SUMMARY

Over the years, raw material handling in the cement industry is becoming more and more challenging. The deposits – especially of long-running plants – are becoming more variable. This leads to an undesirable uncertainty for the people responsible for the product quality at plants, regarding the requirement of consistent product quality. Therefore there are methods to try to predict the chemical composition of variable raw materials in the quarry with borehole analyses, but most of the time, these deliver only a rough indication of the real composition and are sometimes even misleading. As a result, many plants rely on physical belt samplers, which take samples from the conveyor belt after the crusher. There are basically two ways of using the data, either by taking samples from each zone while crushing and using these data for the next blending bed calculation or by sampling continuously and analyzing one sample each hour. The first approach has the disadvantage of not being able to react on the current blending bed, as the chemical composition will only be available, when no more action can be taken. The method of immediately analyzing the sampled material after about each hour has the advantage of being able to react on variability, but a big problem is the representativeness of the data. In the past CEMMAC, a Slovakia cement plant, used a belt sample and analyzed one sample every hour, but according to their experience, the delivered values were rather uncertain, as physical preparation of the sample with a spinning cup favours the fine silica fraction over the coarse lime fraction. This resulted in a lower measured LSF value on the belt than it actually is on the blending bed. Therefore, plants with variability in the quarry and plants planning to use variable alternative raw materials on the blending bed require an online measuring system together with powerful software managing the available resources to achieve the moduli targets on the blending bed, while using all available raw materials. The contribution shows the benefits of the quarry management by ABB’s preblending software based on data from the SpectraFlow Online Analyzer installed at the CEMMAC cement plant in Horné Snie, Slovakia.

((English text supplied by the authors))
Real time quarry and stockpile optimization
Echtzeit-Rohmaterialgewinnung und Mischbettoptimierung

1 The technology

1.1 The Expert Optimizer Expert System
At the CEMMAG cement plant in Horné Srní, Slovakia, ABB installed an Expert Optimizer expert system with the raw material blending strategy. The software uses MPC (Model Predictive Control), the most advanced mathematical method for process control on the market. Based on the online data of a SpectraFlow analyzer, the average stockpile composition and LSF value is calculated by the software. The task is to calculate the material demand from the different quarry sections. Based on these calculated demands, the software has to schedule the trucks to deliver the requested material. Basically the expert system takes on the role of the quarry manager.

![MPC based control approach](image)

Figure 1: The principle of Model Predictive Control (MPC)

1.2 ABB SpectraFlow Analyzer based on SOLBAS™ technology
The online data are delivered by the SpectraFlow Analyzer. The SpectraFlow CM100 uses the SOLBAS™ (Save On-Line Bulk Analyzer System) technology, which is based on the unique environmentally friendly Near Infrared (NIR) technology for analyzing the material. When high-intensity infrared light hits matter the molecules in the matter start vibrating. The molecules can take six different movements and each molecule with a specific movement has a characteristic frequency. Due to the vibration of the molecules, the crystal structure of the material also starts vibrating and adds mineralogical information to the spectrum. The result is a spectrum from 350 to 2500 nm, a unique spectral range in NIR analysis, containing all molecular and mineralogical information about the material that passes underneath the analyzer (Fig. 2).

The analyzer was calibrated with sample material from the customer. The samples represented the full range of material that would be analyzed later on. In NIR a mathematical analytical model is created to represent the reality.

The analytical model was developed using the standard method of partial least square multivariate linear regression (PLS1). This means a sufficiently large training set, in the actual case 50 customer samples, were used. The key constituents CaO, SiO₂, Al₂O₃ and Fe₂O₃ were modeled for the LSF control (Table 1). MgO, K₂O, SO₃ and Cl were modeled for information purposes only. Moisture was modeled to calculate the dry material composition. For each of the constituents a separate model was compiled using PLS1 with tailor-made preprocessing to optimize the respective constituent.

While acquiring the training sample spectra, their potential moisture content was systematically taken into account by taking spectra starting with completely dry samples and systematically adding water until the samples were saturated with water. A moisture range from 0 to 10 % was incorporated in the analytical model. Mixing the training samples took into account the effect of statistical variation of the position of the individual training sample member. Every 100 milliseconds the analyzer acquires a full spectrum. Spectra are accumulated over one minute and the average minute analysis is reported.

