Automated sample preparation in a cement plant- Part I: From quarry to the raw mill

Abstract

This application note is the start to a series of publications to explain the importance of correct sampling and sample preparation within the cement production process. Topics covered by this application note are a brief explanation about the raw material situation at cement plants, raw material sampling, manual sample preparation and fusion using high frequency technology. The application note is concluded with an outlook to Herzog´s newly developed raw mix calculation software within the PrepMaster Analytics suite.

Key words

• **Raw materials** • **Crushing** • **Grinding** • **Fusion** • **Raw mix calculation** • **Model predictive control**

Raw materials and sampling

Cement production starts with the claim of the raw materials. Depending on the local situation different raw materials for the production of cement are available. In general, limestone is the most important raw material, followed by clay, sand and components of minor importance such as iron ore and bauxite. When looking at a ternary chemical plot (Fig. 1) with CaO, SiO_2, and Fe_2O_3 and Al_2O_3 at the tips of an equilateral triangle it is clearly visible that cement is a very Ca-rich material. In Figure 1 not only the chemical composition of clinker is shown but also the chemical composition and variability of the most important natural raw materials.

Unfortunately, nature does not provide a raw material with the chemical composition needed for cement production (with the exception of a local resource in Beckum, Germany). Therefore, there is only one solution: The plant has to mix different raw materials.

Nowadays, many cement plants use secondary raw materials derived from industrial waste as well. Especially in developed countries raw materials are scarce while recycling and usage of waste materials are a requirement and bring a financial benefit. This is why many different raw materials have to be blended in order to match the required chemistry.

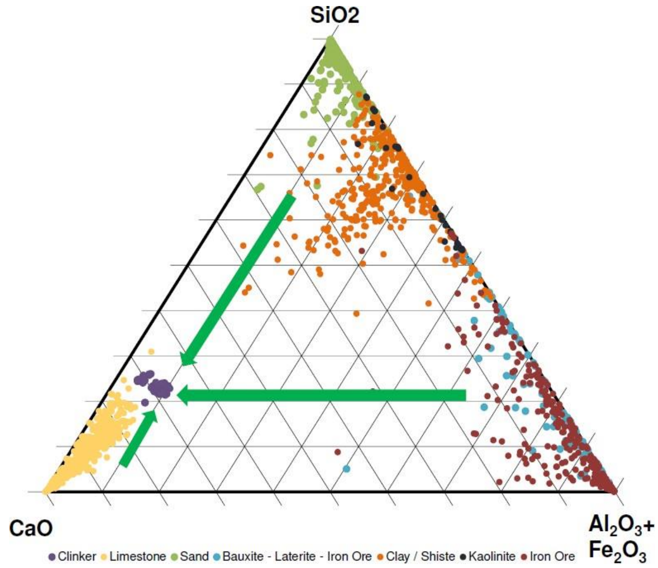

Figure 1: *Ternary chemical plot of* CaO, SiO_2, Fe_2O_3 and Al_2O_3 with common raw materials for cement production.

To mix the raw materials in a proper way two prerequisites have to be fulfilled:

• First of all, the chemical composition of each raw material must be known.

• The chemical composition of the raw material should be constant or the variations have to be monitored (i.e. by analysis of blast hole samples).

Therefore, sampling of raw materials for later chemical analysis is mandatory. This is also the step where most of the analytical errors arise from. (Fig. 2)

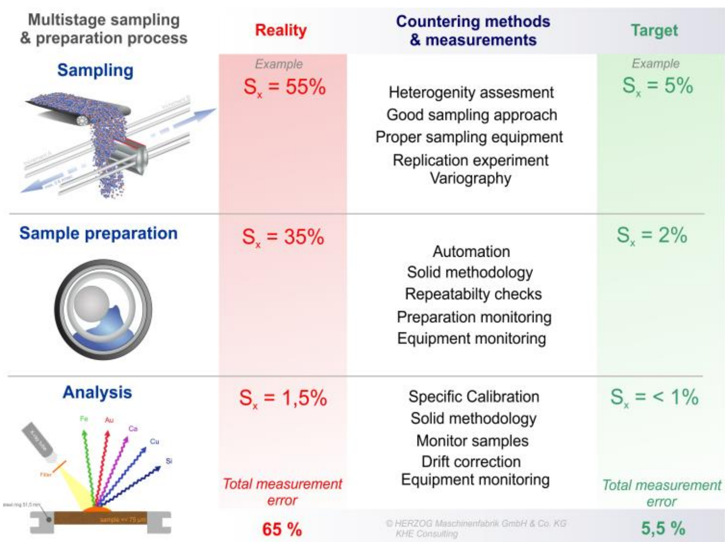

Figure 2: *The total analytical error of a measurement is composed of sampling, sample preparation and the analysis itself.*

