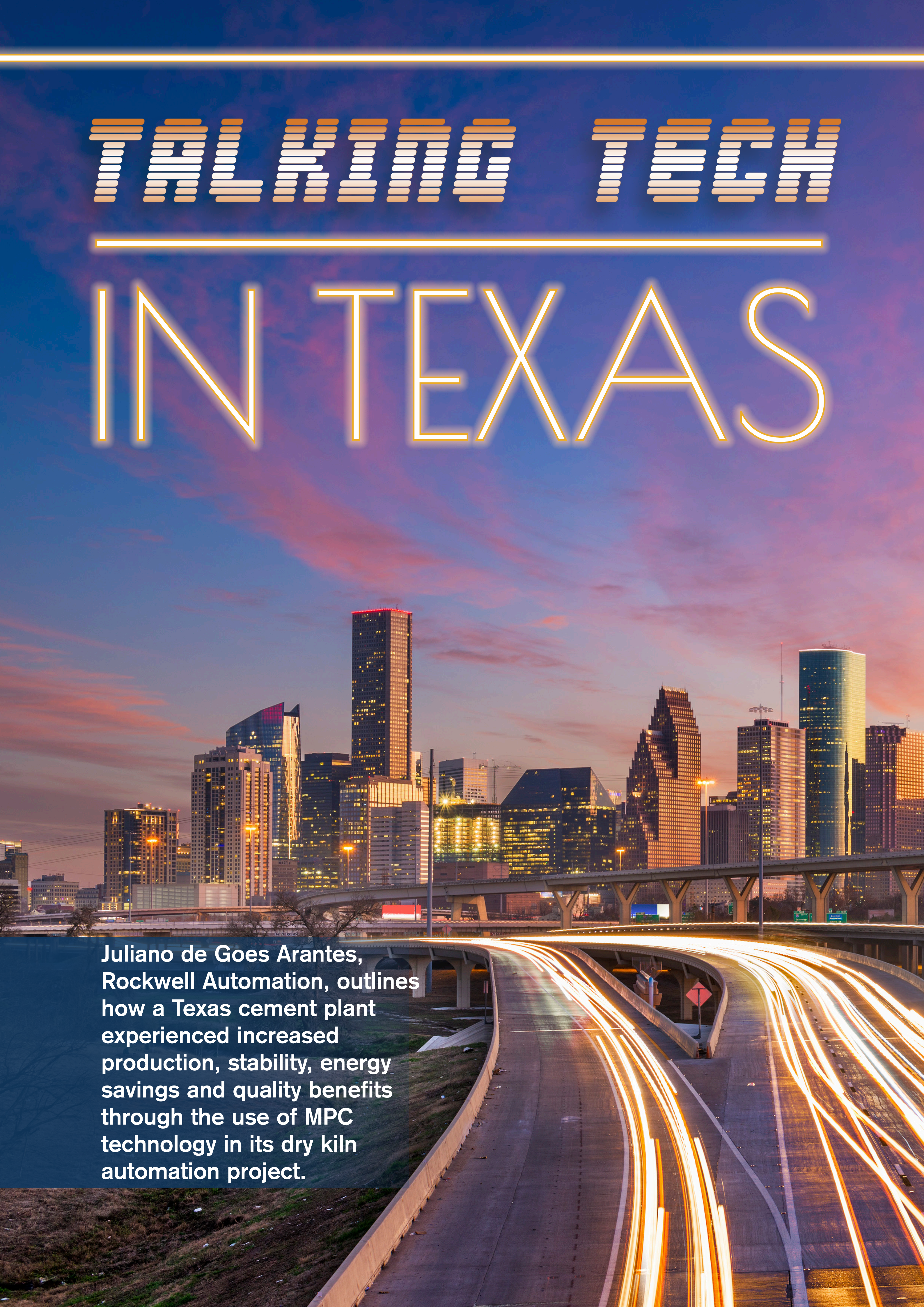
TALKING TECH IN TEXAS

Juliano de Goes Arantes, Rockwell Automation, outlines how a Texas cement plant experienced increased production, stability, energy savings and quality benefits through the use of MPC technology in its dry kiln automation project.