2 The situation at the CEMMAC plant
The quarry of the CEMMAC plant (Fig. 3) consists of two different types of marl. Marl 1 (red) is quite stable at about LSF 100 to 120 while Marl 2 (green) is very variable from LSF 20 up to about LSF 90. The high-grade limestone (orange) is pure and quite stable. The time needed for the trucks to travel from the crusher to the Marl 2 quarry, to be filled...
up and to return is about 20 to 25 minutes, while the total traveling time to the Marl1 and limestone quarry is about 10 to 15 minutes as both raw materials are mined from the same quarry but from different locations.

The crusher has a capacity of about 100 t/h. After the crusher, the material is transported towards the circular blending bed. The SpectraFlow Online Analyzer and the belt weigher are situated before the physical sampling station on the first transfer point between the crusher and the blending bed.

The circular blending bed has a capacity of about 30000 t of raw material. It is continuously built up and reclaimed. The LSF target on the blending bed was 80±5.

The task for the CEMMAC plant was to:

- reduce the LSF variations on the blending bed to ±5 of the target value
- maximize the use of the highly variable Marl 2
- retain a high throughput at the crusher
- operate in the given constraints.

3 The solution

3.1 The operation before the optimization project

Before the implementation of ABB’s SpectraFlow Analyzer (Fig. 4) and Expert Optimizer, the operator at the crusher based his decisions regarding how to schedule the trucks on the results of the physical belt sampler, which provided the operator one value at approximately each hour. The first task for the operator was to combine this value with the amount of material passed and then to integrate all the values, in order to know the actual chemical composition of the blending bed. Although this was quite hard to do manually, it was feasible. However the task for the operator became impossible to solve in cases when the chemical composition of one zone used was unstable. With the variable Marl 2, this happened very often and then the operator was faced with a great many difficulties in achieving the LSF targets on the blending bed. This was the case, when

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Range [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>2.5 to 43</td>
</tr>
<tr>
<td>CaO</td>
<td>15 to 54</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0 to 15</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0 to 6</td>
</tr>
<tr>
<td>MgO</td>
<td>0 to 3.3</td>
</tr>
<tr>
<td>Moisture</td>
<td>0 to 10</td>
</tr>
</tbody>
</table>

Table 1: The calibration ranges of the oxides [%]
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Marl 2 suddenly had an LSF above or near the target of the blending bed. The operator tried to bring down the LSF with more Marl 2, as he assumed the LSF of Marl 2 was low, which it was not. Then the LSF on the blending bed increased rapidly and ruined a sector on the blending bed.

Marl 2 suddenly had a very low LSF of 20 or less. The operator was using Marl 2 to reduce the LSF on the blending bed, however if Marl 2 had a LSF of 20, the LSF on the blending bed was decreasing rapidly and the use of Marl 2 had to be reduced. Another option was that the very low Marl 2 was blended with a higher Marl 2.

If any of these things happened, the operator had to wait for an hour to get the new value from the sampling station. Then he had to decrease/increase the LSF-value over the next hour, without knowing the upcoming changes of the material. The material throughput over an hour is about 350 t and therefore the LSF on the blending bed started to have a huge variation and it ended in a kind of swinging.

The core of the optimization is ABB’s SpectraFlow Online-Analyzer based on the SOLBAS™ technology, which continuously measures the chemical composition of the material going onto the blending bed, while the belt weigher simultaneously measures the massflow. Therefore the mass of all material with its chemical composition is available in real time. These data were fed to the Expert Optimizer. First the Expert Optimizer integrates the processed material and evaluates the actual LSF of the material on the blending bed. According to this information, over the next 180 t, the system evaluates the LSF required and decides which zones are needed. The Expert Optimizer shows the operator how much material from which zone will be required over the next 180 t and the operator can then coordinate the trucks according to this information.

### 3.2 Which information does Expert Optimizer need from the operator?

As all zones are not always available, one zone should be prioritized or the trucks are out of order, the operator is able to give the system certain constraints. Therefore he can choose the minimum and maximum use of each zone or completely disable the use of a certain zone.

The operator can choose two or three different zones. He has to inform the Expert Optimizer in the Material Data Table about the approximate chemical composition of each zone. This information does not have to be accurate, the only requirement is that one zone is below the target LSF value on the blending bed and one above, which is obvious.

