors, the establishment is recommended of a joint project between CRL, the Canadian Atomic Energy Commission, and industry to develop ash and/or sulphur monitors (stream, slurry, and froth applications) that will benefit the Canadian coal industry.

Table 10 - CRL process control developments

Circuit	Objectives	Status of process control
HMC	Medium density control	Completed
Flotation cell	Reagents addition control	Design only
	Density control	
	Product quality control	
	Yield maximization	
	Specific power control	
Jig	Yield maximization	Manual
	Quality control	
WOC	Yield maximization	Manual
	Quality control	
Water recovery	Flocculants addition control	Manual
	Water clarity	

Table 11 - Process-control development methodology

Area	Methodology	Availability
Sequential start-up and shut-down	Logic ladder diagram programming	National
Instrumentation		National and/or International
Monitoring and report generation	Software programming	National
Simple control loop	Software and hardware programming	National
Process optimization	Modern control theory Adaptive control schemes Parameter identification schemes	National and/or International
Process modelling and simulation	Mathematical models Empirical models Probabilistic models Computer simulation	National and/or International
Expert systems	Modelling of human cognition Intelligent artifacts Use in coal preparation	National and/or International

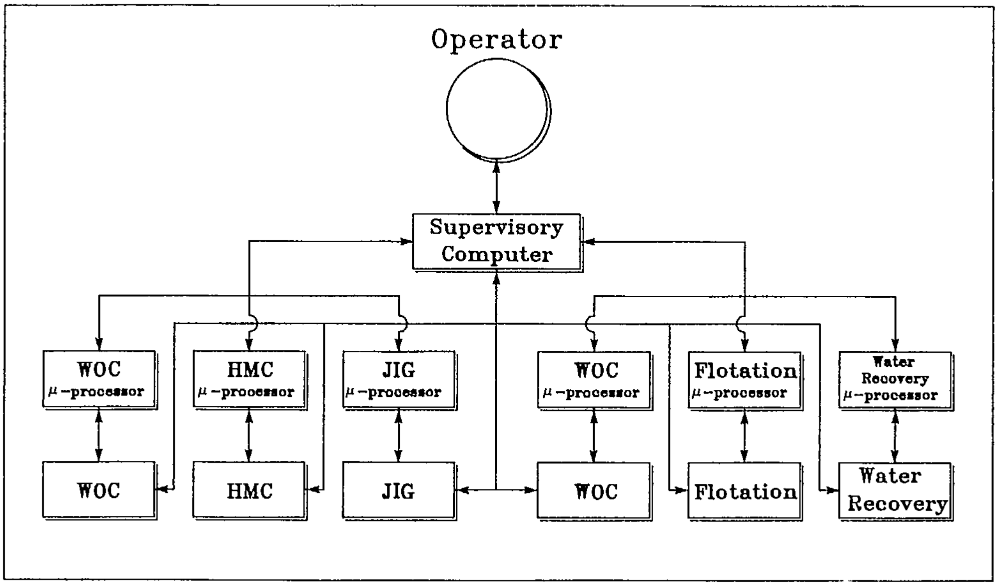

Fig. 5 - CRL process control R&D strategy

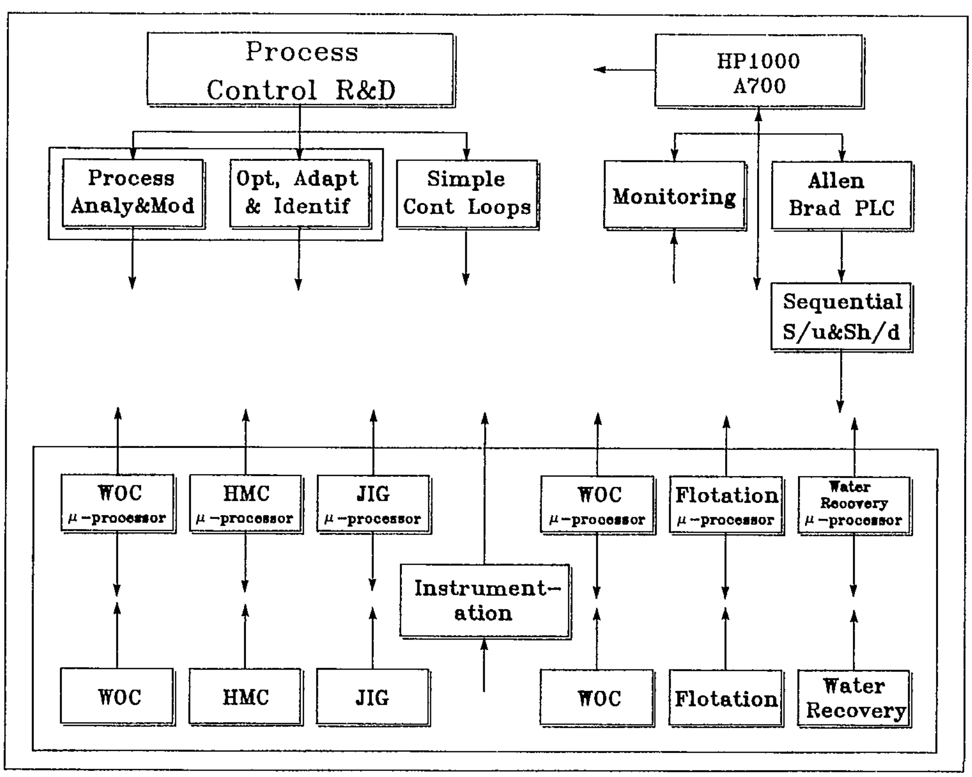

Fig. 6 - CRL process control development scheme

In-house process-control developments should continue and should be implemented on a step-by-step approach depending on the availability of funds. The effort should concentrate on developing effective process-control strategies for the different circuits to maximize recovery. As a direct response to the needs of industry, flotation circuit automation is a top priority. International developments and any fundamental work carried out by Canadian universities could be used depending on their applicability to Canadian coal preparation plants.

Development of effective computer models (dynamic) is being, and will continue to be, pursued at CRL. This development will enhance circuit operation, produce better prediction/simulation, and could be used to train coal preparation engineers. Any recent fundamental and/or overseas developments will be incorporated in CRL development.