Despite the possibility to induce a high analytical error due to wrong sampling it is usually not paid enough attention to this aspect in the analysis of materials. Correct sampling is a theory of itself and the interested reader is referred to the state-of-the-art review provided by the paper from Kim H. Esbensen: “Introduction to the Theory and Practice of Sampling” [1].

To give a short summary, the most important aspects of sampling are as follows:

1. How heterogeneous is your sample? Take a larger sample if heterogeneity is significant.

2. What is the particle size of the sampled material? The coarser the sample the larger the sample must be.

3. Take all samples at least in duplicate to cross-check results.

Sample preparation and fusion

Once the sample has been correctly taken the reduction of the particle size is the first step of sample preparation. For this purpose a jaw crusher (e.g. HSC 590) is the best choice (Fig. 3). Modern crushers reduce the particle size below 2 mm. This step is quite important as only a small particle size allows the next step in sample preparation: mass reduction. Key factor in reducing the size of a sample is to create a representative sub-sample. Representativity can only be achieved if the crusher produces a final particle size of smaller than 2 mm.

Subsequent sample mass reduction is achieved by splitting the sample using a rotary splitter or a riffle splitter.

Once a representative sub-sample has been established the particle size must be reduced to < 64 µm. Grinding can be performed in a vibratory disk mill, e.g., by using Herzog´s HP-M 100 (Fig. 4). The grinding parameters have to be adjusted to the specific properties of the sample. Overgrinding will cause the formation of agglomerates and impair cleaning of the grinding tools as material may stick at the surface of the grinding vessel and set.

Figure 3: *Herzog jaw crusher model HSC 590 for crushing of material with a particles size of 90 mm or smaller.*

Figure 4: *Herzog semi-automatic vibratory disk mill model HP-M 100 used for grinding of cement-related and other powder materials.*

Subsequently, the finely grained sample is ready for further processing steps. This can be either pelletizing into rings for pressed pellet analysis or mixing with flux for fused bead preparation. In this application note, we will discuss the latter technique. For cement applications, common fluxes are lithiumtetraborate, lithiummetaborate and mixtures of both. Typical sample: flux ratios range from 1: 6 until 1: 10.

Once the flux has been dosed the sample is ready for fusion. A fast, safe and reproducible fusion process is a requirement for XRF analysis. The Herzog Bead One HF is equipped with a high-frequency furnace allowing many different heating options. The heating process of the furnace is controlled via a pyrometer measuring the temperature of the crucible.

Figure 5: *Semi-automatic fusion machine model Bead One HF used for production of glass beads from a wide range of different powder materials.*

Herzog has developed a method to correct the pyrometer temperature by calibrating the crucible with the pyrometer [2], [3]. In this approach, the temperature within the melt is measured simultaneously with the pyrometer temperature using a thermocouple. At two different temperature stages, the emissivity value is adjusted until the pyrometer temperature is aligned to the actual temperature. As for a narrow temperature range an almost linear relationship between the temperature and emissivity can be assumed, the emissivity values between the two measured temperature stages can be calculated.

This procedure takes only a few minutes of time but guarantees a temperature control of +/- 5°C which is by far more precise than any fusion system operating with gas or resistance furnace.

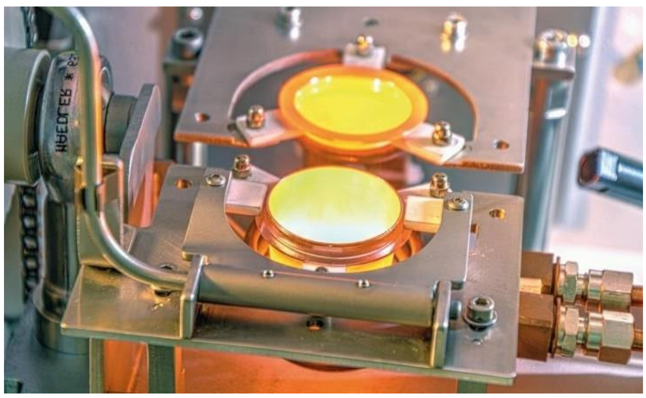

Figure 6: *Fusion unit in the Bead One HF. The high-frequency system allows a separate heating of the crucible and the casting dish.*

