AUTOMATED CEMENT PLANT QUALITY CONTROL

In-situ versus extractive sampling and instrumentation

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INCREASING PRODUCTION AND QUALITY demands in the cement industry have resulted in the need for improvement in the speed and accuracy of quality-control results. This need has been addressed by many technological advances in quality-control automation in recent years. Two distinct methods of sampling and analysis, in-situ and extractive, have gradually developed. In-situ analysis occurs in the field at the process equipment, with the results transmitted through a computer control system. Extractive sampling requires removing a sample from the process stream and transporting it to the laboratory for further preparation and analysis. Both approaches have distinct advantages and disadvantages. This article discusses the characteristics and differences in analyzer and control technologies that utilize the two different methods of obtaining a result. The operation, accuracy, maintenance, troubleshooting, and relative costs associated with the two types of control are presented. Emphasis is placed on the criteria for primary selection of one technology over another at various points in the cement manufacturing process.

Online Analysis Technology

Looking at the different types of analyzers widely in use in the

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cement industry today, one sees a distinct separation between those which are located in close proximity to the process sampling point (in-situ) and centralized laboratory instruments. Some of the in-situ analyzer types are: prompt gamma neutron activation analysis (PGNAA) for raw materials control; small online X-ray fluorescence machines for raw materials, clinker, or cement; online X-ray diffraction for clinker and cement; and online laser particle-size analyzers for cement. The main type of modern online extractive analyzer is a centralized robotic laboratory, where one or more of the above analyzer types are situated in a central location with sample transport from the process sampling point. The laboratory instruments are usually larger and are designed for use in a more stable environment. The majority of new analyzers in use in the U.S. cement industry today are in-situ, as shown in Table 1.

The vast majority of PGNAA applications are of the cross-belt type. The instrument is installed on a belt conveyor and measures a cross section of the material conveyed. Figure 1 presents a typical cross-belt PGNAA analyzer. A source of neutrons, usually in the form of a small radioisotope source located below the conveyor, bombards the conveyed material with neutrons. As a result of the neutrons striking the nuclei of the material atoms, gamma radiation is given off. The gamma radiation spectrum thus generated is characteristic of the elements in the material. Detectors located above the conveyor sense the gamma spectrum and the control computer deconvolutes the spectrum, interpreting and reporting the results, typically with 1-min updates.

Online X-ray analyzers are becoming more prevalent in the United States as this relatively new technology is refined. Reliably handling and properly preparing the sample in a field enclosure has proven difficult in some applications. Ensuring the accuracy of the results usually requires further grinding of the sample before presentation to the X-ray fluorescence (XRF) analyzer, otherwise, the analytical results are adversely affected. The time required to grind and prepare the sample limits this analyzer to 5–10-min cycle times and requires advanced robotics. A typical online XRF analyzer is shown in Figure 2.

The development of X-ray diffraction (XRD) technology is reaching the point that it can be utilized to quantify the actual clinker-phase composition. An online XRD could not only measure clinker-free lime and the actual clinker minerals, but also measure the gypsum, hemihydrate, and mineral additives in the finish mills. An online XRD analyzer is shown in Figure 3.

Automatic, online particle-size analysis can be accomplished by extracting a sample stream and passing it

TABLE 1. SELECT ANALYZER TECHNOLOGIES IN USE IN THE U.S. CEMENT INDUSTRY.

Process Control Application	Analyzer Technology	In Situ or Extractive	Number of Units Installed in U.S. Plants
Quarry ore chemistry	PGNAA	In Situ	23
Raw mix chemistry	PGNAA	In Situ	29
	Online XRF	In Situ	6
Slurry chemistry	PGNAA	In Situ	4
Clinker free lime	Online Free Lime	In Situ	8
Cement chemistry	Online XRD	In Situ	1
Cement particle size	Online LPSA	In Situ	14
Centralized robotic laboratory	Varies, All available	Extractive	12

1

A typical PGNAA cross-belt analyzer.

2

A typical online XRF enclosure.

through a laser analyzer, shown in Figure 4. This produces very fast, continuous particle-size measurement and can be tied directly back to the mill process control. The sample returns to the product stream, eliminating handling problems. Accurate material sampling can be difficult to achieve. As with any laser particle-size analyzer, the sample presentation to the laser is critical to accuracy and precision.