In conclusion, it must be noted from the survey that the industry is striving to improve efficiency of preparation plants under difficult economic and operating conditions.

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APPENDIX A

INDUSTRY SURVEY QUESTIONNAIRE

INDUSTRY SURVEY QUESTIONNAIRE

NOTE : ANY QUESTIONS OR CLARIFICATION REGARDING THIS QUESTIONNAIRE, PLEASE CONTACT:

NAME : Dr. Ahmed I.A. SALAMA

POSITION : RESEARCH SCIENTIST

Phone : (403) 987-8235

PROCESS-CONTROL DEVELOPMENT

Plant : ______________________________

GENERAL OVERVIEW

CIRCUITS :

Heavy Medium Vessel
Heavy Medium Cyclone
Jig
Hydrocyclone
Flotation
Dewatering
Drying
Water Treatment

1. What method(s) of quality and/or process control are used in the plant? Are they reliable/adequate for your purposes?

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2. Does the plant use in-line monitoring? For what purpose, and where?

3. Which circuit do you believe the plant would benefit most from in-line monitoring and process control - i.e., list your circuit priorities (in order) and what you feel needs to be controlled.

4. Which circuit(s) are most problematical and need most attention in terms of maintaining or achieving optimum performance? Can you estimate losses of product and/or costs associated with present performance and gains that could be achieved with process control?

5. Has any attempt been made in the past to implement process control and later been discontinued? If so, can you describe the instrumentation and what problems were associated with it?

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SPECIFICS

1. If I specify the on-line process-control activities as:

   Monitoring and trending

   Sequential start-up and shut-down

   Simple control loops

   Process optimization

   Adaptive control

   Please mark 'X' in front of the activity which applies to your plant.

2. If I specify the off-line process-control activities as:

   Density separator modelling

   Size separator modelling

   Flotation modelling

   Crusher modelling

   Thickener modelling

   Please mark 'X' in front of the activity which applies to your plant.

