PCS PHOSPHATE WHITE SPRINGS AUTOMATIC CONTROL AND ON-STREAM ANALYSIS INNOVATIONS HAVE PAY-OFF IN BIG GAINS

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PCS Phosphate mining operations near White Springs in North Florida adopted in 1985, at that time an industry innovation, centralized computer consoles as the operating base for beneficiation plants. Soon after, a development was started for bringing a new concept of on-stream analysis into practice to supply real-time data on rougher flotation BPL to the control consoles enabling quick recognition of process changes. "BPL" is "bone phosphate of lime", the industry term for mineral grade.

Both programs have become successfully implemented. The pay-off is shown in graphical illustrations below -- up to five per cent gains in production. Improved product value can be measured in several million dollars per year for a typical mine beneficiation plant.

Continued beneficiation plant control improvements are planned at PCS Phosphate - White Springs toward applying expert systems control techniques linked to artificial intelligence and other advantageous technologies available in current state-of-the-art. High-points of operating efficiencies - illustrated by peak values in Figure 3, "Increased Recovery" - will be approached more consistently with use of advanced control techniques to produce further gains.

KEY FACTORS IN ACHIEVING PRODUCTIVITY GAINS

A first factor essential to implementing an innovative productivity improvement program is recognition by management that risks implied in the work are worth taking because gains are potentially substantial. Management support at White Springs has been steadfast through the ten years devoted to these developments.

The second factor is making available critical information needed for process control at an operating station which is "user-friendly" to plant personnel. A Moore Systems computer package in use at White Springs has been successful in process control over the last ten years.

Measurements of all possible plant variables in a reliable manner are essential inputs for process control. The important missing input at the beginning was process stream BPL data. Soon after, magnetic resonance (MR) analysis was identified as a practical approach to on-stream BPL measurement. MR on-line BPL analysis was proven at the Suwannee beneficiation plant by 1989, and MR was shortly adopted at Swift Creek. With Suwannee put in standby (1992), the Phospholyzer^{tm} magnetic resonance analyzer became fully operational at Swift Creek by the end of 1992.

THE RESULT - IMPORTANT GAINS IN PRODUCTIVITY

The following three graphical figures show the results. Figure 1 shows ratio of tails to feed BPL indicating a steady decrease in tails losses as the control system introduced in 1985 became fully operational with availability of on-stream analysis data. The upper line of Figure 1 indicates estimated loss ratio for operation without a control system. Tails losses tend to be proportional to feed BPL, but this relationship becomes minimized as operator control techniques became more proficient. Improvement in loss ratio converted to productivity calculates to more than four per cent increased recovery.

Effect of tails to feed losses is shown on Figure 2 in terms of BPL in feed. The classical linkage -- the higher feed BPL becomes, the higher are BPL losses in tails -- is seen clearly in Figure 2 as diminishing to a negligible effect by the flattened slope of the linear relationship after implementing automatic control. Impact on product recovery with control is estimated to be approaching five per cent improvement in 1996 through converting BPL tails losses to product. Finally, in Figure 3 depicting recovery to feed ratio on an annual basis beginning in 1980, improved recovery results are confirmed as process control became increasingly successful from year to year.

BENEFITS FROM PHOSPHOLYZER^{tm} ON-STREAM ANALYZER

The on-stream analyzer's contribution to productivity can be observed from immediate reaction by plant operating staff when the analyzer is taken out of service for maintenance. The question is put, "How soon will we have analyzer BPL data again?" The analyzer and its slurry sample supply circuits recently have about 95 per cent operating time. With analyzer data, not only are mechanical problems in the plant quickly identified to alert maintenance, but feed grade changes are spotted and immediately compensated by reagent adjustment or other control means.

An important subsidiary benefit is monitoring of feed quality from drag line operation. Plant operators can interact quickly with mine production to take action when abnormal feed grade is seen in matrix supplied to the mill. On-line analyzer BPL data in combination with central control already have provided upwards of four per cent improved productivity, and will contribute further with future introduction of higher level controls.

PROCESSING MINE MATRIX AT PCS PHOSPHATE NORTH FLORIDA OPERATIONS

Mining of phosphate matrix from north Florida deposits by PCS Phosphate predecessors began in the early 1960's, and until mid-1992 was carried out at two independent mining and beneficiation facilities (Suwannee River and Swift Creek) in vicinity of White Springs in Hamilton County. Full capacity is several million tons of phosphate mineral annually. Almost all concentrates are consumed in the production of phosphoric acid and phosphorus based fertilizer products at chemical facilities located adjacent to mining areas. Currently, the Swift Creek mine is operating on a full 24 hour seven-day schedule, and Suwannee River is in standby status.