One of the ever-present drives in cement manufacturing is the push to improve production throughput, quality, and efficiency whilst saving energy and reducing emissions. Usually, in order to achieve these results, cement companies were required to invest in new capital projects or major retrofits to expand capacity or replace and upgrade old, less efficient equipment with modern, energy-efficient units (for example, converting a long dry kiln to a precalciner kiln). However, these types of projects are multi-million dollar investments and can be difficult to justify in a changing economic marketplace.

Incremental improvements for significant technology advancements

Significant incremental improvements can be made using advanced process automation technology. These projects are much smaller in cost, duration, and risk. Yet they still have quantifiable benefits and paybacks measured in months, if not weeks, as opposed to years. There are also indirect benefits associated with these projects that result from increased plant stability. Stable operations are easier to maintain and require less operator involvement.

These types of advancements are not new. Over the past 50 years, heavy industries have adopted distributed control systems that allow advanced optimisation technologies to be layered into them. Over time, the underlying hardware has improved dramatically, and the cost has dropped, resulting in most existing manufacturing plants having a modern DCS or PLC-based control system.

Two major advanced optimisation technologies grew out of this effort: model-based predictive control and expert systems. While model predictive control (MPC) has seen much more success in other process industries, the cement industry has been almost exclusively served by expert systems technology to date. But there is significant potential for MPC technology in the cement industry and successful projects have been executed.

The technology: Model predictive control using machine learning models

Supervised machine learning and MPC are major artificial intelligence (AI) techniques that can and are being used in the cement industry. With more than 30 years of experience to draw from, the technology has been a staple in offerings from Rockwell Automation. The basic principle behind MPC is that the controller/optimiser uses a detailed dynamic model of the process.

The model follows an input/output standard, where it relates the effects of the inputs on the outputs. The machine learning model can be built from several data sources (operational plant data, historical or process knowledge). Then MPC allows the controller/optimiser to take current and recent operational data and predict the future behaviour of the plant. This prediction is dynamic; it determines not only the size of the response, but the time evolution of it as well.

Figure 1 shows a portion of a full kiln model where a change in precalciner fuel rate results in a change in temperature over time.

The MPC controller/optimiser receives current information about the process and uses dynamic models to predict the response of the process to a sequence of future moves over a specified timeline, say for the next hour. It defines the sequence of moves and predicts the effect on the dependent outputs (controlled variables) to meet multiple targets and objectives.

Tracking the process response to the first of the moves and comparing to the prediction trajectory allows the controller to compensate for differences seen in the predicted versus actual responses, enabling the controller to function even with unmeasured disturbances that impact the process.

This procedure is repeated so the future prediction timeline is maintained. The controller/optimiser considers process constraints, which improve stability and operational safety. MPC technology includes several key advantages:

- Tuning requirements are minimal and are carried out with the system online for accurate and rapid assessment of changes to dynamic behaviour or process limits.