3. On the simple control loop level, what type of control schemes (PI, PID, or otherwise) are used and on what process variables are they implemented?

4. On the simple control loop level, please indicate the type of control scheme used - analog or digital.

5. On the circuit level (jig circuit, HMC circuit, WOC circuit, flotation circuit, water recovery circuit, etc.), please indicate the control strategy used.

6. On the plant level, please indicate the control strategy used.

7. What type of computer systems are used for on-line process control?

8. Outline your experience with the computer system you have in terms of reliability, industrial environment, etc.

9. What type of computer models are used for off-line process control or prediction or evaluation?

10. Any other comments?

APPENDIX B

COAL PREPARATION AND COMPUTER APPLICATIONS

COAL PREPARATION AND COMPUTER APPLICATIONS

In the last 20 years, enormous progress in the area of computer technology has been witnessed. Rapid advances in computer hardware and less rapid but significant advances in computer software have led to development of the minicomputer, microcomputer, and microprocessor. Significant computer control development in mineral processing has already been achieved. Although progress has been made in the area of computer applications in coal preparation, more concentrated effort is needed to use the full potential of computer technology development.

Computer applications in coal preparation can be viewed as off-line and on-line. However, development in one area could be used in the other. Considerable progress has been reported in the area of off-line computer applications, especially in the areas of process modelling (static models), performance evaluation/prediction, flowsheet analysis/optimization, and statistical analysis (Fig. B-1). However, little effort has been reported in on-line computer applications, especially in the areas of process control, model reference control, process optimization, and adaptive control.

COMPUTER, INSTRUMENTATION, AND CONTROL

Long before the invention of the computer, people were an integral part of many process systems in which the human sensors were used to sense the process variables and in which the brain was employed for decision making. Later, instrumentation was developed to replace human sensors and was used by people to assist in making certain decisions for the adjustment of process variables to achieve certain objectives. The performance of the human-process system was acceptable to some degree, but human errors and delays were the main disadvantages. The response of the whole system was slow, and precision and accuracy suffered. The invention of the computer revolutionized the concept of the human-process system by turning over some of the human decision-making tasks to a computer. Computers can perform these tasks accurately and reliably and in much less time. As a result, the role of humans has become a more supervisory one with only higher level decision-making. In such a