Similar to the concept of placing a particle-size analyzer in the field, other systems are now being manufactured to utilize laboratory-type analyses in-situ. For example, several European plants have installed online ignition loss systems to measure the calcination rate in the preheater. A hot meal sample is extracted, cooled, and transported a short distance to the analyzer cabinet. There, it is homogenized and dosed volumetrically to a scale. After weighing the sample, it is placed in a small electric oven and heated to 975 °C for 25 min. The sample is weighed again to calculate the loss. A programmable logic controller (PLC) controls the material transport system, robotics, and the transfer of data.

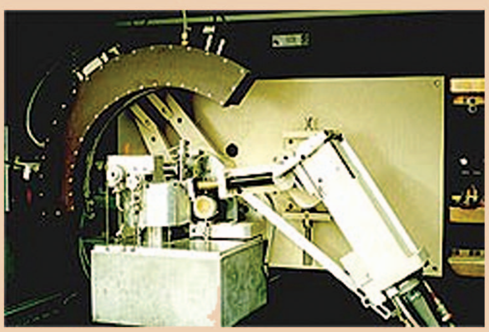
Clinker-free lime is also being measured online via glycol conductivity. An online free lime analyzer is shown in Figure 5. A clinker sample is transported to the analyzer cabinet where it is crushed and split. The sample is then mixed with mono-ethylene glycol, and the solution conductance measures the liberated calcium ions. A maximum of six measurements per hour is possible. The excess clinker sample can be returned to the system, but the used glycol must be properly disposed. Again, a PLC controls the sample transport, preparation, and data transfer.

As varied as the number of manufacturers, centralized robotic laboratory systems come in many configurations to suit the desired analyses. A typical robotic laboratory system is shown in Figure 6. The centralized robotic laboratory can utilize most of the instruments commonly used in cement-plant control labs. Additional samples can be manually presented to the robotic system by the lab analysts.

Advantages of In-Situ Analyzers

Cement plant quality-control departments covet large, representative samples taken with a high frequency that can be analyzed quickly and accurately. Ideally, the results are then quickly and scientifically used to make rapid process control adjustments. This is the very essence of in-situ analysis.

Some technologies, such as PGNAA, can actually analyze every ton of material as it passes by. This is particularly attractive for modern pre-calciner plants with inline vertical roller mills. Since the roller mill can accept a large feed material size compared with ball mills, accurate sampling anywhere between the crusher and the raw mill is quite difficult and expensive. Other in-situ instruments require extractive sampling but utilize short transport distance and rapid sample preparation methods coupled with rapid analysis to achieve a high sampling frequency. The results are sent electronically to a control computer that can automatically adjust process setpoints to keep the quality control on target. The control computer can be programmed to consider factors, such as materials cost and availability,



3

An online clinker XRD.

5

An online free lime analyzer.

4

On-line particle size analyzer.

6

An example of a robotic laboratory.

process control lag times, actual deviations from setpoint, and many other factors in order to minimize costs and maximize benefits to the plant. A number of vendors provide software packages for this type of control. With proper engineering, the system can be tuned to minimize operating cost while still achieving stable setpoint control.

These systems do not require that a sample be transported to the lab for subsequent sample preparation and analysis, and expensive robotics can be minimized. Excess sample material can be easily returned to the process, saving the labor of disposal. The capital cost of an individual in-situ analyzer is often not much more than a similar new instrument installed in the lab, and twisted-pair wires are much easier to install than sample transport lines. Since no operating labor is added in the field for sample collection or at the laboratory for preparation and analysis, these systems often appear to be significantly cheaper to operate.

Disadvantages of In-Situ Analyzers

However, not all costs are readily apparent. For example, each analyzer will require maintenance that, in turn, will require specialized training and labor from the plant personnel. The technical nature of the modern instruments tends to require more sophisticated maintenance. If laboratory personnel maintain the instruments, significant time may be lost as they leave the central lab to troubleshoot a problem. Often, a quick decision must be made to leave an instrument down in order to avoid excessive backlogs of other critical quality-control samples. Some plants have been surprised by the amount of trouble-shooting time required of nonlaboratory instrument technicians and process engineers. Conflicts over priorities must be considered in advance.

Some of the in-situ analyzers require nearly the same degree of robotics as a centralized lab. Maintaining the controls and the control systems of numerous dispersed analyzers can be daunting.