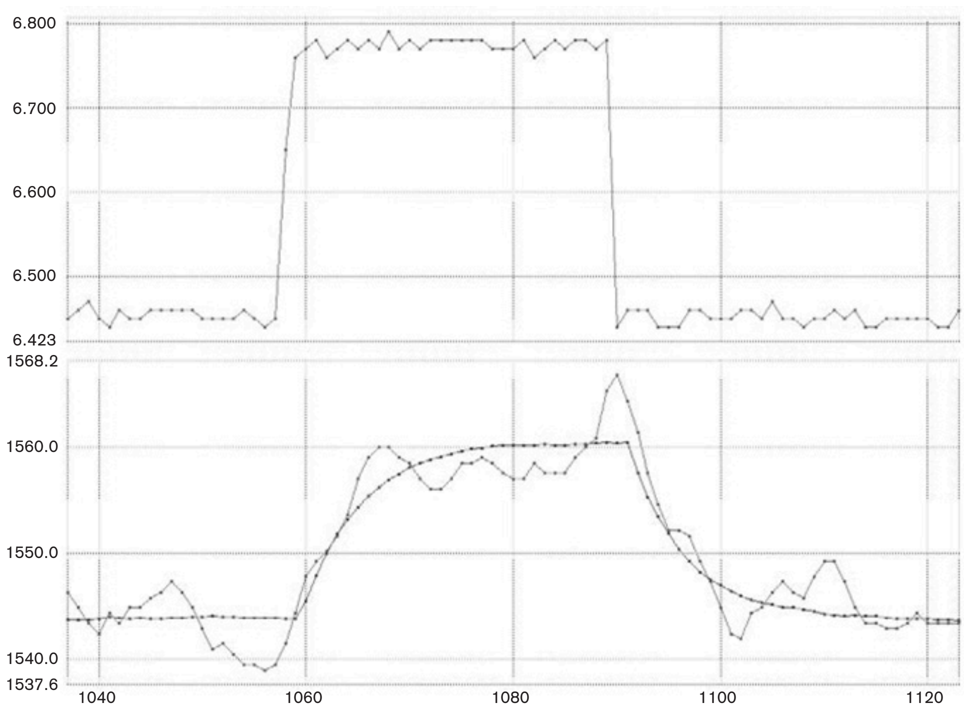


Figure 1. The top trend shows a change in precalciner coal rate, while the bottom trend shows actual 4th stage temperature and the dynamic model (smooth curve).

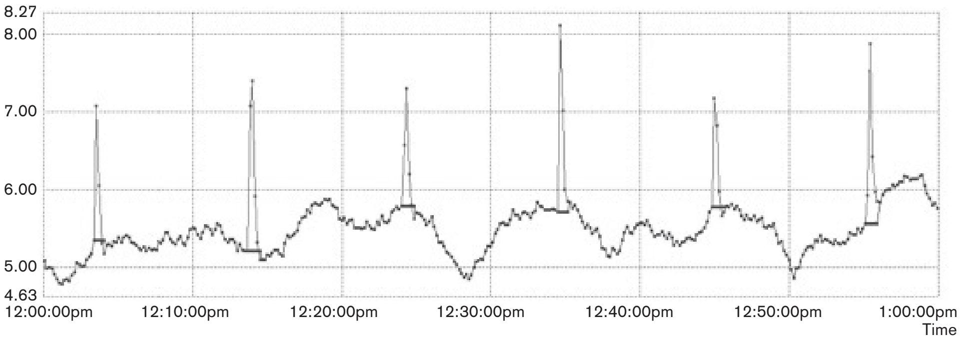


Figure 2. The effect of the signal conditioning: Tower oxygen, raw signal (grey) and filtered (black).

- Process models are robust and do not require retraining or annual checkups. Modification is required only for a major process change, for example, a new variable for control.
- The technology is excellent at rejecting disturbances, keeping the process on track in the face of random, natural process alarms.

MPC is able to move the process closer to its physical limits – optimisation. During an upset, larger step moves are calculated for initial correction, becoming progressively smaller as the process recovers – control.

Using out of the box machine learning tools, the system can also 'self-tune' for changes without redefining process limits or parameters. For example, if the main objective of a cement kiln is to increase production, but partial blockage of the riser reduces available draft, the controller will maintain good combustion conditions under the temporary constraint. When the blockage is cleared, the controller will detect that more draft is now available at the same fan speed and the controller will increase production. The system delivers stability within the limits and robustness when encountering process drift, yet will also show better regulatory control in a steady state to deliver superior performance.