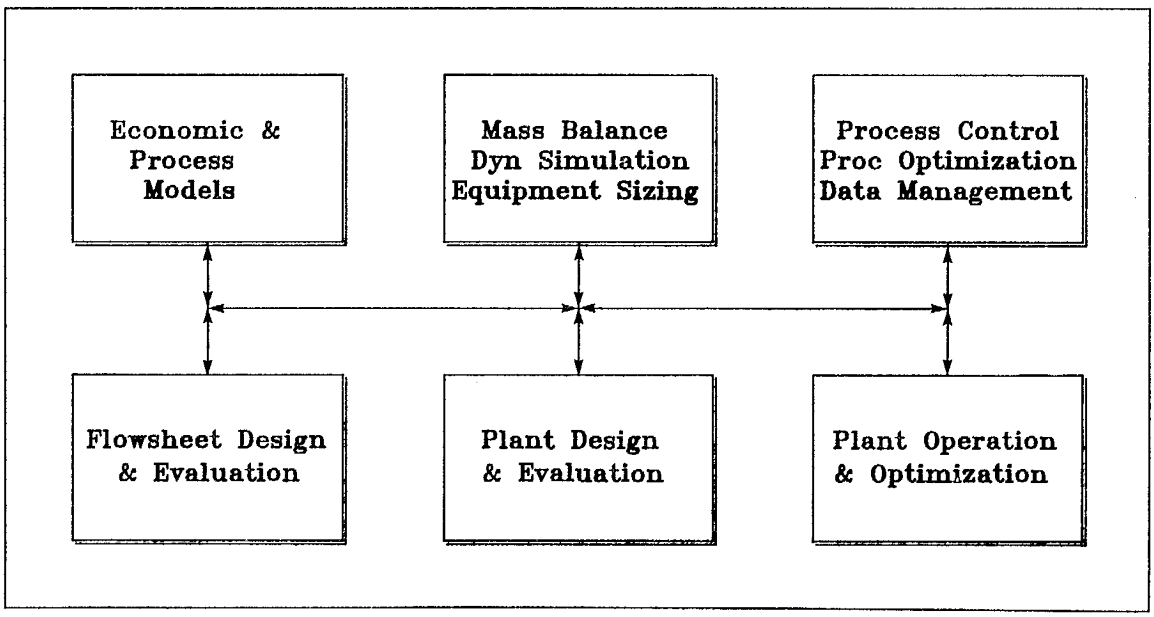

Fig. B-1 - Coal preparation computer applications system (human-computer-process), most of the disadvantages of the earlier system (human-process) are eliminated and, as a result, the overall system response is fast and the accuracy and reliability are greatly improved.

The link between the process and the computer is instrumentation. To achieve good control, instrumentation and sensors must be accurate and reliable because erroneous measurement leads to poor control. Therefore, instrumentation is the key to an effective and successful control system. In general, control commands of the process are generated by the computer but some control units such as programmable logic controllers (PLC's) are used instead of, or in conjunction with, computers. The PLC and computer have processors (functional electronics), but the PLC's are dedicated to certain tasks and are relatively inexpensive and robust, especially in the hostile environment of a coal preparation plant. Although the computer costs more than a PLC, it has much larger capabilities.

APPENDIX C

COAL PREPARATION PROCESS CONTROL

COAL PREPARATION PROCESS CONTROL

Coal preparation is thought of as the process of improving the quality of run-of-mine coal to meet certain quality requirements. This process is drastically hampered by the inherent heterogeneous nature of coal, which creates a wide variation in the characteristics (washability and size or surface characteristics, etc.) of plant feed, resulting in deterioration of washing processes. Control of these processes and the equipment performing them can lead, if appropriately applied, to a variety of benefits:

- improved product quality
- better use of equipment by reducing down-time
- independence from human limitations
- potential for totally unmanned production.

On the other hand, process control requires:

- an understanding of the coal preparation process through physical laws that govern the process or collecting data that assist in establishing realistic (not simplified) dynamic models (mathematical, empirical, or otherwise) of the process;
- a system of components that must work together appropriately and match one another for the process-control system to work efficiently; and
- the change and adaptation of the entire system to the results and improvements brought about by the use of process control.

In general, process-control systems aim to achieve optimum performance or to meet quality requirements by the following components:

- sensing devices
- electronic controllers
- actuators
- adequate control strategy expressed in computer software.

PROCESSES THAT CAN USE PROCESS CONTROL

- Coal preparation
- Dewatering
- Drying

<u>PROCESS VARIABLES</u>

- Pressure
- Density
- Flow rate
- Temperature
- Force
- pH
- Vibration
- Turbidity

<u>Sensors</u>

- Analog
- Digital

or

- Electrical variable
- Mechanical variable
- Fluidic variable
- Thermal variable
- Optical

<u>Actuators</u>

- Solenoids
- Relays
- Hydraulic cylinders
- Pneumatic cylinders
- Stepping motors

<u>Data Conversion</u>

- Standard
- Tailored to specific need

COMPUTER INTERFACE

Sensor signals are weak and are not suitable for direct input into the peripheral data channel of the control computer.

Signal Amplifiers

Drift problem

Integrated components as large-scale integration (LSI)

Advantages: broad frequency range/DC-AC up to MHZ range

Multiplixers

Low level

- Inexpensive
- Transducer/sensor with low impedance, high level signal
- A/D converter/amplifier peripheral

High level

- Weak signal/small amplitude
- First amplified

Control Strategy

Automation can be categorized as:

- Sensors - Human operation
- Sensors - "Intelligent" signal processing
- Sensors - Computer control
- Sensors - Computerized control system
- Adaptive control constraint (ACC)
- Adaptive control optimization (ACO)

Control strategy and hardware and software requirements of control system depend on the level of automation.

