The future of process control

The global task to ensure sustainable clinker and cement production has increased the complexity of plant operations. New process control technologies, including online reactivity measurements, contribute to the production of robust clinker and cement with minimum GHG emissions. Neural networks and AI are the first choice when managing large arrays of process and quality data. A new approach is essential to overcome time gaps from process control to systematically delayed compressive strength data.

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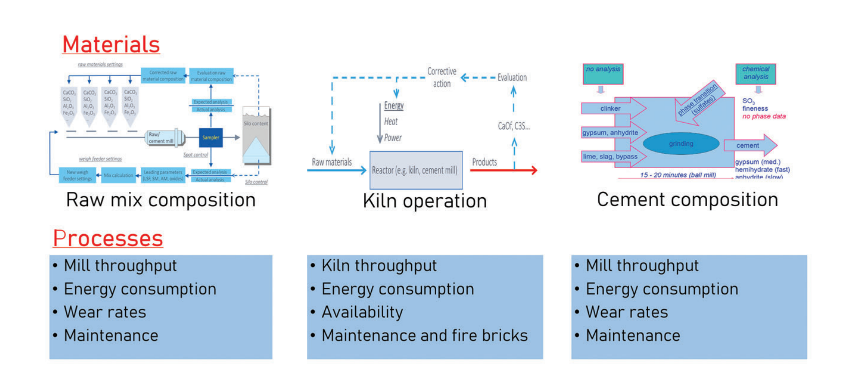
Climate change has become the major driver in terms of technology for clinker and cement production. Reducing the clinker content in Portland cement and the application of alternative fuels (AFs) are key to improving the ecology and economics of cement production.[1] The clinker content in cement has steadily decreased through substitution with natural and synthetic composite materials. Meanwhile, fossil fuels such as coal, oil and gas are being replaced by AFs from waste, sewage sludge or renewable combustibles.[1,2]

Today, clinker reduction and AFs have passed the evolutionary phase, and further improvements are limited by the availability of quality composite materials and AFs. New technologies such as carbon stripping (separate limestone calcination, oxyfuel, CO_2 removal from flue gases) and clay calcination are attracting increasing attention to reach demanding emission targets in cement production.

Overall, individual processes have become more complex and new processes are being added with the multiplication of signals for process supervision. Cement reactivity will become a critical property during process control to reach environmental targets. Portland cement systems remain important, as alternative binder systems face constraints in raw materials, the production process or non-routine application.[3]

Human capabilities are limited in the analyses of complex data sets. Digitalisation, neural networks and artificial intelligence (AI) are new tools to handle the increased complexity of cement plant operations. Learnings from large datasets from multiple analysers and sensors will be crucial for future clinker and cement production (see Table 1).[4] This article outlines the application of modern data analyses to cement plant process control.

Figure 1: two independent views on plant operation: chemistry and engineering



The journey is just starting, but the targets are clear: more sustainability, less cost and reliable clinker quality and operation in a state-of-the-art technological environment. thyssenkrupp Industrial Solutions' polab®Cal[7] and laboratory automation will be an integral part of the control cycles to supply high-frequency analyses of reactivity and material properties.

The status quo

Today, many cement plants are operated in what can be considered 'parallel universes' (see Figure 1). In the material world, chemists are supervising quarry operations, adjusting the raw mix, and verifying an acceptable free lime of clinker and a targeted cement composition including gypsum.

Meanwhile, in their world, mechanical and electrical engineers are optimising machinery to achieve acceptable energy consumption levels, minimum wear and high availability.

The understanding between both worlds strongly depends on communication skills, tolerance and transparency.

This situation is often encountered within the common trend of operating whole plants with a lower headcount. As a consequence, human skills and expertise need support from an increased degree of automation. The role of humans will change from taking decisions to accepting decisions suggested from automated controllers overlooking large arrays of process and quality data. In the beginning, those automated controllers will be supported by man, but in time, when cars start to move autonomously, a steady journey towards autonomous plant operations can be expected. Then the software will decide when the alert system is activated to call for human support.

One example in terms of complexity is firing a kiln with petcoke and other AFs. Petcoke increases C_2S in clinker and lowers clinker reactivity. At the same time, increased SO_2 emissions modify volatile cycles in the kiln atmosphere. AFs add additional moisture, increasing volatilisation. In this case condensation in the kiln inlet causes coatings and increased kiln downtime is common.