The analytical instruments themselves must be constructed with the cement-plant environment in mind. Some of the environmental conditions that should be evaluated are:

- vibration
- magnetism/electromagnetic/radio-frequency interference
- power line noise
- temperature
- humidity
- sample condition
- dust.

These conditions limit the achievable accuracy and precision over time. The central laboratory will have to keep an eye on the drift and calibration of the instrument. In addition to drift problems, the inherent accuracy of some analyses is clearly not as good as laboratory instruments can achieve. In-situ instruments must operate almost continuously in the ambient conditions of the plant; often design sacrifices are made regarding sample preparation, resulting in skewed analytical results. For example, online XRF raw materials analyzers often minimize, or omit, the sample grinding. Thus, as mill operations change or changes in the silicate mineralogy cause changes in the raw mix grindability, the analyzer can't maintain its calibration due to the different particle sizes. Subsequently, the critical, and most basic, LSF and C_3S results are skewed; the analyzer will be inaccurate at the very time the process control most needs it.

Certain chemical compounds present inherent difficulties for certain types of instruments. PGNAA, for example, has difficulty analyzing for MgO. Many instruments have trouble with Na_2O or K_2O or SO_3. Depending on the ore grades in the quarry, control of one or more of these compounds may be critical. Table 2 presents typical accuracies and precisions.

Table 2 illustrates some of the wide differences in accuracy between laboratory instruments and field instruments. In the case of MgO and alkalis, this can be either a major factor or an insignificant one, depending on the chemistry of the quarry deposit. The accuracy combined with drift due to the aforementioned environmental influences leads to frequent monitoring of field instruments to ensure the calibration is consistent with more accurate laboratory analyses.

The accuracy and precision data for XRD instruments is virtually impossible to compare due to the nature of the standards used. Laboratory XRD instruments are validated with NIST standards which have been microscopically examined for mineralogical content. These samples are quite small, on the order of 5 g. Online XRD instruments use a continuous stream of sample, requiring a much larger sample size to obtain a result. One manufacturer states the accuracy when analyzing a sample with known gypsum content as $\pm 0.25\%$ by weight on hemihydrate.

Advantages of Extractive Analyzers

Extractive analysis traces its roots back to the original cement-plant laboratory. Sample runners would manually collect the samples and bring them to the laboratory. There, the sample was prepped and analyzed utilizing the analytical chemistry methods of the day. As modern instruments began to replace traditional wet chemistry, the test results were faster, more detailed, and often more accurate. A ten-channel XRF pellet gave the quality manager much more information than his old A/A titration. Laser particle-size analyzers produce much more information than a Blaine test and 325-mesh sieve analysis.

Eventually, laboratory staffs were reduced and technicians began to replace chemists. It seemed logical to further the automation concept by automating the sample delivery to the laboratory. The sample can be tracked by a PLC controller so that it is identified and can be prepared to suit the required tests. Using modern robotics to move the sample through the preparation and presenting it to the analyzer saves labor and time. By arranging the laboratory instruments around a central robot, all the basic cement quality-control tests can be performed automatically. Significant labor savings can be realized by minimizing sample collection in the plant and laboratory staffing. Additional samples can be fed into the system manually for special, or extra analyses, or if the sample system breaks down.

Since the equipment is located in the laboratory, it is in a climate-controlled environment and easily supplied with clean water and instrument-quality compressed air. The laboratory staff is close at hand to maintain the instruments and monitor calibration and drift. The instruments can be larger

TABLE 2. COMPARISON OF IN SITU AND EXTRACTIVE ANALYZER PRECISION AND ACCURACY.

Analyzer Technology	CaO Accuracy % RMSD	CaO Precision σ	SiO_2 Accuracy % RMSD	SiO_2 Precision σ	MgO Accuracy % RMSD	MgO Precision σ	Na_2O Accuracy % RMSD	Na_2O Precision σ
In-Situ								
PGNAA	0.42	0.32	0.94	0.29	0.58	0.36	0.45	0.45
On-line EDXRF	0.16	0.10	0.10	0.05	0.05	0.08	NO	NO
On-line XRD	NA	0.65% Alite	NA	NA	NA	NA	NA	NA
	% Vol on D(50)							
On-line cement particle size	±2%	Sample presentation to the instrument is critical to achieve the instrument's stated accuracy						
Laboratory/ Extractive								
XRF (Raw Meal)	0.045	0.03	0.053	0.014	0.049	0.006	0.011	0.004
XRD	±3% Alite	NA	NA	NA	0.5	NA	NA	NA
	% Vol on D(50)							
Cement particle size	±2%							

NA = Not applicable or not available; NO = most analyzers do not accurately measure.

in physical size and are generally more stable and reliable than field-grade instruments. Further, they are often the same instruments the laboratory staff is already familiar with.