Analysis and data processing with raw mix calculation

The precise temperature control is reflected in low analytical errors of the analyzed fused beads. A study similar to ISO 29581-2 (Fig. 7) carried out by Mehling et al. (2020) [4] using cement reference samples clearly points out that the deviation for all elements falls within the expert level. This study has been carried out using the fully-automated fusion system HAG HF with high-frequency furnaces.

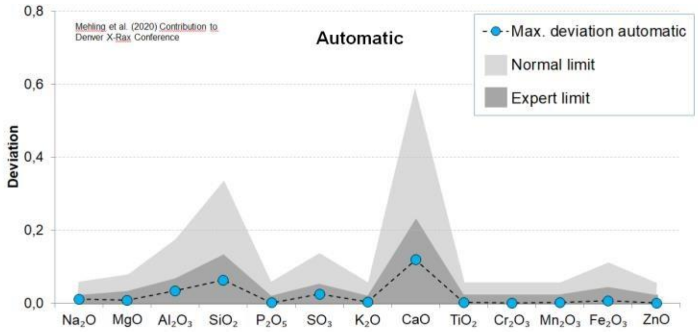

Figure 7: *Results of precision test according to ISO 29581-2 (Mehling et al. 2020).*

High-precision XRF analysis is the key to sufficient process control in cement plants. As stated before, one of the most crucial steps in plant control is the correct mixture of raw materials. Herzog just recently developed an additional module for its PrepMaster Analytics software package where raw meal and cement blending is implemented. Within the next paragraph this novel product is discussed briefly.

Smart cement software solution with many advantages

Raw meal analysis and given raw material chemistry are applied to calculate set points for each individual raw material belt feeder. The user simply defines his target chemistry for the raw meal by using the cement moduli LSF Lime Saturation Factor) , SM (Silica Modulus) and AM (Alumina Modulus). Further constraints like feeder limitations or raw material availability can be taken into account to calculate a raw mix composition to the plant´s needs. Once the set points for the individual belt feeders have been calculated the software will automatically adjust the feeder values. The effect of the belt feeder changes will become visible in the subsequent raw meal analysis. The speed at which changes become apparent depends on the plant layout. The software will take into account the delays until changes of belt feeder are getting effective. This procedure prevents the software from overriding the target which might result in a high oscillation of the raw meal chemistry.

The advantages for the cement production process are manifold ranging from lower fuel consumption or higher alternative fuel substitution rate to more stable and smooth kiln operation. This, in turn, leads to less thermal stress on kiln parts, such as lining, resulting in fewer and shorter kiln stops.

Model Predictive Control algorithms for a reliable production

Herzog´s raw mix and blending software relies on state of the art model predictive control (MPC) algorithms. MPC is an advanced method of process control which can be used in many industrial production processes. For setting up MPC in a cement plant, a model of the raw meal production process has to be established. This model includes many variables like frequency of sampling, time of analysis or retention time of raw meal within the mill. The great advantage of MPC against classic PID controllers is the ability of the MPC to anticipate future events and to take countermeasures.

The theory behind MPC is based on iterative, finite-horizon optimization of the before established plant model. At a certain point of time, the raw meal is sampled and analyzed and the optimal raw mix composition is calculated according to the pre-defined setpoints (LSF, TM, AM, Cost of raw mix, CO2 emission) for a time horizon in the future (t+tn) by using Euler-Lagrange equations. As soon as the next raw meal sample will be analyzed the calculated model for t+tn will be updated and the prediction horizon will be shifted a step more into the future tn+1.