Case study

Background

A major cement plant in Texas was limited by the capacity of the finish mills, and previous automation projects to increase milling production were employed using MPC technology. Even with mill limitations, the local market conditions presented the opportunity to capitalise on the excess clinker capacity in two ways – sell clinker and shift production from a less efficient wet kiln to a modern dry precalciner kiln. Given the success of previous MPC projects and the company's continuous efforts to improve its operation further, MPC was selected for the dry kiln automation project.

Process description

The preheater-precalciner is a four-stage tower using a mixture of coal and petroleum coke as fuel. These characteristics were noted about the precalciner:

- The raw meal is fed from one of two feed bins, however the flow measurements are not calibrated to be consistent between the two bins.
- The dry kiln main burner uses the same mixture of coal and coke as fuel. The kiln is equipped to also burn tyres, but this is not currently done.
- There is a camera for burning zone temperature, but the signal is only on the camera display, and there is not any analog output to the control system.
- The cooler is run with constant fan speeds and the grate speed is normally set at minimum to maximise heat recovery to the tertiary air.
- Clinker free lime is sampled every four hours.

The MPC architecture used a staged modular implementation concept to fully incorporate the multivariate and interactive nature of the kiln-cooler operating conditions. A single variable MPC controller is used on the cooler to control cooler bed depth (CFG fan manifold pressure) by manipulating the grate speed. This controller replaces the PID loop previously used in the PLC, which did not control smoothly due to the difficult dynamics in this loop. An MPC kiln controller is used for controlling the kiln and precalciner. This includes stage four temperature control, previously done in a PLC PID loop.

The controller is supported by three calculation block applications, which provide external functionalities and calculations, including analyser signal validation, free lime prediction, and free lime lab biasing.

The project execution methodology was designed to demonstrate the advantages of the machine learning and MPC technology including the speed of implementation, design flexibility, ease of use, lack of maintenance required and sustained performance. The control objectives for the projects included maximising stability, production rate and efficiency. The process methods to obtain these objectives were:

- Control tower stage four temperature to stabilise the calcining operation.
- Control kiln burning zone temperature, by controlling kiln exit NOx as a surrogate for temperature.
- Control tower exit excess oxygen, to minimise heat lost to the stack.
- Predict free lime changes based on temperature and kiln operation condition.
- Control free lime to maintain clinker quality.
- Control kiln production rate to stabilise overall line operation.

Application optimisation

Dry kiln

To meet the objectives, the dry kiln controller provides thermal control/stability, emissions control, and production rate control/optimisation, and is configured to meet the desired objectives. Although the initial dynamic models have been identified using machine learning based on the historical dataset, the implemented dynamic models were simplified to user-specified first-order models rather than higher-order model dynamics.

The facility has developed DCS graphic-user interfaces (GUI) which include the functions of the controller GUI to assist board operators in engaging different modules of the APC solution. It includes built-in logic checks to facilitate the smooth 'transition' from in-house DCS control schemes into APC controls and gracefully shed the APC controllers in case of network communication failure.

Cooler controller

The cooler controller maintains the cooler bed depth/ undergrate pressure (CFG fan manifold pressure) at the target specified by the operators by adjusting the cooler primary grate speed controller output. The controller replaces the existing DCS PID loop for cooler CFG fan manifold pressure. The cooler controller is implemented with integrating models. This means that the gain is the change in the rate of increase of the bed delta-pressure for a unit change in grate speed controller output.

Tower O_2 filter calculation block

The tower O_2 filter calculation block validates the analyser signal for tower O_2 for use in the dry kiln controller application. Approximately every 10 minutes, the analyser probe is cleaned by blowing air over the probe. This 'blow through' causes the analyser reading to spike above its actual value for one minute in duration. This application filters out these spikes to avoid unnecessary/incorrect adjusting of the manipulated variables. Additionally, this calculation block also handles the maintenance and service alarms built into the analyser system. Figure 2 shows the effect of the signal conditioning.