Phosphate ore matrix processed from north Florida mine production is from unconsolidated Miocene deposits characterized by almost equal amounts of phosphate and clay fines with sand as the major component. Widely varying but relatively minor amounts of pebble product (+ 1 mm.) recovered from matrix during processing are ground and then added to production. Flotation feed preparation is primarily comprised of screening and cycloning to produce a product in the 1 mm. to 100 micron size range. Phosphate values (concentrate product) are recovered using two flotation stages without further sizing or size reduction.

The character of phosphate rock sent to processing not only reflects natural geologic variations in ore quality, but is also the mixture of feed from several draglines sending matrix to beneficiation. The result is feed with random quality variations. Conventional sampling and testing under these conditions is seen as futile in terms of process control requirements. By the time samples collected from the process are transported to a laboratory, run through analysis, and results returned to the operator, rock matrix from the process represented by original sample has all been processed and discharged.

HOW THE PHOSPHOLYZER^{tm} MEASURES PHOSPHORUS

The Phospholyzer^{tm} on-stream analyzer measures hydrogen and phosphorus in flowing slurry by the pulsed nuclear magnetic resonance technique. Slurries or solutions containing phosphorus are carried through a tube surrounded by magnets for orienting (polarizing) phosphorus atoms. Polarized atoms of phosphorus absorb radio energy of a certain known frequency. A radio transmitter with correct frequency for polarized phosphorus is arranged to beam timed RF pulses of controlled intensity into the flowing stream. Each polarized atom of phosphorus, after absorbing radio energy, retransmits the energy but at a different and specific frequency -- in essence becoming a tiny radio station.

The Phospholyzer^{tm} is provided with detectors set to phosphorus frequency, and the amount (intensity) of phosphorus radio transmission indicates how much phosphorus is present. Measured intensity is converted by calibration to phosphate content of the slurry. Hydrogen measured simultaneously by the same procedure is used to determine how much water is contained in the flowing slurry. These data enable calculation of per cent solids (density), and by further calculation BPL (equivalent to 0.458 P_2O_5 per cent). As a practical matter in measuring water for density calculation, hydrogen in water requires relatively long times to polarize. Time requirements are shortened by adding paramagnetic ferric chloride solution in small quantities by metering pump during analysis.

Although single measurements are completed within a fraction of a millisecond, time needed for practical assay values are related to sensitivity factors and material characteristics. Experience has led to averaging data over one minute to produce reliable phosphorus measurements of phosphate mine matrix. Up to ten gallons of slurry flows during a one minute measuring time. The large volume of measured slurry increases analysis reliability by statistically averaging anomalies in slurry characteristics. A single sampling cycle totals less than two minutes from starting a new slurry stream flow, measuring, and water flushing to start the next cycle. Eight streams are continuously analyzed (four feed and four tails) for rougher flotation control.

Figure 4 illustrates the Phospholyzer^{tm} assembly installed in a sealed, insulated, and air conditioned cabinet. Cabinet size is about 6-ft. length, 5-ft.height, and 3-ft. width. The cabinet houses magnet assemblies, a power stabilizer, power supplies, and PC type computer along with required transmitters and receivers for phosphorus and hydrogen signals. Polarization and inspection magnets are placed in the temperature controlled section of the cabinet with an inspection probe (sensor) unit. An LED display of BPL assay and stream number is on a panel with valve controls.

The Phospholyzer with sensor and electronic modules for operation are supplemented by external components comprising slurry sample flow presentation and control units, equipment for sample flow recycling (reject return), ferric chloride metering pump, and a local operator terminal with an on-line printer. Arrangement of this equipment is shown schematically in Figure 5. Slurry and water valves installed with sample presentation are automatically timed and operated from the system processor computer. Slurry and water valves are manually operated from toggle switches mounted on the cabinet sample control panel.

WHITE SPRINGS PHOSPHOLYZER^{tm} DEVELOPMENT PROJECT - A BRIEF HISTORY

The Phospholyzer^{tm} project was initiated in 1986 by a cooperative program with Harrison R. Cooper Systems directed toward developing the first NMR system for on-stream analysis. In 1987 a laboratory prototype was tested at the Southwest Research Institute in San Antonio, Texas. As a consulting organization skilled in applying magnetic resonance for industrial use, Southwest Research provided the necessary technical expertise for system design and development (ref. 2).

