Advanced Process Control Increases Usage of Alternative Fuels in Precalciners and Cement Kilns

Dr Eduardo Gallestey
ABB

Abstract

Due to the pressure for profitability, but also due to the need to address environmental issues inherent to cement production, the number of cement plants using alternative fuels has increased dramatically over the last few years. Management goals are to reduce thermal energy costs, but also to be more environmentally friendly by substituting traditional fossil fuels.

Alternative fuels, albeit interesting in economical and environmental sense, are difficult to dose, have high calorific value variability, and thus impose the need for automatic control to ensure good process conditions in the kiln.

The controllers presented in this work were implemented on Expert Optimizer, a commercial advanced process control and optimization platform developed by ABB. The underlying controller technology is Model Predictive Control, which is implemented in a graphical modeling environment. The graphical interface allows the model to be constructed from easily understandable and configurable sub-models. The modeling environment is such that the optimization problem is constructed by dragging generic modeling elements from the library, and dropping them on the model space. The model predictive control problems are then generated from this graphical representation. The goal is that the complexity of the mathematical formulation can be hidden from the users, increasing the ease of use and decreasing the cost of ownership.

In the presentation, results from different installations in Europe and USA will be described. It will be shown how Expert Optimizer has been able to increase the usage of alternative fuels, helping our customers in their quest for profitability and environmentally friendly production.

1 The challenge of using alternative fuels in cement plants

The kiln process is schematically represented in Figure 1.

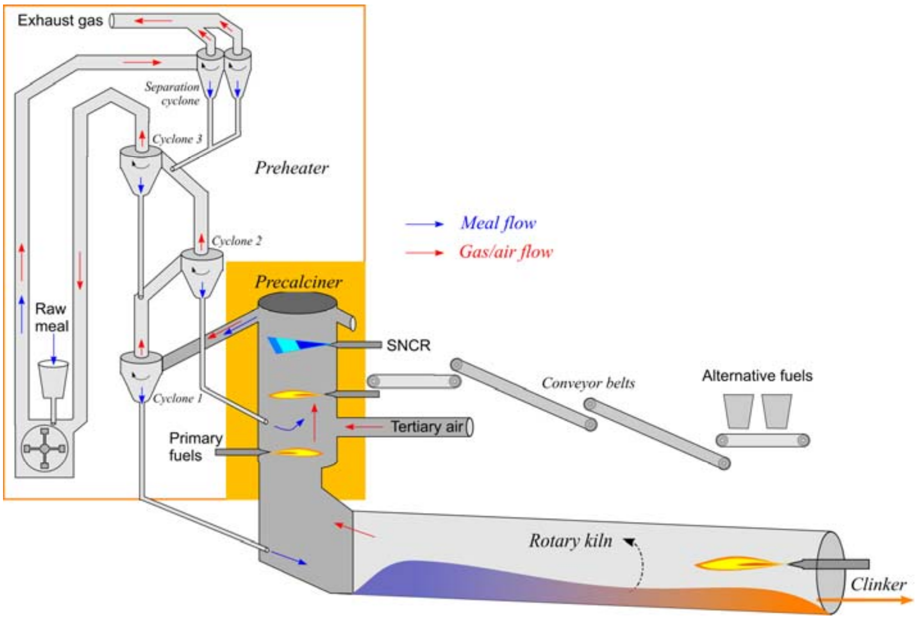

Figure 1: Schematic representation of the clinker production process.

Many different plant setups are possible. Newer and more energy efficient plants have a preheater tower with several cyclone stages and a precalciner. The preheater recovers heat from the exhaust gas of the combustion downstream of the process. In the precalciner additional heat is provided to the process and at a temperature between 860oC to 950oC decarbonising of the raw meal takes place.

$CaCO_3$ + Heat → CaO + CO2.

The decarbonised hot meal then enters the rotary kiln where the actual sintering of the clinker takes place.

Changes in the degree of decarbonation of the meal entering the kiln will affect the quality of the clinker. In particular, in precalciner kilns dips in the decarbonation degree cannot be compensated by the rotary kiln due to its short length. Typically, in cement plants up to 70% of the heat used within the clinker production process is obtained from the combustion of fuels within the precalciner. It follows that the high variability of the alternative fuels is bound to cause instabilities within the clinker burning process 2.