Kiln NOx filter calculation block

The kiln NOx filter calculation block validates the analyser signal for the kiln exit NOx for use in the dry kiln controller application. The analyser probe is manually cleaned daily. Since the probe is removed from the kiln for cleaning, the reading no longer reflects kiln conditions. This application filter holds the last good value and the controller uses its internal model prediction instead of the analyser. This calculation block handles the maintenance and service alarms built into the analyser system.

Free lime lab update

Every four hours the clinker is sampled and analysed for free lime content. The free lime lab calculation block supports the indirect control of free lime by monitoring the lab results and then determining a change to the dry kiln controller kiln NOx target to drive the free lime closer to the target. In this manner, if the kiln is overburning the clinker (low free lime), the NOx target will be reduced, resulting in a lower burning zone temperature and increased free lime. In the case of additional burning zone temperature indicators, the same logic can be applied to update the targets according to the free lime results.

Results

After approximately six months of performance, the application pushed the kiln towards better, more efficient operation. The increase in throughput, reduction in excess oxygen, reduction in NOx, and the increase in tertiary air temperature all contribute directly towards energy efficiencies. The facility saw:

- Average feed increase of 2.5%.
- Reduction in exit O_2 of ~10% and reduction in O_2 standard deviation of 41%.
- 8% reduction in NOx lbs and reduction in standard deviation of 42%.
- 7% increase in average tertiary air temperature and reduction in standard deviation of 33%.
- 14% increase in average free lime (closer to limit) and reduction in standard deviation of 36%.
- Controller uptime of 89%.

Conclusion

The facility has followed its successful implementation of MPC on its two finish mills with a new MPC project on its dry precalciner kiln. The project took three months to execute, and resulted in sustained benefits to production, stability, energy savings and quality. The project benefits paid for themselves in less than six months. ■

About the author

Juliano de Goes Arantes began his cement career during his Electrical Engineering studies in Sorocaba Brazil, joining Votorantim Cimentos in 1997. For the next two years, he worked in various roles and got to know the industry and the intricacies of advanced process control. In 2006, Juliano moved to Switzerland to join ABB, where he worked as a Senior Application Engineer implementing APC solutions worldwide. In 2012, he shifted to sales, where he targeted mineral, mining and cement businesses. In November 2019, Juliano joined Rockwell Automation as a Sales Executive for the EMEA Region, focused on Analytics Solutions (AI, ML and MPC) for cement, mining and metals. Juliano is a regular speaker at conferences, and is fluent in Portuguese, English, German, and Spanish.

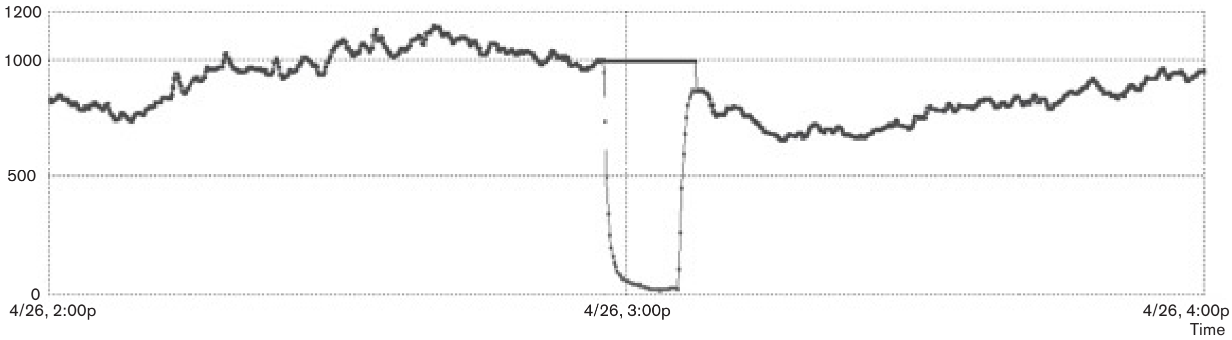


Figure 3. The effect of the signal conditioning: Kiln NOx, raw signal grey, and filtered (black).