The first production prototype unit was assembled in Salt Lake City and delivered to the Suwannee River mine in 1988. Over time, until shutdown of Suwannee River in early 1992, improvements and upgrades were made as derived from experience using the first unit. This development took place while operating a first-of-its kind magnetic resonance on-stream analyzer in an industrial environment twenty-four hours per day.

BPL assay measurement error was seen to be well in the range required for process control. Calibration data for feed with average of 18 BPL was had approximately 0.8 BPL for one standard error. Tails calibration was 0.5 BPL standard error or better for tails averaging 6 BPL. The first application of fatty acid reagent closed loop control using a control model with on-stream analysis of flotation feed and tails began during the final year of operation at Suwannee River (ref. 3).

Upgrading the Swift Creek Mine beneficiation plant process control system was made during this time. The existing Moore Mycro central control computer and console was replaced by more modern Moore distributed Control System hardware and software. A new Phospholyzer^{tm} of current design was delivered January 1993 and installed in a small analyzer building constructed at a location central to flotation slurry sampling.

Equipment for sample presentation handling eight slurry streams was attached to the outside wall of the analyzer building, and reject return pumps were installed to send slurry flows from the measurement system back to flotation. Figure 6 provides a view of the sample presentation unit at the analyzer building. Figure 7 illustrates sampling for analyzer calibration from flow out of the analyzer. With an operator terminal and printer placed for local use with the analyzer room, communication to the control room is handled with an analog output cable to link BPL assay data from the analyzer to the Moore computer for display via a dedicated control room terminal as well as to the process control system. Operators view charts of assay trend data from displays in the control room.

The Phospholyzer^{tm} system was effectively in routine operation by early1993, with availability steadily improving to a level of about ninety per cent at the end of 1994. Improving availability has depended on resolving problems with sampling and sample presentation -- the instrument itself has operated without significant interruption after debugging improvements over the 1989 to 1991 period at Suwannee River.

SLURRY SAMPLING FOR THE PHOSPHOLYZER^{tm} ON-STREAM ANALYSIS SYSTEM

Sampling problems were attacked and solved one-by-one in the course of reaching availability required for operational status during the year of trouble-shooting to the end of 1993. For example -- sample pumping: an original slurry sample transfer pump was a double-diaphram air drive positive displacement design. Service problems were encountered, and Sala tank type centrifugal pumps were installed as replacements. The tank pumps have proven more suitable to the low pumping head application requirements for sample transfer.

Wear problems in pumps and slurry lines can be minimized by running water between measurement times as the Phospholyzer^{tm} processes each sample in sequence. Timing signals programmed into the analyzer system processor computer operate solenoid valves to turn water valves on and off as required to allow slurry flow only when needed for analysis.

Another trouble point arose because of screen leakage, allowing pebble size matrix to mix with process flows and subsequently entering into sample streams. A high proportion of down-time resulted from plugging by coarse particles in sample presentation valves and tubes. A solution to this problem has been placing a scalping screen at the pump. Figure 8 depicts a slurry sampling unit with screen and transfer pump. Trouble-shooting and problem solving were domains of technicians assigned to the analyzer project whose hard work and practical solutions were key to steadily increased analyzer availability.

PHOSPHOLYZER^{tm} AND CONTROL SYSTEM ACCEPTANCE BY OPERATING STAFF

A key factor in operating personnel acceptance of the system was minimizing trouble-shooting work required of operators by providing simplified procedures as guidelines. Demands on operating staff to perform tasks necessary for continued operation have become a reduced burden. At this point, having available complete data arrays displaying minute-to-minute operating records outweighs nuisance requirements for attending to occasional sampling interruptions to keep data flowing.

Specific measures taken to improve acceptance have been using the Phospholyzer^{tm} computer to an increased degree in "self-diagnostic" mode. Additional programming has been provided to make the system user-friendly, in that alarm conditions for failure of sampling or other upsets are printed on the display screen with as much advice for solving the problem as can be offered. The same philosophy is applied to creating computer generated menus on the analyzer room display for assisting technicians to the degree possible in performing their duties (calibration sampling, changing calibration parameters, checking for analyzer service needs, loading programs, etc.) while avoiding undue complications and a requirement to comprehend computer jargon.