APPENDIX D

EXISTING PROCESS-CONTROL SYSTEMS

Table D-1 - Existing process-control systems

MODEL AND MANUFACTURER	PROCESS SYSTEMS MICON	BAILEY NETWORK 90	ROSEMOUNT SYSTEM 3	MOORE MYCRO	FISHER & PORTER MICRO DCI	RATING ON THIS POINT
Feature						
CONTROLLER PACKAGING	15 Analog in 8 Analog out 16 Discrete in 8 Discrete out	NCOM 03 4 Analog inputs 2 Analog outputs 3 Discrete inputs 4 Discrete outputs NMFC 01 252 Analog in 126 Analog out 189 DI 252 DO	16 Analog in/out (14 in, 4 out or 8 in, 8 out or any other combination). Contact controllers are separate devices. Additional components make these controllers work.	Multiloop Controller 64 Analog in 32 Analog out 400 Discrete This takes physical form of one vertical cabinet.	Single Loop, each controller with its own indication and side panel configuration or controllers without indication and configuration. Can be rack mounted.	MICON superior MOORE, BAILEY, ROSEMOUNT equal F & P-single loop
LOCAL CONTROLLER CONFIGURATION AND INDICATION	Excellent. Side panel configuration and front panel indication and loop control. Can be ordered blind, and/or without configuration panel.	Configuration by buying Configuration Module. Indication by buying Digital Control Station, one for each loop where local indication/oper. is desired.	Indication by buying individual control stations for each loop needing indication. Local configuration method not shown.	Indication on CRT (in cabinet or portable). Configuration from CRT and an extra keyboard.	A rack mount version would have blind controllers, one for each loop chamelon if req'd, one supervisor, one programming panel.	MICON better, F & P good, MOORE next if MYCROterm is included in cabinet. ROSEMOUNT, BAILEY, equal.
KEYBOARD OR KEYBOARDS	One special purpose keyboard for all functions. Coffee proof. Special keys to access displays and manipulate control loops. Configuration and graphics generation also from this keyboard.	Special purpose keyboard for operation and configuration. Second plug-in keyboard for graphics generation. Keys to access displays and operate controllers.	Special purpose, not known if one keyboard does all functions.	For 2. Special purpose control keyboard, separate configure keyboard. Graphics generation assisted by digitizer and configuration keyboard.	One keyboard for process control, a separate keyboard for configure.	MICON (1 only) BAILEY (2) ROSEMOUNT (with universal console) MOORE, ROSEMOUNT (with Mini Console) F & P, not sealed surface.

Table D-1 (Cont'd)

MODEL AND MANUFACTURER	PROCESS SYSTEMS MICON	BAILEY NETWORK 90	ROSEMOUNT SYSTEM 3	MOORE MYCRO	FISHER & PORTER MICRO DCI	RATING ON THIS POINT
OPERATOR INTERFACE CHOICES	One choice only. Does all functions.	One choice. Engineering work station may be an alternate.	1. Mini Console interface. 2. Command Console interface. 3. Universal Console interface.	1. MYCRO term built-in, portable or console. 2. MYCRO basic CRT station.	Often used without CRT; Supervisor can be linked to color CRT and keyboard.	Not rated.
HOST COMPUTER INTERFACE PLC INTERFACE	PLC interface. Bulletin MDC200 11s. Computer interface 9600 baud - see PG. 85 MDC800 book. Allows access to and change of all points. Software required.	CIU computer interface unit. Software available for HP 1000, Fortran level subroutines. ASCII or Binary form of transmission. PLC link also available.	Computer interface available fall of '85.	ICI-3 special device intended to provide access to all data of MYCRO system.	Available from the Supervisor at RS232 Serial various speeds. Programming required.	BAILEY (software developed) MICON, ROSEMOUNT. MOORE, F&P
CALCULATION CAPABILITY FUNCTIONS	70 functions including 10 math functions. Uses function blocks exclusively for easy programming.	MFC can do 1000 lines of BASIC for user-defined functions plus 60 math functions. BASIC programming requires external terminals and external disc storage.	32 math operations. 25 other functions; also user-defined functions can be written and interconnected.	27 programmed functions (algorithms). The calculator function (#18) can do any math or decisions required.	3 preprogrammed functions. User programming of other functions. Special programming language F-TRAN Not as convenient to program.	BAILEY COM 03 but programming is awkward to use full capability. ROSEMOUNT, MICON, MOORE, F & P
DISPLAYS ON CRT AT OPERATOR INTERFACE	Colour. Real time data. Can operate from custom graphics. LOOP, MICON GROUP, BULK GROUP, ALARM SUMMARY, TREND INPUT with TREND, ANNUNCIATOR, FUNCTION VALUE.	Colour. Real time data. Can operate from custom graphics. INPUT, LOOP, GROUP, AREA, ALARM, SYSTEM STATUS, PCU STATUS, OIU STATUS, TUNING TRENDING.	For 1 and 2. Mono. Real Time. GROUP, ANALOG FACE PLATE, CONTACT FACE PLATE, TREND, ALARM, CONF, STATUS. NO CUSTOM For 3. Colour. Many but release date is 1985.	For 2. Colour. Real time data. Operate from custom graphics. OVERVIEW, GROUP, GRAPHIC, POINT DTL., TREND is option.	Preformatted displays are Summary Display Group Display Point Display	BAILEY, MICON, MOORE, ROSEMOUNT

