Kiln and cooler developments

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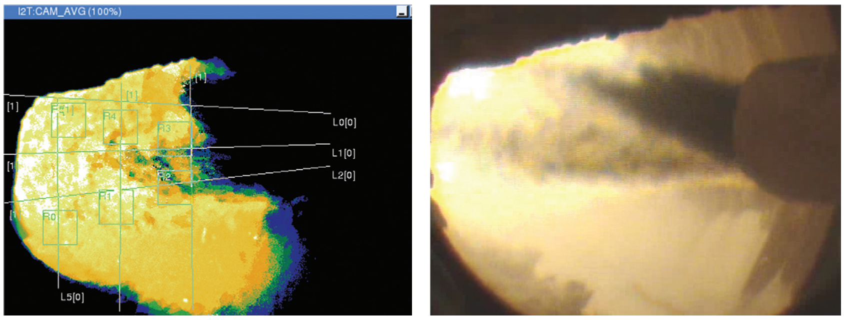
With more than 100 PiT Indicator (thermography) and the Auto-Optimiser PiT Navigator (NMPC, non-linear model predictive control) systems installed, the solutions offered by Powitec are currently at the cutting-edge of process observation and control in the cement and lime industry. Based on the positive experiences of such technology being applied in the kiln, the company's customers are now starting to apply these solutions in the clinker cooler as well.

Since 2008, many plants have chosen to observe the ignition gap at the burner tip with new side thermography technology. This is carried out to achieve alternative fuel rates of up to 85 per cent, especially in kilns without a calciner where more than 80 per cent of these fuels are being fed to the burner. It also accounts for the unavoidable fluctuations in the quality of alternative fuels. The necessary adjustments to the burner and the cooler can be controlled and this has, therefore, turned into a routine job.

Figure 1: thermogram- (left), Video-image (right)



Ignition gap better process set point than classical pyrometer for temperature of sinter zone and secondary air

At high rates of alternative fuels at the main burner, the mutual reciprocal effects between cooler and kiln lead to an increased utilisation of the cooler, ie fans 1+2, for controlling the complete system. Experts state: "Today, we drive the kiln for 50 per cent by the cooler".

The new 'ignition gap' information and the common unreliability of classical pyrometers, operating in the high temperatures of the sintering zone and secondary air due to dust, streaks, drift and caking, make the operators rethink."My target is a stable flame and not the slavish tracing of a certain secondary air temperature, that would mean basing decisons on an inaccurate measurements. Additionally, I can compensate for the fluctuations in alternative fuels which have never been measured online."

Secondary air control

The control loop between the main actuators (fans 1+2) and the ignition gap reacts very fast. Fully-automatic control takes over the former manual changes in the cooler's operation mode (air distribution, grid velocity) while the fuel-/burner-adjustments remain the operator's duty.

Approach

- Automatic camera-based flame analysis (determination of ignition point).
- Modelling of the cooler condition (grey box process model).
- Automated and optimised cooler operation (NMPC, non-linear model predictive control).

Due to the occasional adjustments of the burner position through a remote-controlled hydraulic drive, operated from the control room, both the position of the burner tip and the ignition point are automatically measured in this project. Subsequently, this allows for the calculation of the ignition gap.

The control is based on a Grey Box Model:

- the system is, where possible, mathematically described by a balance equation (White Box Model)
- unknown correlations and parameters are modelled data-driven (Black Box Model).

This solution uses advantages of both the White Box (application of known balance equations) and the Black Box approach (data-driven modelling of unknown parameters).