ACKNOWLEDGEMENTS

Development of the Phospholyzer^{tm} at PCS Phosphate - White Springs and its predecessors over the past several years evolved from many efforts. Support from upper management, particularly Fred Myers, General Mine Manager, since inception of the work with continued dedication to success of the project has been crucial to achieving the goals. Acknowledgements are made of contributions from Frank (Smokey) Wood, currently Maintenance Leaderman at Swift Creek Mine who greatly assisted in developing sample handling and resolving its problems; of Jimmy Blanton, Metallurgical Laboratory Supervisor, whose routine upkeep and troubleshooting was fundamental to day-by-day successful operation and to increased level of availability; to Jake James, first class mechanic, who has recently provided innovative ideas to improve equipment availability; of James Grant, I & E technician, whose instrumentation experience combined with computer knowledge has allowed him to troubleshoot and correct electronic bugs within the system; and to Swift Creek Mine maintenance and electrical departments whose personnel reliably and diligently dealt with problem solving and servicing of Phospholyzer^{tm} equipment over the years. Finally to be acknowledged is the Florida Institute of Phosphate Research for their support of the Phospholyzer^{tm} application study to quantify potential benefits to phosphate fertilizer industry.

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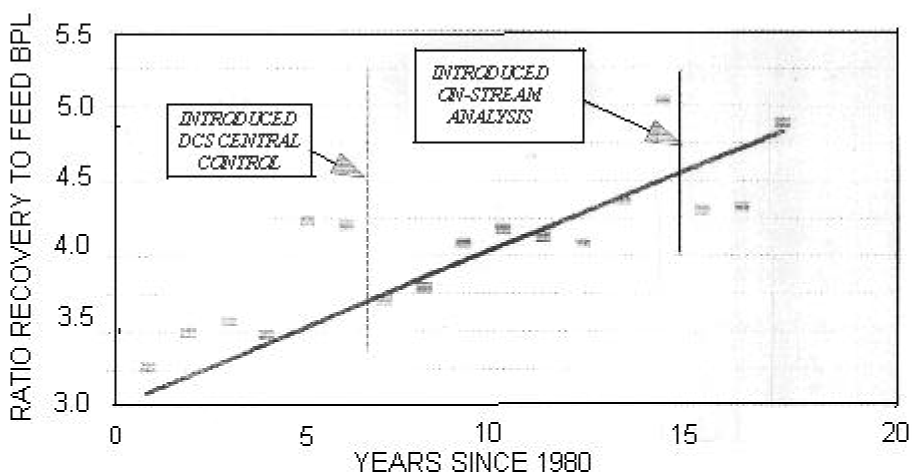