In manual control, kiln operators essentially try to keep the precalciner temperature high to ensure high decarbonation degree and therefore to stabilize the process 2. However, with high precalciner temperature many other problems occur. The high temperatures accelerate wear of refractory lining in the cyclones increasing maintenance and repair activities. Additionally, the meal grows more “sticky” and the risk of capital cyclone blockages increases considerably. And of course, energy consumption rises.

It turns out that tight control of the precalciner temperature is crucial for efficient usage of alternative fuels in cement plants. The problem becomes critical when substitution rates beyond 30% are pursued.

In this article we present an advanced control solution to tackle this problem. It allows increasing the alternative fuels usage rate to up to 100% of the thermal energy need.

2 The technical solution

For many years ABB has been designing and deploying advanced process automation solutions and applications in different plants worldwide. ABB is constantly in contact on how to improve the current products to meet the customer requirements. These systems are deployed using ABB's advanced process control system Expert Optimizer, which is a comprehensive engineering tool 3 that facilitates the development of generic control solutions for complex problems within the process automation industry. Most installations have been made in blending, kilns, and grinding operations. In particular, 45 blending systems, 195 rotary kilns and 90 mills have been commissioned by the ABB team during the last 10 years.

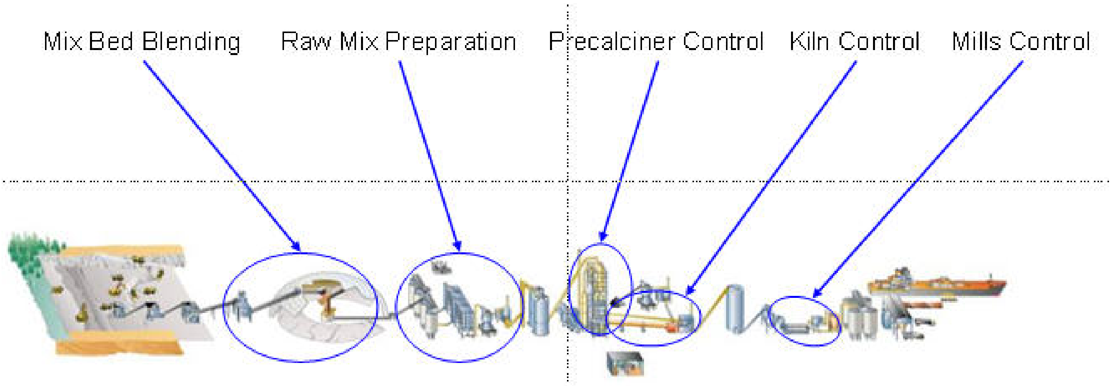

Figure 2. Expert Optimizer Applications Scope

A “precalciner and kiln control while using alternative fuels” was a natural extension to ABB’s portfolio.

2.1 Model Predictive Control as enabling technology

MPC is based on the “receding horizon”. A sequence of optimum actions extending into the future are calculated while incorporating the dynamics of the process. The first element of the optimal action sequence is transferred to the control system as the new actuator setpoint. If new measurements are available the algorithm is repeated and a new sequence is calculated.
Typically, this approach is compared with a chess player:

1. The position on the chess board is evaluated, i.e. measuring and assessing the state of the process.
2. Future moves are considered, i.e. a mathematical algorithm calculates the optimal sequence of actions.
3. The first move is applied, i.e. a new setpoint is sent to the actuators.

This sequence is repeated after the opponent has made his move. An important advantage of such a system is that the mathematical algorithm can take limits and constraints into account when deriving the optimal control sequence. Analogously, the chess player has a restricted area to make his moves (the board) and has a limited range of moves (depending on the chessmen).
Expert Optimizer supports many different control technologies including MPC. However, it was so far not used to control a calciner combustion process in the cement industry.

2.2 The control problem

The temperature in the precalciner is the main continuous indicator for the quality of the hot meal. It is therefore used as the main controlled variable. Furthermore combustion of the fuel needs to be guaranteed and therefore oxygen levels need to be maintained above predefined limits. Carbon monoxide exhaustion is legally regulated and may cause the system to trip if the limits are violated.