The control system and its input/output (I/O) are centrally located in the laboratory. Computer communications are simplified with a single data link. A single communications protocol can serve the laboratory instruments, a business information database, and communication to the plant control system. Computer and control upgrades can be handled much easier than if different instruments are scattered around the plant, each with its own control PLC and communications protocol.

Disadvantages of Extractive Analysis

The high capital cost of the automated sample transport system and the central robotics unit is a major deterrent. Coupled with the system's complexity, it can be a daunting prospect to propose such a system at an existing plant. Though overall labor savings can result, the laboratory personnel must become skilled in PLC logic as well as quality control. The technicians who replaced the old chemists are now replaced by chemical engineers.

Reliability of laboratory instruments is critical to plant quality control. Without a local plant "champion," who is in a position to allocate the necessary personnel to debug and then maintain the system, good reliability of the robotic laboratory can be difficult to achieve.

Another disadvantage of the central system is intrinsic to its centralization: it can only process so many samples per hour. Though the sample frequency can be adjusted at various points in the plant, the system capacity is dependent on the various cycle times of the sample transport, the sample preparation, and the analysis for each point. A dedicated in-situ analyzer will produce a more frequent analysis and, therefore, allow better control.

Comparison of Capital Cost

The true relative cost is obscured due to both the nature of in-situ instruments and the overhead laboratory instrument requirements. The plant laboratory will already have to have the instruments required for quality assurance and certification of the cement. A centralized lab allows some of these instruments to be utilized for quality control. In-situ instruments are typically purchased and installed one at a time over a period of years as totally separate projects. To accurately compare the true total capital costs between extractive and in situ systems, one must look at the entire plant need and determine if the isolated in-situ strategy will truly provide the best end solution. If multiple in-situ analyzers are considered for various analyses throughout the plant, the total cost is closer to a centralized system than initially thought. This especially applies to plants with multiple kiln lines or mill systems, each of which has its own sampling and analytical requirements. Table 3 illustrates this concept.

The values contained in Table 3 are derived from several plants with differing applications for each technology, therefore, the data is provided for illustration purposes only.

Thus, if a particular plant with an inline roller mill would benefit from quarry PGNAA analysis for preblend control, the total quality-control system relative cost would be 2.7 (traditional lab plus PGNAA). However, if the same plant considers adding online raw mix control, the total cost quickly approaches the cost of the extractive robotic system. Since the robotic system replaces the traditional laboratory XRF/XRD, the base cost of these instruments is already included. So the comparison for a plant with quarry PGNAA and EDXRF for raw mix versus a robotic laboratory is 3.8 against 4.0, respectively. This does not factor in any operating cost differences, only installed capital cost.

Comparison of Operating Cost

Reduced labor hours are usually part of the justification for large centralized systems. However, complex robotics and multiple sample handling components require integrated controls and electronics that must be maintained. In general, a higher level of technical skill will be required of the laboratory staff in a centralized lab. Of course, having skilled people in the laboratory will allow a plant to fully utilize other laboratory instrumentation such as GC-MS, flame photometry, calorimetric analyses, or X-ray diffraction while providing a fertile training ground for young process engineers.

Overall, in comparison to multiple in-situ systems attempting to perform similar analyses, the maintenance expenses for the analyzers themselves should be lower with a centralized system. The traditional lab analyzers and instruments are replaced or supplemented by the centralized system, whereas in-situ analyzers are added as an addition to the existing laboratory instruments. In-situ instruments require daily inspection and, at a minimum, weekly preventive maintenance and cleaning.

In-situ instruments allow better process control and, therefore, may lead to greater potential process efficiency savings than the slower extractive systems. Some consumables for certain types of analyzers are expensive, i.e., californium sources for PGNAA, radiation safety inspections, or maintenance contracts.

Practical Experience Results

PGNAA for Preblend Control

The Arizona Portland Cement (APC) Rillito, Arizona, plant has operated a PGNAA analyzer on its overland belt conveyor system since 1995. The analyzer is located on a 36-in wide, 1,000 stph conveyor that carries quarry mix rock from the quarry crusher to a preblend pile in a stacker/reclaimer building.