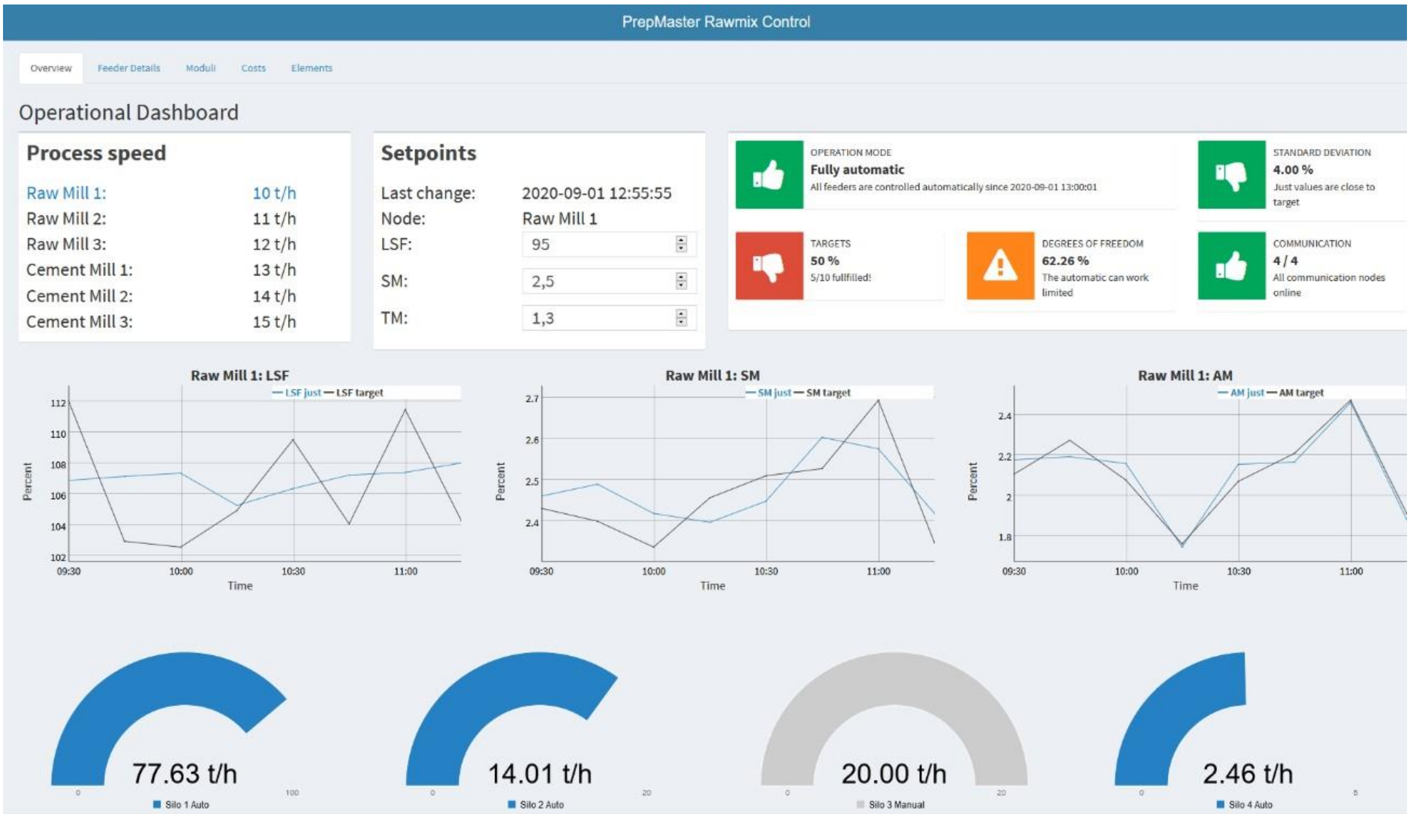

Figure 7: *Operational dashboard of PrepMaster Analytics raw meal control.*

The raw mix and cement blending software is embedded into Herzog´s PrepMaster Analytics suite (Fig. 7). The dashboard of the blending software provides all relevant information for process control: The defined set points of the mill of interest, standard deviation over a dedicated time period, and a graphical illustration of the belt feeder values as well as graphs of actual and target values of the cement moduli (LSF, SM, AM) of the raw meal. As a matter of course, more detailed views on individual feeders are available as well.

The design of the software is flexible and can be adjusted to the customer's needs.

References:

[1] Kim H. Esbensen: Introduction to the Theory and Practice of Sampling

[2] HERZOG Application note 24/2019: Pinpoint temperature control in induction fusion

[3] HERZOG Application note 23/2019: Novel technology for enhanced temperature control in induction furnaces

[4] A. Mehling et al. (2020) Contribution to Denver X-ray Conference

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