Table 1: learnings from large datasets from multiple analysers and sensors will be crucial for future clinker and cement production

	Today: materials/ processes	Future: materials/ processes	New quality target	Sensors	Data analyses
Materials	• Marl, clay and Fe-ore	• Waste streams from other processes (acid production, ceramics)	• Complete digestion in clinker • No compromise on quality	• XRF, XRD (intermediate and final product) • Lab automation • Mix control • Reactivity tests	• LAI for data collection • Data analyses • Artificial intelligence controller • IQCnet mill operation • IQCnet kiln operation
Fuels	• Coal • Gas • Oil	• Combustible waste (solvents, tyres, plastics) • Biogenic fuels	• Manage heat requirement • Low free lime, sufficient C_3S • Minimum emissions • Continuous process	• Gas composition • Temperature profile • XRF/XRD hot meal and bypass dust • Kiln tyre supervision • Pressure profiles	
Cement grinding	• Ball mill with separator • VRMs • High pressure grinding rollers (HPGR) • Waste streams from iron mills (GBFS) and power plants (Fly ash)	• VRMs • High pressure grinding rollers (HPGR) • Combined cycles (HPGR and ball mill) • Ultrafines (Booster mill)	•Targeted product qualities • Minimum electricity consumption • High availability • No compromise on quality	• XRF, XRD, PSD • Vibration • Feed rate • Hydraulic pressure • Table speed • Wear	
Pyro-technology	• Suspension preheater kiln	• Clay calcination • Carbon stripping • Separate calcination	• Minimum GHG emissions • Minimum heat requirements • Manageable with standard raw materials • No compromise on quality	• Carbon capture plants • Clay calcination plants oxygen supply	

Therefore, both the chemical properties of the intermediate and final product and operational issues such as kiln availability have to be evaluated. This situation cannot be solved by stopping the use of secondary fuels but by balancing secondary fuels, kiln availability and raw mix to achieve continuous production at good economics.[5, 6] Often the best solution is a complex correction that includes the anticipation of cement performance.

The future of process control

Digital analyses of large data arrays

The main task for future process control is to find viable solutions with robust products, minimum emissions and reaching targeted volumes. The increasing complexity calls for the application of AI and the collaboration of engineers, automation experts, material experts and data analysts.[4]

Data acquisition and data analyses

Today, various sensors are placed in the plant to collect data, eg vibration, electricity and heat consumption, pressures and chemical/mineralogical. In future, the data will be permanently collected on a single database by high-frequency recording.

thyssenkrupp Industrial Solutions applies the concept of the local analytics interface (LAI) that is installed at the cement plant. Each LAI is interfaced with sensors and collects information. The data is assessed by local personnel and software tools, and can be made accessible to thyssenkrupp Industrial Solutions for remote support through the company's cloud services and experts.

In a first step, a correlation matrix identifies cross-referenced data. The matrix is used to cluster data and observations and to identify principal drivers.

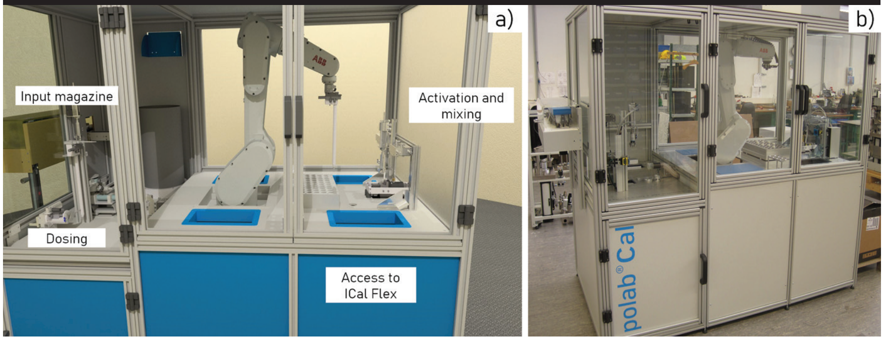
From that point, an initial neural network can be built from the data. In a training phase the neural net is optimised from historic data. Expert knowledge and fundamental constraints are added.

The last step is training during operation, where decisions suggested from the AI are verified in practical work. The degree of human support is reduced step by step towards autonomous operation.

Control mechanism based on AI and the polabCal

In a simplified approach the product quality of a cement mill is controlled by the clinker factor and the separator speed. In the past cement production was controlled by fineness, chemistry and mineralogy. The targeted cement quality was extrapolated from historical data only. The actual quality of the end product is only confirmed when compressive

Figure 2: (a) rendered image of polabCal – polabCal prepares samples for automated reactivity measurements (b): view into the workshop showing the final assembly of a polabCal unit



data is available at the earliest 48h after production (24h sampling of composite sample plus 24h of curing).