The primary objectives of the project were to replace the large B6 sample preparation plant while improving the uniformity of pile chemistry, particularly between pile changes, and allow increased ore utilization by pushing the MgO content to the highest level possible without creating operational problems. The results of the project indicate an improvement in standard deviation of CaO in the crushed rock going to the pile of 32.3%. The raw mix daily C_3S standard deviation improved by about 3% on their D2 raw mill and 55% on the ac raw mill system. The Kiln 4 clinker daily C_3S standard deviation showed a 22% improvement. The sample preparation plant was demolished to make room for other equipment.

One of the primary control points for the APC quarry is the MgO level in the mix rock. The plant's ability to maximize the MgO content of the rock has a significant impact on the quarry life since ore that is above the maximum MgO specification must be wasted. The project has had mixed success at maintaining steady MgO control. This is due primarily to calibration drift that has created intermittent periods of high MgO levels that create kiln operating problems such as excessive coating and preheater buildup. Thus, the plant tends to operate at a lower MgO level than is possible to protect against this situation.

While the objective of improving mix rock variation was met, the goal of increasing quarry ore utilization was only partly realized. The accuracy of the analysis must be factored into the overall strategy. If "walking the line" on

TABLE 3. COMPARISON OF CAPITAL COSTS AND ANALYSIS FREQUENCY FOR IN-SITU AND EXTRACTIVE QUALITY-CONTROL AUTOMATION.

		Chemical Analysis Frequency				
Analyzer Technology	Relative Cost	Quarry	Raw Mix	Kiln Feed	Clinker	Cement
Traditional Laboratory						
XRF/XRD and Bench Top PSA	1.0	M	M	M	M	M
In-Situ Instruments (Not including traditional lab equipment above)						
PGNAA for Quarry	1.7	1 min	M	M	M	M
PGNAA Raw Mix	1.7	M	1 min	M	M	M
EDXRF for Raw Mix	1.1	M	6 min (at best)	M	M	M
Cement XRD	1.6	M	M	M	M	10 min average
Extractive Instruments (replaces traditional lab XRF/XRD)						
XRF for Quarry, Raw Mix, Kiln Feed, Clinker, and Cement; XRD and PSA for cement	4.0	1 hour	20 min (at best)	2 hr	2 hr	2 hr

M = Manual field sample and analysis in laboratory.

certain compounds is a key to project success, alternatives should be carefully evaluated based on the accuracy and drift of the instruments.

PGNAA for Raw Mix Control

The California Portland Cement Company's Colton, California, plant has operated a PGNAA analyzer on their raw mill system for raw mix chemistry control since 2003. The analyzer is located on a belt conveyor feeding the raw grinding system consisting of two ball mills. Vibrating feeders under raw material silos control the rate of each raw mix component.

The main goal of the project was to improve the chemistry stability of the raw mix fed to the kilns and decrease the frequency of manual sampling and X-ray analysis in the laboratory. The chemistry goal was achieved and surpassed. The plant kiln feed C_3S standard deviation decreased to less than one half the original value. The kiln clinker daily C_3S standard deviation decreased by about 70%.

However, the plant has not been able to significantly decrease the frequency of manual XRF sample analyses. This is due to the variation in instrument calibration over time, which requires constant monitoring. The plant quality-control personnel spend a significant amount of time tuning and recalibrating the signals to ensure the analyzer provides the same on specification raw mix from day to day.

Online EDXRF for Raw Mix Control

APC's Rillito plant has operated an online XRF analyzer since 2002. The analyzer is located near the vertical roller mill product airslide. A sampler in the airslide provides the sample to a homogenizer on top of the analyzer building. The analyzer enclosure is housed in a small building to protect the enclosure and maintenance personnel from the elements. The analyzer equipment consists of a dosing unit, ring and puck mill, pellet press, pellet transporter, portable X-ray fluorescence unit, pellet ring cleaning station, and a spent sample transport system.

The goal of the project was to improve the raw mix chemistry control, particularly during switching between blending piles when the toe of each pile contains significant swings in chemistry. A secondary, less tangible goal was to free up analysts' time for other duties by reducing the frequency of manual sampling and analysis. A labor reduction was not anticipated, but rather shifting the analysts' focus to other areas of the plant, such as clinker chemistry control, in this multiple-kiln plant.