As manipulated variables the primary fuels are used. These are mainly coal, and in specific cases, high quality waste fuels. Primary fuels need to be transported via pneumatic means to the precalciner and be fast and reliable actuators of the system. Other alternative fuels can/may be used, which are for instance transported via conveyor belts. These fuels have a transport delay up to many minutes before they reach the precalciner or kiln and are therefore not suitable as manipulated variables.

2.3 The Mathematical Model

Generally speaking, the better the model describes the real process, higher expectations can be placed on the performance of the controller. However, it is often also generally true that the more sophisticated the model is the more sensitive the controller reacts to uncertainty in the process. The uncertainty and variability of the process in this specific case is significant. For example the calorific values of the alternative fuels change constantly depending on composition of the originating waste but are updated once a month only. It follows that good knowledge of the process AND of control techniques are needed for a successful application.

In ABB’s case the model comprises two separate parts; the transport model and a combustion model. The transport model is a series of unit time delays corresponding to the different transport delays of each of the fuel feeders.

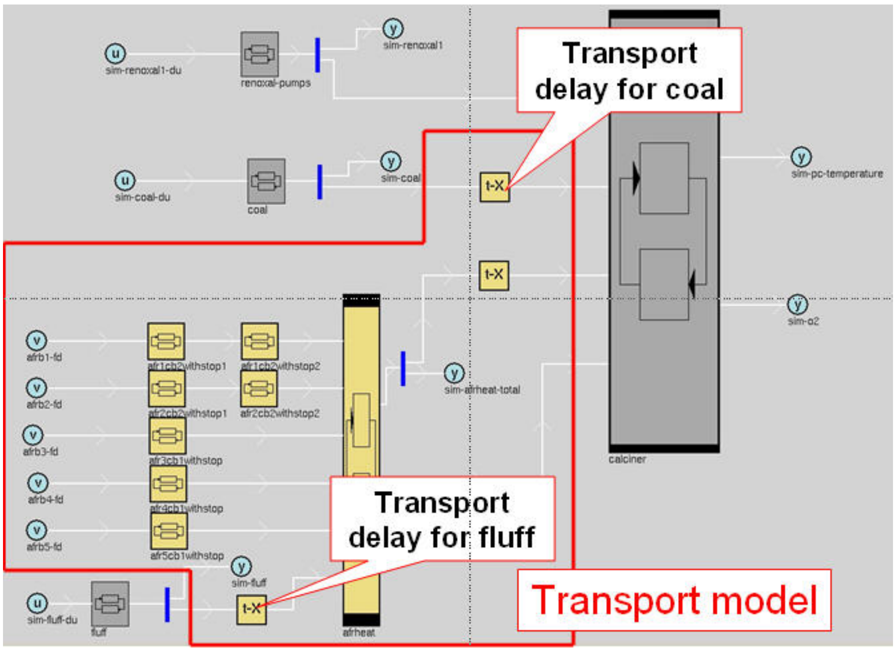

Figure 3. Transport Model

The combustion model consists of two parts: i) a heat balance and ii) an oxygen balance. The heat balance considers any heat which is added or drawn from the precalciner. This includes fuel input, gas and air flows, meal feed rates and the decarbonation reaction which consumes considerable heat. Varying meal composition also introduces a significant variation of the heat used for decarbonation. Usually these composition variations are considerably slower in relation to the thermal reaction and therefore can be captured in adaptive bias terms.