White Box Models (parametric models) result from a detailed theoretical analysis of system behaviour. This

Figure 2: camera-based analysis of ignition gap

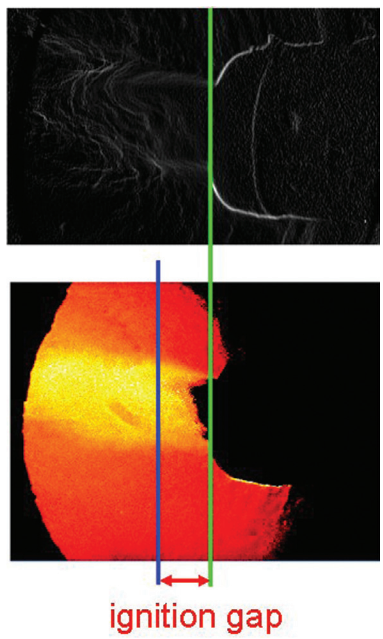


Figure 3: process model with one auxiliary element each per fan

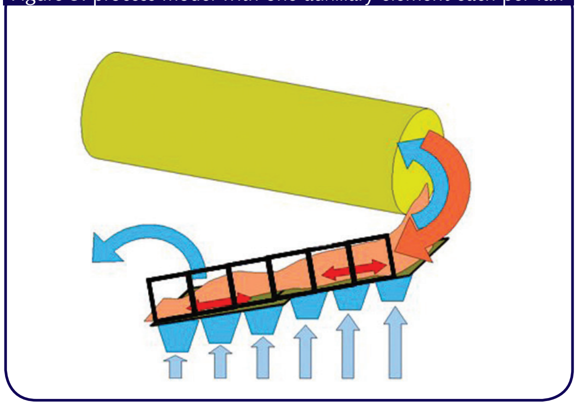
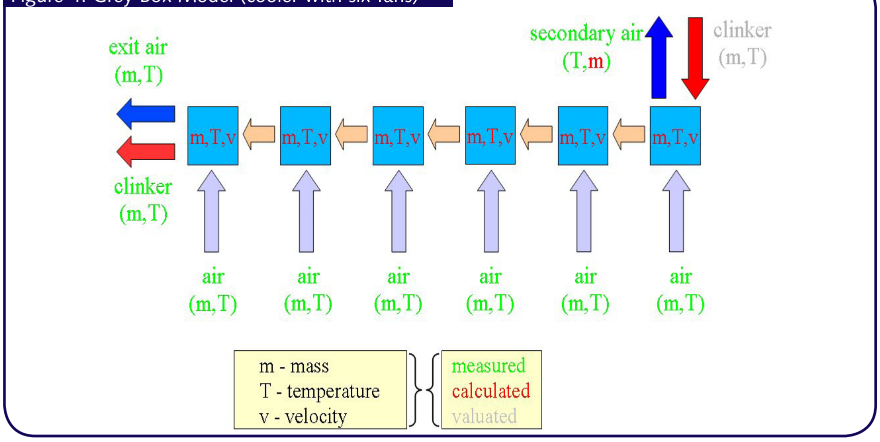


Figure 4: Grey Box Model (cooler with six fans)



analysis is carried out by finding physical and geometric equations. The main characteristic of White Box Models is that the model structure is known precisely and the model parameters correspond to physical parameters. The model parameters can be compared with measurements. White Box Models have high accuracy assuming, however, that the system behaviour was analysed in great detail, which can be very time consuming. In practice this becomes very difficult where interference, noise and constantly changing conditions on different time horizons permanently appear.

To avoid an elaborate theoretical analysis or if only very little is knowledge is present about the system behaviour with its interference and noise, experimental analysis or identification is used. The result of this identification is a so-called *Black Box Model* (non-parametric model). The main characteristic of the black-box model is that there is no known or very little prior knowledge about the system behaviour or the system structure and the model parameters have no physical meaning. The model reflects only the input/output behaviour, eg with neural networks, and the physical parameters are obtained, eg in the form of weight functions or clusters or probabilities.

Since white box models rarely work in the multi-dimensional, complex clinker production process with severe changes through raw material, fuel properties and plant drift, unknown variables (often used as constants in those mathematical formulas) are supported by data-driven modelling. This is called *Grey Box Modelling* which allows for a transparent control concept even for processes with 'black spots' or extreme drift.