### 3.3 Example of control

An example shows how the Expert Optimizer controls the LSF value on the blending bed (Fig. 6). It will be assumed that all three raw materials should be used: Marl 1 with an approximate LSF of 100, Marl 2 with an approximate LSF of 30 and the pure limestone with an LSF of over 500. The target on the blending bed is LSF 90. The Expert Optimizer calculates the first material of 180 t based on the information on the Material Data Table. This calculation is quite easy. Then the Expert Optimizer shows the demand of each zone on the operator’s screen. Additionally the Expert Optimizer generates a plan for the trucks. It is a constraint that the truck distribution in the quarry is not changed too often, as this is logistically difficult.

After the delivery of the requested material, the SpectraFlow continuously measures the chemical composition of the material processed onto the blending bed and calculates the actual LSF. The LSF would be right on the target of 90, if all the material had exactly the chemical composition in the Material Data Table and the trucks were able to deliver any amount of material, however, that will never be the case as the zones are variable and there are only two different sizes.
of trucks. It was assumed that the variable Marl 2 did not have an LSF-value of 30, but 60, therefore the LSF on the blending bed is higher than 90, e.g. 95. For the next hourly material charge of 180 t, the Expert Optimizer will decrease the LSF and will request more Marl2, which will lead to an LSF of closer to 90, when the LSF of Marl 2 is still around 60. If the LSF of Marl 2 is changing e.g. decreasing for example to 20, then the LSF of the blending bed will drop below 90 and the Expert Optimizer will request less Marl 2 and more limestone.

It is now becoming obvious, that no accurate information about the chemical composition of the raw materials is necessary as the system acquires the actual chemical composition of the materials online. The information given by the operator in the Material DataTable to the Expert system is only an indicator, if the material should be used to decrease or increase the LSF-value on the blending bed. Furthermore it is clear, that if in the Material DataTable the operator inputs an LSF below the target on the blending bed, although it is actually above it, then the Expert System could run into an infeasible situation, as when the LSF on the blending bed is above the target, the system will request more of the low material, which is actually above the target. Therefore the LSF-value will further increase on the blending bed and the system will even request more of the low material.

### 4 Final results

The installation at the CEMMAC plant (Fig. 7) is now in full operation as the final acceptance test was carried out in December 2009 and January 2010. The target of the acceptance test was to verify the ability of the Expert System to build up a blending bed in the narrow ranges of LSF 80 ±5.

The acceptance test should prove, that the LSF-value was over 40 000 t of raw material in the accepted range. The blending bed was separated into sectors of 2500 t each, therefore 16 sectors were tested. Two test sets were made of eight sectors each. It was agreed, that each test set could have one outlier. However only one outlier was accepted to be free, whereby one outlier to be in the range of LSF ±10. To evaluate the actual LSF-value of the blending bed, the additives on one of the two raw mills were stopped for four hours, while the relevant samples were taken after three and four hours. The average of these two samples was the value of the sector tested and had to be in the range of 80±5.

The results (Table 2) show, that 14 out of 16 sectors were in the narrow bend of an LSF-value between 75 to 85, whereby one was slightly out and one was far to low. However it has to be mentioned, that at the time, when a value far too low was observed, there were problems with the outcome of the silo before the raw mill. A kind of segregation was observed, where after the low material, a sudden rush of high LSF-value material followed. The operators at the raw mills reported, that this kind of thing always happens, when high humidity combined with freezing temperatures block the material in the silo.

### 5 Outlook

In the future, CEMMAC is planning to use alternative raw materials, which can be incorporated into the mix on the blending bed. The plant is currently investigating potential suppliers, as the variability of the material no longer matters. Therefore it is planned, that the model of the SpectraFlow Analyzer will be expanded to wider ranges of existing constituents or new constituents might be added.

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### Table 2: The results of the acceptance test (LSF Target = 80; ABB performance guarantee = ±5)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Mill</th>
<th>LSF</th>
<th>Dev. All</th>
<th>Result</th>
<th>Dev. Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.12.09</td>
<td>13:59</td>
<td>OM2</td>
<td>82.20</td>
<td>2.20</td>
<td>Passed</td>
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<td>22.12.09</td>
<td>12:07</td>
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<td>OM2</td>
<td>84.30</td>
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<td>06.01.10</td>
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<td>Average deviation over 40 000 tonnes -0.69 Passed -0.28</td>
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