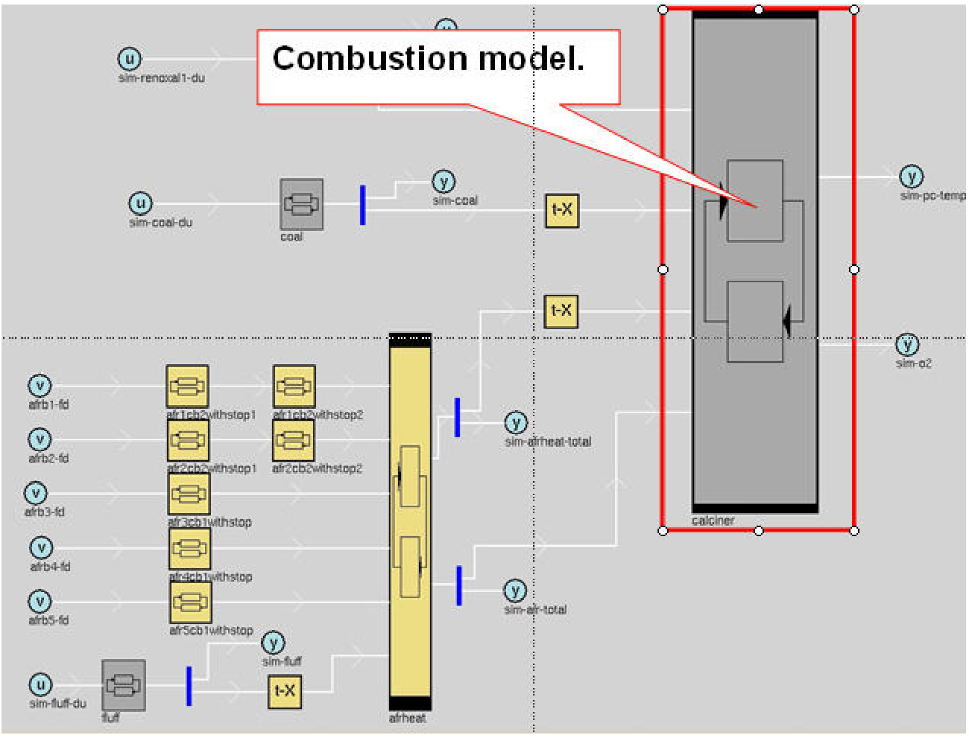

Figure 4.Thermo dynamical Model

3 Results

A recording of plant operations is shown in. In the top subplot the temperature and the target temperature is seen. The middle subplot shows the input heat flow to the combustion model related to all of the alternative fuels. The second plot shows the main manipulated variable, the coal feed rate.

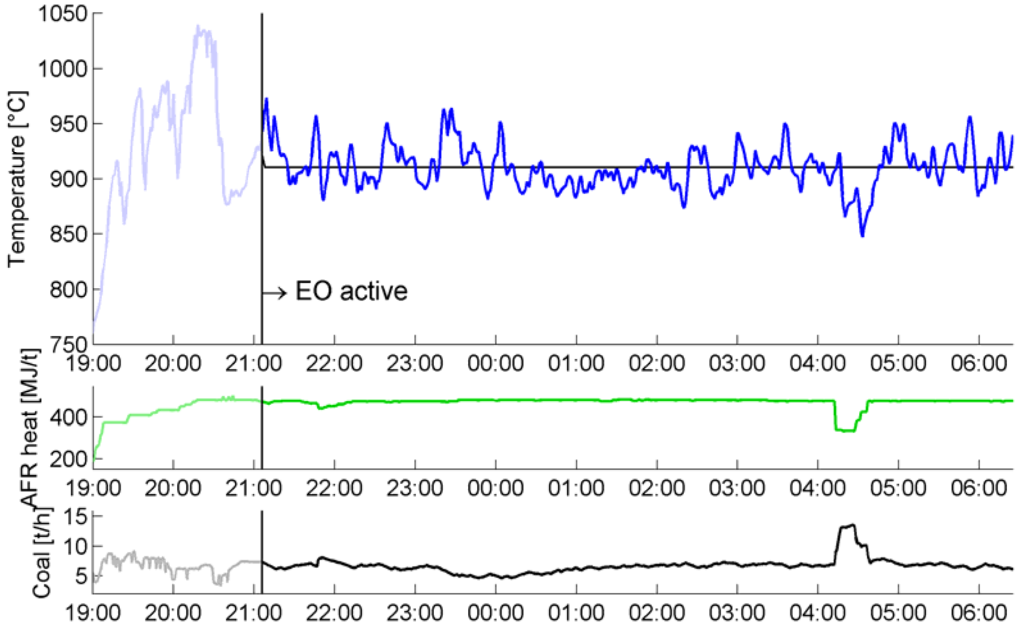

Figure 5. Typical controller behaviour.