After several months of commissioning, the results were only partially achieved. The daily raw mix C_3S standard deviation decreased by about 24%. The frequency of manual laboratory XRF analysis has decreased from once per hour to once every four hours. This has allowed more frequent analysis of clinker chemistry, which provides valuable information to the kiln operators.

However, laboratory personnel are sometimes forced to spend valuable time troubleshooting the instrument when there are problems. This leads to periods when other analyses simply do not get done at their normal frequency. The uptime is good when the analyzer is operating smoothly, with some months greater than 95% run time. The average uptime per month has been about 88%. However, when a problem does occur, it often requires outside assistance from the equipment manufacturer in order to solve the problem. Programming problems have required online help from the supplier's main office due to the proprietary (and, in some areas, password protected) software programs.

The EDXRF unit was initially problematic at best. In several instances the calibration was so far off target that the entire set of standards had to be run and the calibration started from scratch. The analyzer failed twice and had to be sent back to the manufacturer in Europe for repair. This caused lengthy downtimes. A spare analyzer was purchased to improve the uptime of the system. This has allowed swapping out the unit if it fails, resulting in only days of downtime rather than weeks.

Overall, the project was a success from a control standpoint, but maintenance and troubleshooting requirements are much higher than anticipated. The unit requires (at minimum) daily inspection, weekly cleaning, and periodic parts replacement that can lead to long downtimes due to poor U.S. parts availability. Hopefully this will improve with more units installed in the United States.

Online XRD for Cement Control

The Ashgrove Cement Company's Leamington, Utah, plant has operated an online XRD analyzer since 2001. The analyzer is located near the cement mill product belt conveyor. An auger sampler in the belt conveyor material stream provides a sample to the analyzer enclosure in a clean analyzer building below. The analyzer equipment consists of a feed hopper, feed screw, sample turntable, X-ray diffraction unit, and an excess sample transport system.

The ultimate goal of the project is to integrate the cement mineralogy data with their online particle size analyzer to allow real-time strength prediction. So far, the analyzer has been used to control the gypsum addition rate, identify hydration rates of gypsum and free lime in the mill system, and identify feed material composition changes. The correlation of strength to XRD and online fineness data is in progress. The anticipated benefit of correlating strength is to allow more rapid fineness, gypsum, and clinker feed stock changes to ensure consistent quality at maximum mill production.

The plant made modifications to the original sample system design to improve the reliability of signals from capacitance type level probes. The probes would get build up on them, which gave false level signals to the sample controller. This problem has been solved by relocating the sample probes to a location that prevents buildup from starting.

Online PSA for Cement Fineness Control

The Ashgrove Cement Company's Leamington, Utah, plant has operated an online particle size analyzer since 2001. The analyzer is located near the online XRD unit and utilizes the same sample system.

The analyzer operates in closed loop to the high efficiency separator rotor speed to control the 30-μm size of the cement product. This has been an effective strategy for eliminating sampling and measurement errors from the Blaine fineness test. The operators no longer rely on Blaine measurements to adjust the separator speed, only the particle size analyzer.

Initially, the unit was located on a chute prior to the cement product belt conveyor. The sample system was problematic at best, requiring daily cleaning to ensure the eductor sample train did not plug. Since relocating the unit to a clean room near the XRD and changing the method of introducing the sample to the unit, the plugging problem has been virtually eliminated. Periodic cleaning about once per week is still required.

In at least one other installation, similar sampling problems led to the removal of the analyzer. If the system cannot operate without frequent cleaning, the benefit provided by reducing the frequency of manual analysis disappears. Despite the goals of plant management, if plant personnel do not realize the benefit, the project may fail, particularly when the trade off is cleaning out a sample train in a noisy, dusty environment versus performing a test in a clean laboratory.

Robotic Laboratory

The California Portland Cement Company's Mojave, California, plant has operated a robotic laboratory since 1997. The system is located in the plant's main office/laboratory building. The automated chemical analysis includes quarry samples every 1 hr, raw mix every 40 min; and kiln feed, clinker, and cement every 2 hr.

The primary goals of the project were to decrease raw mix chemistry variation and provide a labor savings by reducing the laboratory staffing hours. The project justification was based on a slight clinker production increase due to improved raw mix control and a reduction of laboratory staff.