A simple mill controller could use the polabCal and reactivity data (see Figure 2).[7] Reactivity data points directly to separator settings and the clinker factor. Depending on the deviation of the quantified reactivity data relative to the set point, either the fineness or clinker content needs to be adjusted. In a mill controller, additional constraints, such as the minimum clinker content or SO_3 values, can be locked. Each reactivity set point of cement can be reviewed in short time schedules based on polabCal data (usually 30-60min). This set-up is much faster and more accurate than extrapolation from compressive strength testing. Also, for grinding stations this could start a completely new approach for quality control.

A complete mill controller based on the IQCnet and AI will work with complex data, including mill temperature, roller pressures and table speed, chemical/mineralogical composition and reactivity data are analysed and used for control (see Figure 3). The complex database combining different data sources will be trained for targeted cement quality at accepted cost. The concept can be easily modified to fulfill the requirements of a kiln controller for optimum and consistent clinker quality over time (see Figure 4).

> *"Process control systems of the future need a holistic view of the available data from the chemical lab and the process and a rapid response."*

Outlook

The future of the cement industry will be less clinker, more alternative fuels and raw materials, and new technologies for clinker and cement production. The core task is maintaining sufficient reactivity and achieving maximum robustness at minimum emissions. Frequent adaption of raw materials and fuels make clinker and cement susceptible to quality fluctuation. Process control systems of the future need a holistic view of the available data from the chemical lab and the process and a rapid response. Humans will need software support to rapidly identify the best solution from a large data array. New controllers, including reactivity signals from the polabCal, can close the gap. These new controllers evaluate complex data arrays including reactivity data with AI and neural networks. ■

Figure 3: IQCnet for mill operation. Process and QC data is collected in a common database. AI tools evaluate the data and control mill operation. Reactivity data is a valuable signal to get direct information for separator and weighfeeder settings

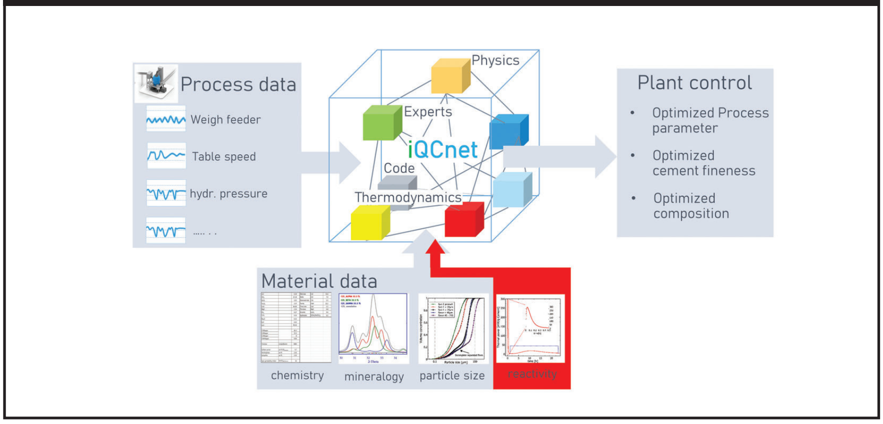
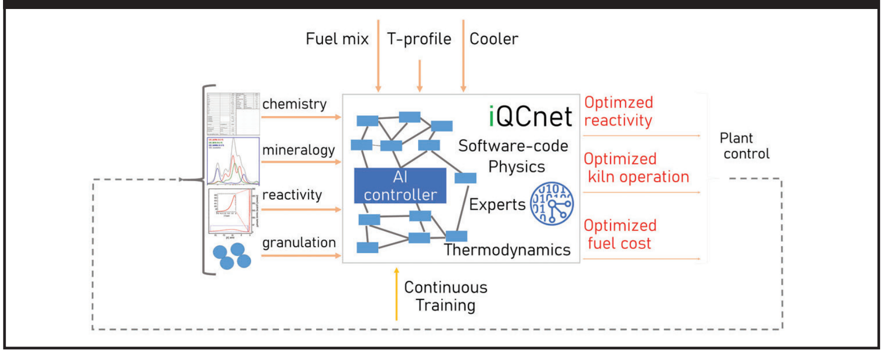


Figure 4: IQCnet for kiln operation. The kiln controller starts from process data plus clinker and hot meal data to establish consistent and continuous kiln operation



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