Table D-1 (Cont'd)

MODEL AND MANUFACTURER	PROCESS SYSTEMS MICON	BAILEY NETWORK 90	ROSEMOUNT SYSTEM 3	MOORE MYCRO	FISHER & PORTER MICRO DCI	RATING ON THIS POINT
EXPANDABILITY	Add new MICON for each 8 loops. Keep new systems each on own MICON.	New COM for each 8 loops. New systems plug into first rack if it is big enough. One MFC would do present and future.	New systems plug into same rack 8 loops/unit.	One unit is quite large (32 Analog O) and first unit may do all future systems also.	Can be expanded, large enough for all pilot plant loops.	Little to choose. The appearance of one new MICON for each new system is a plus. For froth flotation, MICON is most compact - 1 cabinet.
SPACE	Most compact installation.	One cabinet plus interface.	One cabinet plus interface.	One cabinet plus interface.	Can be all in one cabinet.	MICON, F & P, others equal.
COST WITH SIMILAR CAPABILITIES	35,684 1,376 1,238 2,591 320 1,754 18,818 8,089 15,550 7,110 $ 92,530	109,628 -7,269 MPC HP 1000 -7,860 software $ 94,499	5,675 835 2,500 10,500 47,700 5,000 325 8,500 2,500 30,650 $114,185	45,500 9,560 38,220 5,720 1,050 10,005 3,900 $113,955	Not similar	MICON and BAILEY are close. MICON preferred because of packaging. BAILEY preferred because of HP 1000 software.

APPENDIX E

CIRCUIT PROCESS VARIABLES

CIRCUIT PROCESS VARIABLES

JIG CIRCUIT

Disturbances to the Process

- Coal rank and type
- Feed size distribution
- Presence of clay slimes
- Feedrate

Measured Variables

- Coal composition
- Volume flowrates
- Pulp density
- Product ash

Manipulated Variables

- Bed depth
- Makeup water feed rate
- Pulse window and frequency

Controlled Variables

- Recovery (yield)
- Grade (Btu value)
- Circulating loads
- Product ash

HEAVY-MEDIUM VESSEL CIRCUIT

Disturbances to the Process

- Coal rank and type
- Feed size distribution
- Presence of clay slimes
- Feedrate
- Magnetite losses
- Water injected

Measured Variables

- Volume flowrates
- Medium density
- Level
- Viscosity
- Product ash

Manipulated Variables

- Medium density (magnetite:water ratio)
- Medium viscosity
- Retention time
- Upward current
- Settling rates
- Magnetic separator level

Controlled Variables

- Recovery (yield)
- Grade (Btu value)
- Circulating loads
- Product ash

HEAVY-MEDIUM CYCLONE CIRCUIT

Disturbances to the Process

- Coal rank and type
- Feed size distribution
- Presence of clay slimes
- Feedrate
- Magnetite losses
- Water injected