The Grey Box Model for optimisation of the cooler operation mode includes:

- segmentation of the cooler in volume elements (boxes)
- description of the condition in these boxes (m, T, v)
- modelling of the correlations between these boxes.

Such interactive solution of the system of equations gives an online description of the status for mass, temperature and velocity of the clinker in each box of the cooler.

Conclusion and target group

Control of secondary air is a cost-effective and quick to implement solution for the stabilisation of the flame and thus the sinter zone at high rates of alternative fuel in the main burner. Thus it becomes very interesting for kilns without calciner but with elder coolers perhaps, to achieve the required 'high and stable secondary air' without having to invest in cost-intensive engineering optimisation.

Or from the economical point of view: high alternative fuel rates or economical interesting alternative fuels become practical.

Cooler control based upon thermography and performance-evaluation through scoring

Alternative sensor positions

Basing on the positive experience at the kiln, plants have been applying the Powitec thermography at the cooler since 2010. Often it replaced video cameras, within the scope of cooler optimisation or in process instrumentation of new kiln lines. As with the kiln, after years of pure visualisation, the customers put enhanced emphasis on the extraction of reliable process data.

Depending on the customer targets and the geometry of the cooler, three

Figure 5: control concept

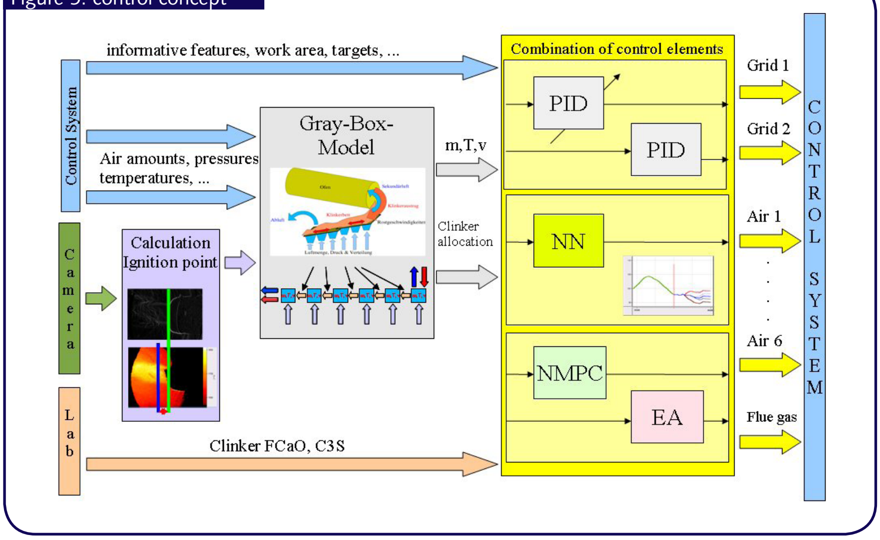


Figure 6: possible sensor positions

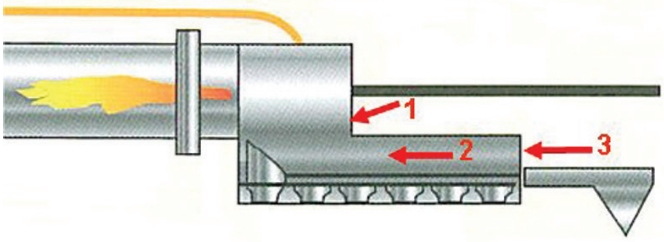
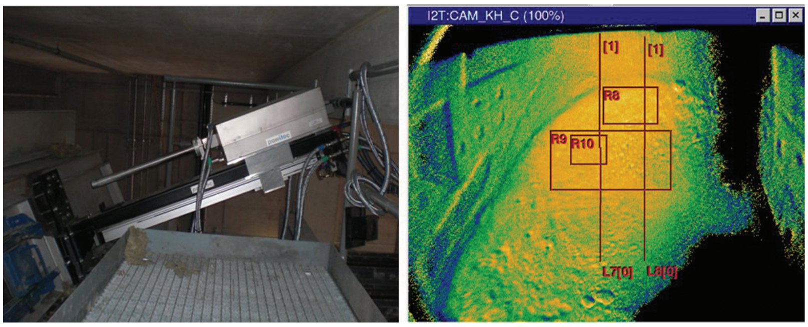


