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Energy and environmental savings via optimisation of the production process at a Spanish cement factory

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ABSTRACT

With the aim of optimising the production process at the La Robla Tudela Veguín cement factory and improving the characteristics of the final product, a statistical study has been carried out relating kiln parameters with clinker quality. The parameters that most influence the manufacturing process have been identified and correlated with quality parameters. The importance that all these parameters might have with one another has also been shown. Applying the results thus obtained has led to significant energy savings. These findings represent production advantages from both the economic and environmental standpoint, bearing in mind the tons of CO_2 which cease to be emitted to the atmosphere.

The most important parameters in clinker production have been identified, as well as those that have the greatest influence, using a PLS (Partial Least Squares Projections to Latent Structures) regression program which explains the variability of "kiln" variables (X) with respect to dependent "quality" variables (Y). An analysis of the most important X and Y variables, such as Alite and Free Lime, was carried out. It was found that a decrease in the kiln Sintering Temperature (standardized at 50 °C) yielded produced the same level of quality in the final product. This finding implies a reduction in petroleum coke consumption and a reduction in CO_2 emissions to the atmosphere, with the subsequent energy and cost savings at the factory, in addition to contributing to greater sustainability of the clinker production process.

1. Introduction

The production process at the cement factory is controlled via a system of control centre panels (Castañón, 2011). Each part of the facility is displayed, with all the kiln parameters being tracked and recorded (Huntzinger and Eatmon, 2009). The kiln parameters are stored in a database which is used to perform statistical analyses, along with the quality parameters provided by an automatic POLAB system.

The quality parameters studied are those obtained via quantitative phase analysis (QPA) of the clinker (De la Torre et al., 2002; De la Torre et al., 2003). For this purpose, a study was conducted using the Rietveld method (Esteve, 2006; Ferreira et al., 2008; Vidal et al., 2008) in conjunction with X-ray powder diffraction analysis (XRDP) (Peterson et al., 2006; Le Saoût et al., 2011). The factory laboratory has implemented a computerised system that continuously analyses the diffractograms obtained every two hours. Thanks to this quality control, the chemical and mineralogical composition of the clinker can be determined and tracked (Castañón et al., 2012). Moreover, a database has also been created that stores quality records as well as kiln parameters. Using this tool, operation of the production process has been automatically optimized in real time.

All the quality and kiln parameters stored in the database were studied using multivariate statistical models (Eriksson et al., 2006). To this end, the data are arranged in matrix form with a block of predictor variables (kiln parameters), called the X variables block, and a block of response variables (quality parameters of the clinker obtained), called the Y variables block. The rows of the matrices show the results of measurements at different instants of time (Gerlach et al., 1979). The dimensions of the matrices thus generated are accordingly very large: they can comprise thousands of rows and several dozen columns. As a result, in order to draw conclusions about the relationships between variables, it is necessary to use data reduction and pattern recognition (PR) techniques to extract the information and obtain conclusive results.

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The purpose of the method employed, PLS (Partial Least Squares Projections to Latent Structures) (Wold et al., 1987) (Eriksson et al., 2006), is to reduce the size of the matrices of the original data, X and Y, with the aim of collecting in the fewest possible components not only the variability of these data separately, but also the covariance, i.e. the variation in X which is related to Y, which will subsequently serve to predict Y as a function of X. The new variables thus generated are called latent structures and allow the mathematical treatment and interpretation of the results of the regression (Y as a function of X) to be greatly simplified, as the information contained in the hundreds or even thousands of variables that make up the X and Y blocks is concentrated and projected onto a few new variables that contain most of the information that actually relates X to Y. Furthermore, by simplifying the dimensions of the original problem, PLS can generate charts in which the internal structure of the relations between the original variables in both X and Y is clearly perceived, as is the relationship that links them with one another. As with any analytical application, the data are usually pre-processed before using PLS regression.

Once the statistical study had been carried out, we obtained the parameters that most influence the process and determined the correlations with the quality parameters and any correlation all these parameters might have with one another (Svinning et al., 2010). It is necessary to analyse each parameter individually as well as its importance in the clinker manufacturing process, analysing the optimal range to improve the process, which would lead to significant energy savings, among other aspects (Vatopoulos and Tzimas, 2012).

The amount of fuel that can be saved was calculated and the reduction in CO_2 emissions estimated (by means of GEI, 2011) (Hasanbeigi et al., 2010), which jointly represent significant savings from both an energy and environmental standpoint (Benhelal et al., 2012) (Benhelal et al., 2013).