Measured Variables

- Volume flowrates
- Medium density
- Level
- Viscosity
- Product ash

Manipulated Variables

- Medium density (magnetite:water ratio)
- Medium viscosity
- Magnetic separator level
- Sump level

Controlled Variables

- Recovery (yield)
- Grade (Btu value)
- Circulating loads
- Product ash

WATER-ONLY CYCLONE CIRCUIT

Disturbances to the Process

- Coal rank and type
- Feed size distribution
- Presence of clay slimes
- Feedrate
- Per cent solids

Measured Variables

- Volume flowrates
- Level
- Viscosity
- Product ash

Manipulated Variables

- Sump level
- Vortex finder setting
- Feed rate
- Pressure

Controlled Variables

- Recovery (yield)
- Grade (Btu value)
- Circulating loads
- Product ash

SPIRALS CIRCUIT

Disturbances to the Process

- Coal rank and type
- Feed size distribution
- Presence of clay slimes
- Feedrate
- Per cent solids

Measured Variables

- Volume flowrates
- Product ash

Manipulated Variables

- Splitters settings
- Feed rate

Controlled Variables

- Recovery (yield)
- Grade (Btu value)
- Circulating loads
- Product ash

FLOTATION CELL CIRCUIT

Disturbances to the Process

- Coal rank and type
- Coal oxidation
- Feed size distribution
- Presence of clay slimes
- Water composition (pH, hardness)
- Feedrate

Measured Variables

Coal composition

Volumetric flowrates

Pulp density

Level

Power input

Manipulated Variables

Reagent addition level (frother, fuel oil)

Frother addition ratio

Reagent addition points

Aeration

Impeller speed

Pulp level

Conditioning time

Froth sprinkling rate

Coarse/fine split

Controlled Variables

Recovery (yield)

Grade (Btu value)

Circulating loads

Froth level

Per cent solids

THICKENER CIRCUIT

Disturbances to the Process

Feedrate

Per cent solids

Water composition (pH, hardness)

Trace elements

Measured Variables

Volume flowrates

Level

Power input

Torque

pH

Settling rate

Clarity

Manipulated Variables

Flocculants addition

Settling rate

Clarity

Sludge level

Controlled Variables

Settling rate

Clarity

Sludge discharge

pH

APPENDIX F

COAL PREPARATION TRANSDUCERS

COAL PREPARATION TRANSDUCERS

TRANSDUCERS FOR PLANT OPERATION

Speed Monitoring

- Tachoswitches
- Inductive proximity switches
- Dry reed switch sensor
- Hall effect sensor
- Radar Motion detector

Vibration Monitoring

- Magnetic reed switch
- Piezoelectric accelerometer

Blocked Chute Detection

- Tilt switch
- Capacitance probe
- Ultrasonic
- Photo-electric

TRANSDUCERS FOR PROCESS CONTROL

Solids Flow Measurements

- Gravimetric belt weighers
- Nucleonic belt weighers

Solids Level Measurement

- Tilt switches
- Pressure switches
- Paddle switches
- Nucleonic switches
- Plumb bob
- Echosonic
- Weighchain transducer
- Radar techniques

<u>Ash Content Measurement</u>

Constant volume sample
Nucleonic measurement
Iron fluorescence
Plutonium backscatter

<u>Sulphur Content Measurement</u>

Iron content indication

<u>Moisture Content Measurement</u>

Capacitance measurement
Microwave measurement

<u>Liquid Density Measurement</u>

Differential pressure
Nucleonic density gauge

<u>Liquid Level Measurement</u>

Float switches
Capacitance
Conductivity
Differential pressure
Echosonic
Ultrasonic

<u>Liquid Flow Measurement</u>

Magnetic flowmeters
Doppler flowmeters
Transit-time flowmeters
Ultrasonic

TRANSDUCERS FOR PRODUCTION MONITORING

Multi-idler belt weighers

TRANSDUCERS FOR MAINTENANCE MONITORING

Bearing temperature

Oil pressure

Vibration

Misalignment

Canada