Figure 7: example for position 1 sensor- (left), thermogram (right)

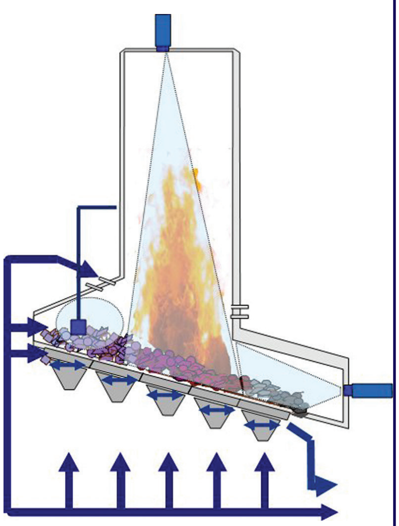


mounting positions or visual ranges can be realised, considering that the temperature range beyond 700˚C has to be detected optimally.

Application of classical solutions from the waste to energy section

In terms of process control Powitec refers to the experience gained from 22 installations in waste to energy (WTE) plants. With up to three sensors, extensive actuator engineering and stringent

Figure 8: example for the Powitec concept at a grid fired WTE boiler



emission standards, the solutions in WTE have a much greater complexity.

Nevertheless, the established strategies, like the aforementioned Grey Box approach, were successfully transcribed. From the point of plant engineering, the WTE-grid firing and the clinker cooling are quite similar, with some plant construction companies active in both branches.

Scoring method

Considering the customer-specific target matrix for the optimal cooler operation, the Scoring Model is applied (performance-evaluation via a quality function per target parameter). This enables the customer to objectively evaluate the control performance as well as autonomously and flexibly adapt to his changing priorities.

The definition of the quality functions for each optimisation target are:

- determination of upper and lower limit for each target
- definition of the value for upper and lower limit (eg 100 for upper (best) and 0 for lower (worst) limit) and of the function between these limits (linear, with leaps, constant, non-linear etc.)
- Prioritisation of each target in relation to the other targets, giving a value between 100 (highest priority) and one (lowest priority). The sum does not have to be 100 – the value is just for weighting the targets.

The result is a weighted target vector, which takes into account the weighting of the targets.

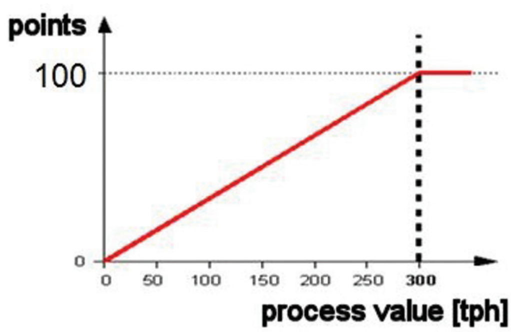
Calculation of total scores

- The value for each target is calculated according to the above described value function (between 0 and 100).
- The result is multiplied with the preselected prioritisation of this target parameter: for instance, if the result of the value function was 100 and the prioritisation 70, the result is 70 scores.
- The total score of all target parameters is then calculated by adding up the scores of all parameters.

Conclusion and outlook

The described cooler control is an innovative approach, which can be applied to existing and new coolers for a stand-alone cooler control or as a part of complete preheater, calciner, kiln and cooler control.

Figure 9: example of value function



Results from this innovative approach will be available at the beginning of next year: from an older cooler (Polysius, four grids, one line) and a new CemProTec PendulumCooler. At one installation, only the cooler is controlled and at the new kiln III at Zementwerk Leube, Austria, calciner, kiln and cooler are controlled.

This first publication describes the control concept including temperature measurement, Grey Box Modelling and Scoring for control of elder existing plants and high-capacity new plants.