2. Experimental

Fig. 1 shows the scheme of one of the control centre panels, in which the two elements with the greatest impact on the process, the kiln and the cooler, are represented. The three most important parameters (of the 35 recorded in the database) in the manufacture of clinker and which present the greatest influence in the statistical analysis were identified: **Sintering Temperature**, **kiln inlet NOx** and **secondary air temperature** in the cooler inlet.

The twenty-two quality parameters are identified and recorded in the database every 2 h, while those of the kiln are analysed every 5 min. In order to have an equal number of observations on the kiln (*X*) and quality (*Y*) parameters when relating them to one another, we first obtained the mean of the values recorded in the kiln every 5 min. These means were then related to the quality parameters measured every 2 h and stored in the database.

The statistical study and the study of the parameters were conducted between 27 March 2010 and 30 September 2010. The final number of data was obtained after eliminating downtimes at the factory, kiln start-ups and short stoppages for maintenance work. After completion of the selection process, a total of 1149 observations were obtained.

Once pre-processed in a program designed to perform calculations with vectors and matrices, namely Matlab® version 7.0.1 for Microsoft Windows (Mathworks, Natick, MA, USA), the data were imported into the SIMCA-P+ program (version 12.0.0.0, Umetrics AB), which automatically classifies the different variables. The PLS model was then studied. The main purpose of this model is to see how different input variables (X) influence the measured quality variables (Y). The ultimate goal is to obtain a good quality final product (Y) by means of slight modifications of X, i.e. maintaining quality while reducing the final cost.

After obtaining the kiln parameters that most influence clinker quality, the optimal intervals to improve the process were studied. The Sintering Temperature, which is the highest temperature reached by the clinkering process in the kiln (1250 °C minimum and 1450 °C maximum), was studied along with two of the most important quality parameters, namely Alite (C_3S) and Free Lime. The values of the two quality parameters were studied according to temperature ranges to obtain the percentages in each period.

Finally, the energy and environmental savings were calculated, constituting the result of this study (Chen et al., 2010).

3. Results and discussion

After testing different statistical models using the SIMCA program, the study focussed of the 23 furnace parameters considered most influential and also on the eight most important parameters of clinker quality, as shown in Table 1.

An 8-component model is obtained with an $R^2 = 0.58$ and $Q^2 = 0.55$. As the values of R^2 and Q^2 are greater than 0.50, which is considered a good model, it is possible to predict what values should be assigned to *X* for a given value of *Y*. A loading plot (Fig. 2) is generated which shows the weights of the first component of this model compared to the second. These weights show which variables make a greater contribution to the PLS regression model and also which variables present a better relationship with one another. That is, the loading plot shows which kiln variables, *X*, will have a greater influence (will present a higher correlation) with a particular quality variable, *Y*.

The parameters with the most weight in the model are those which are farthest from the origin. These may be positively

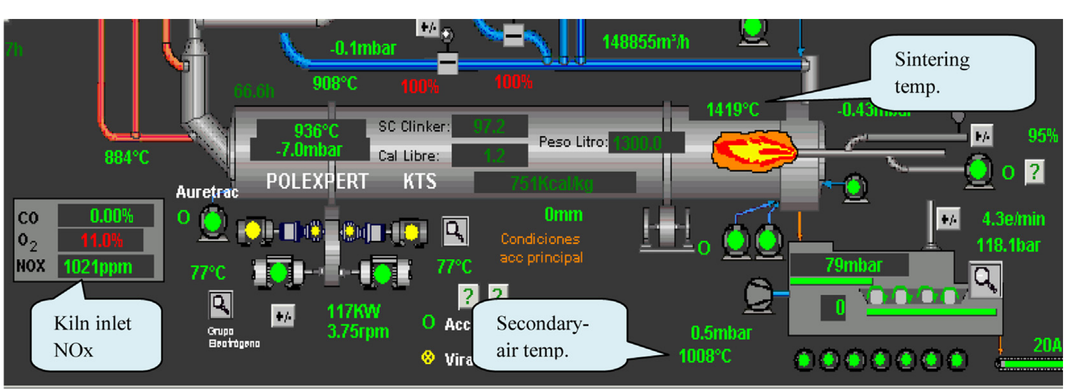

Fig. 1. Sintering kiln and cooler. Location of the three most influential parameters in the kiln.