The performance of the control system outperforms the operators. The temperature targets are better maintained and the variations from set-point are less. Obviously, the operator is occupied by other and more important tasks.
Other benefits which were also observed during the Expert Optimizer operation included lower overall energy consumption, less variability in product quality, a lowering of risk of cyclone blockage and less trips of the system due to high levels of carbon monoxide. Furthermore, due to the fact that the calciner was more stable, the kiln was also more stable and higher overall kiln production was achieved.

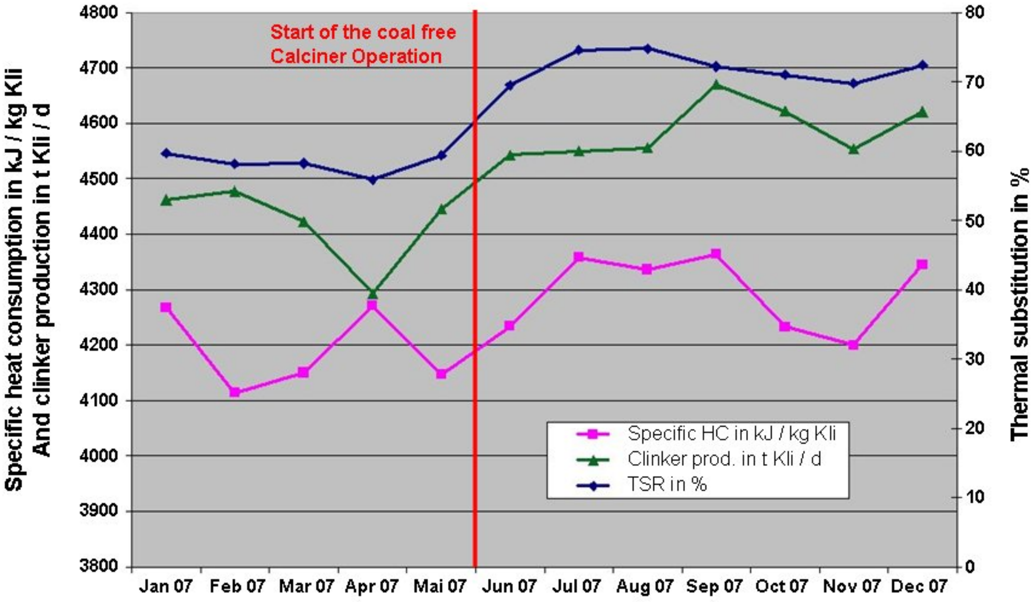

Figure 6. Clinker production, specific heat consumption and thermal substitution rate

4 Conclusion

The controller successfully stabilizes the temperature at a given target and reduces the variability of the deviation from the target. This allows the system to be operated closer to the quality limit, which is more energy efficient and decreases the risk of downtime. By using the control system less stable operating points with lower temperature targets can be achieved without risking insufficient product quality. The generally lower temperature reduces the risk of capital blockages of cyclones. Hence, the controller protects the equipment and increases uptime.
Typical benefits that plants can expect to see when their alternative fuels are under Advanced Process Optimization APC control are in the order of:

1. Increased alternative fuel use (5 % – 20 %)
2. More stable product quality (10 % – 20 %)
3. Reduced fuel costs (5 % – 20 %)
4. Lower maintenance costs and fewer pollution emissions (5 % – 20 %)

The system has been installed more than 20 times in the last 3 years providing benefits to both our customers and the environment.

5 References

1. K. E. Peray: The Rotary Cement Kiln, Second Edition, New York, Chemical Publishing Co. Inc., 1986.
2. K. S. Stadler, B. Wolf, E. Gallestey: Model predictive control of the calciner at Holcim's Lägerdorf plant, ZKG International, vol. 60, no. 03-2007, pp. 60-67, March 2007.
3. D. Castagnoli, M. Kiener and E. Gallestey: Cementing profitability, ABB Review, 4/2006, pp. 59-62.
4. E. Gallestey, A. Stothert, D. Castagnoli, G. Ferrari-Trecate and M. Morari: Using model predictive control and hybrid systems for optimal scheduling of industrial processes, at-Automatisierungstechnik, vol. 51, no. 6, pp. 285-294, June 2003.