The project goals were achieved after an extensive commissioning period. The raw mix daily C_3S standard deviation was reduced by 50% with a 40-min analysis cycle time. Laboratory staffing was reorganized to achieve the two person reduction and allow unstaffed operation of the laboratory for 12 hr/day. In addition, many other analyses are performed by the robotic laboratory that would otherwise be left to staff.

End-user involvement in the commissioning process was a key to the project's success. The increased complexity over traditional sampling and analysis duties mandates a higher level of technical skill. This way, the routine tasks are performed by the automated system, and more technical issues are handled by the laboratory staff.

The Future of Automated Quality Control

Increasing market demand, rising energy costs, and more stringent environmental regulations collide to drive ever closer tolerances to specifications. Wireless technologies may make remote I/O less expensive for distributed in-situ systems, further increasing the opportunity to continue adding analyzers wherever an application presents itself.

New plant designs sometimes are forced to save capital money by reducing material blending and storage capacity. The plant only gets one shot to make the product right, and often rapid, continuous control wins out over accuracy and reliability when trying to achieve tight control. New plants/major expansions should devote the time to fully consider complete plant quality-control systems to save labor and attempt to arrive at a complete quality-control solution, taking the proposed blending and storage capabilities into account. Because of favorable supplier agreements during such projects, this is the best time to approach quality-control automation. Since laboratory instruments are required one way or the other to operate the plant, the additional costs for sampling and robotics may be easier to justify.

The increasing popularity of in-situ units may result in the sudden awareness of the true cost, in total, of having separate systems as plants look around at the sudden need to maintain widely dispersed instruments and control systems that have sprouted up. A shift in the skills and knowledge necessary for laboratory personnel to operate automated quality-control systems is required in order to maintain the equipment. Knowledge of the systems (programmable controllers, interfaces, and instruments) in addition to the routine practices and analyses is becoming more critical. Of course, the wise plant manager will find other uses for these skilled people, resulting in even better process control. This will keep the staff motivated to continuously upgrade their skills.

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References

[1] E.J. Bond, R. Coursaux, and R.L. Worthington, "Review on blending systems and control technologies for cement raw materials," in *IEEE Cement Industry Conf. Rec.*, May 1998, pp. 189–209.

[2] A. Kern, "Accurate quantitative XRD phase analysis of cement clinkers," presented at Accuracy in Powder Diffraction III, Apr. 2001.

[3] G.M. Crawley, et al, "Real-time process optimisation using dry in-line particle sizing," presented at PARTEC 2001: Int. Congress for Particle Technol., Mar. 2001.

[4] X. Dupont-Wavrin and M.C. Mound, "Commitment to the fully-automated cement laboratory concept: A cement industry trend whose time has come," in *IEEE Cement Industry Conf. Rec.*, Apr. 1997, pp. 443–452.

[5] Dr. M. Endress, et al, "Operating experience with online analyzers in cement plants" *No 2/2004, Cement International*, Feb. 2004.

[6] A.P. Malcolmsom and D.J. Holve, "In-line particle size measurements for cement and other abrasive process environments," in *IEEE Cement Industry Conf. Rec.*, May 1998, pp. 411–423.

[7] C. Mathias, D. Retallack, and I. Madsen (Apr. 2001). "Plant optimisation and control using continuous on-line XRD for mineral phase analysis," *ZKG* [Online]. Available: http://www.fctinternational.com/splash/about_fct/fct_actech/products_fct_actech/xrd/zkg_article.pdf

[8] R.L. Patterson, "Automating raw mix control using multifunctional software" in *IEEE Cement Industry Conf. Rec.*, May 1998, pp. 369–384.

[9] M. Pohl (Feb. 2004). "Particle sizing: A quick look at new and improved methods," *Powder and Bulk Engineering* [Online]. Available: http://www.powderbulk.com/getarticle.cfm?articleid=262

[10] S.A. Regis, "Performance evaluation of an on-line PGNAA cross-belt analyzer," in *IEEE Cement Industry Conf. Rec.*, Apr. 1997, pp. 433–411.

[11] B. Shafer, "Laboratory automation: A case study," in *IEEE Cement Industry Conf. Rec.*, Apr. 1999, pp. 313–320.

[12] D. Summit, G.D. Crutchfield, A. Godek, C. Manias, and P. Storer, "Experiences with continuous on-stream XRD at the ash grove leamington plant" in *IEEE Cement Industry Conf. Rec.*, May 2003, pp. 319–332.

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