FIGURE 1. Increased Recovery - Per Cent per Unit Feed BPL

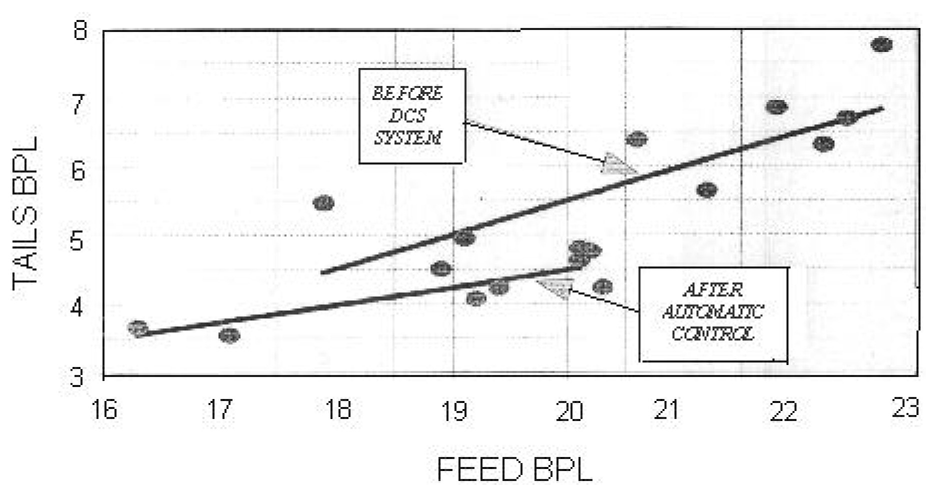

FIGURE 2. Tails vs. Feed BPL - Results of Automatic Control

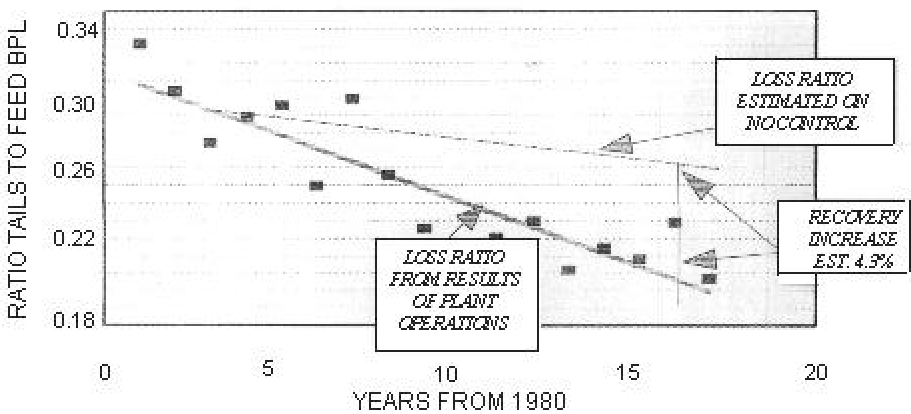

FIGURE 3. Improved BPL Recovery - Decreased Tails Loss per Feed BPL

FIGURE 4. PHOSPHOLYZER Cabinet inside Analyzer Building

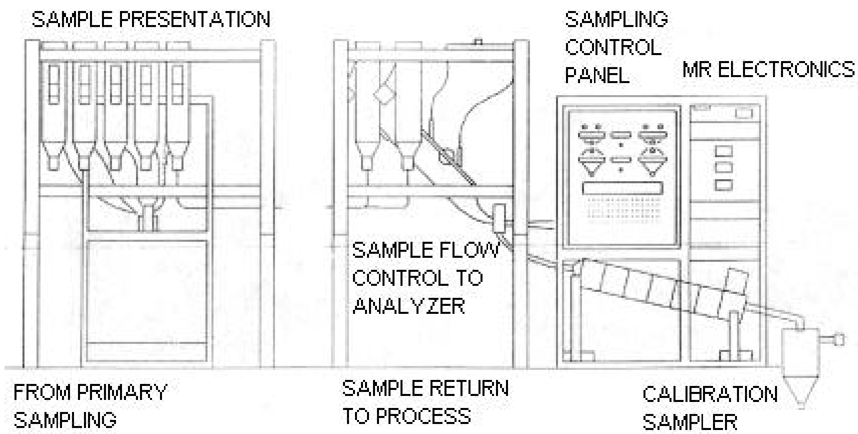

FIGURE 5. Schematic Diagram of PHOSPHOLYZER^{tm} with Sample Presentation Unit

FIGURE 6. Analyzer Building with Sample Presentation for Eight Sample Streams

FIGURE 7. Test Sample Collection during Slurry Flow through the Phospholyzer^{tm}

FIGURE 8. Illustration of Primary Sampling Unit with Pumps for Transfer to the Analyzer

INTRODUCING A NEW TECHNOLOGY FOR ON-STREAM ANALYSIS

Nuclear magnetic resonance has been employed as a research technique in physics and chemistry since the1930's, and in medicine starting with the 1960's for biological tissue examination (full body scan by "magnetic resonance imaging"). The basis for NMR medical use is capability to identify and diagnose condition of organs and other body structures by hydrogen density differences.

Magnetic resonance to measure coal and other hydrocarbons for industrial application has been investigated over several years to quantify heating value and moisture contents -- information potentially valuable for managing fuel control in power plants and similar uses. Now, as reported here by PCS Phosphate, NMR applied to phosphate fertilizer has become the first operational continuous stream flow analyzer for an industrial application based on magnetic resonance.

NMR on-stream analysis is also applicable to a variety of cases in the industrial minerals field to measure many low atomic number elements beyond the capabilities of more familiar analysis methods. In addition to phosphorus and hydrogen measurement by NMR on-stream analysis, Harrison R. Cooper Systems has demonstrated sodium, fluorine, aluminum, boron, and lithium are amenable to measurement using this technology

Notes: Figures 4, 6, 7, and 8 are provided through the courtesy of PCS Phosphate - White Springs.

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