Excerpts from the thesis,

REFLECTANCE SPECTRUM ANALYSIS OF MINERAL FLOTATION FROTHS AND SLURRIES

Submitted by Olli Haavisto as:

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The following excerpts were selected to provide a short overview of the most excellent and comprehensive paper of Olli Haavisto.

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ABSTRACT
The global demand of mining products has increased during recent years, and there is pressure to improve the efficiency of mines and concentration processes. This thesis focuses on froth flotation, which is one of the most common concentration methods in mineral engineering. Froth flotation is used to separate valuable minerals from mined ore that has been crushed, mixed with water and ground to a small particle size. The separation is based on differences in the surface chemical properties of the minerals. Monitoring and control of flotation processes mainly relies on the on-line analysis of the process slurry streams. Traditionally, the analysis is performed using X-ray fluorescence (XRF) analyzers that measure the elemental contents of the solids in the slurries.

The thesis investigates the application of visual and near-infra-red (VNIR) reflectance spectroscopy to improve the on-line analysis of mineral flotation froths and slurries. In reflectance spectroscopy the sample is illuminated and the spectrum of the reflected light is captured by a spectrograph. The main benefits of VNIR reflectance spectroscopy with respect to XRF-based analysis are the relatively low cost of the equipment required and the easy and fast measurement process. As a consequence, the sampling rate of the reflectance spectrum measurement is radically faster than in the XRF analysis. Data-based modeling is applied to the measured VNIR spectra to calculate the corresponding elemental contents. The research is conducted at a real copper and zinc flotation process.

The main results of the thesis show that VNIR reflectance spectroscopy can be used to measure temporal changes in the elemental contents of mineral flotation froths and slurries in the analyzed process. Especially the slurry measurements from the final concentrates provide accurate information on the slurry contents. A multi-channel slurry VNIR analyzer prototype is developed in this thesis. When combined with an XRF

analyzer, it is able to measure the slurry lines with a very fast sampling rate. This considerably improves the monitoring and control possibilities of the flotation process. The proposed VNIR analyzer is adaptively calibrated with the sparse XRF measurements to compensate for the effect of changes in other slurry properties. The high-frequency slurry analysis is shown to reveal fast grade changes and grade oscillations that the XRF analyzer is unable to detect alone. Based on the new measurement, a plant-wide study of the harmful grade oscillations is conducted in order to improve the performance of the flotation process.

Page 11:
The economic effect of the on-line analysis in flotation plants has been investigated for example by Cooper (1976), and the importance of the analysis accuracy by Flintoff (1992). In addition to accuracy, Remes et al. (2007) studied the influence of analysis and sampling rate on the flotation control. They showed that the economic performance of a flotation process is significantly dependent on the sampling rate of the analysis, since faster sampling enables faster control actions as well.

Page 51:
Another difficulty is the rather long temporal and spatial distance between the two measurements. As it turned out later with the slurry VNIR measurements (Publication II), the slurry grades typically contain high-frequency variations with a considerable amplitude. This means that the precise synchronization of the VNIR and XRF measurements is of utmost importance in order to form an accurate model for the slurry grades. However, the measurement setup used in Publication I prevents the proper determination of the time delay between the VNIR and XRF analyzers, since the zinc concentrate is transferred through slurry pipes and a pump sump before it is sampled for the XRF assay. In addition, the changing slurry flow speed causes the delay to vary.

Page 52:
At the same time, the measurement principle where slurry is flowing through a jet flow cell and the VNIR reflectance spectrum is acquired through the cell window is demonstrated to work.

Page 53:
The algorithms clearly improve the accuracy of the VNIR assay in the case of sudden increases of the copper content, while the performance during normal operation remains at the same level as with the regular rPLS model. The importance of the result is that it enables the rapid detection of process failures, which should be dealt with as soon as possible to prevent financial losses in the form of reduced concentrate quality or valuable minerals lost in the tailings.

An advantage of the reflectance spectroscopy is the fast sampling of the spectra as opposed to the XRF analyzer with a sampling interval of around 10–20 minutes. The froth and slurry VNIR spectra were sampled every five to ten seconds in all the measurements of this work, which together with the up-to-date calibration model enabled the calculation of the high-frequency assay. Already in Publication I the froth is assayed from the dense VNIR measurements in order to fill in the gaps between the sparse XRF analyses.

Page 55:
The main observation that can be derived from the obtained high-frequency assay is that the elemental contents of the slurry at Pyhäsalmi can contain significantly large short term changes that cannot be detected by the XRF analyzer alone. During the period illustrated in Figure 7.1, a major zinc grade drop takes place. However, the high-frequency peak-to-peak amplitude of the zinc grade is as large as two percentage points. Based on this result, the following observations can be derived:

- Accurate synchronization of the XRF and VNIR sampling is crucial to obtain
- reliable data for multivariate regression calculation. As demonstrated in Publication II, already a temporal difference of 20 seconds between the two sampling methods significantly decreases the modeling performance
- XRF analyzer assay is only an instantaneous sample of the slurry grade, and
- thus does not necessarily accurately match with the more averaged slurry contents. The low-pass filtered VNIR assay, on the other hand, captures the longer term grade changes reliably.
- The discussion about the deficient sampling in froth VNIR analysis (Section 7.1 and Publication I) is supported by the slurry results. A more precise calibration sampling would most probably improve the accuracy of the froth VNIR analysis as well.

As a result of the work described in this thesis, the high-frequency VNIR assays of the most important elements (zinc, copper and iron) of the final copper and zinc concentrate slurries are in continuous use at the Pyhäsalmi concentration plant.

Page 56

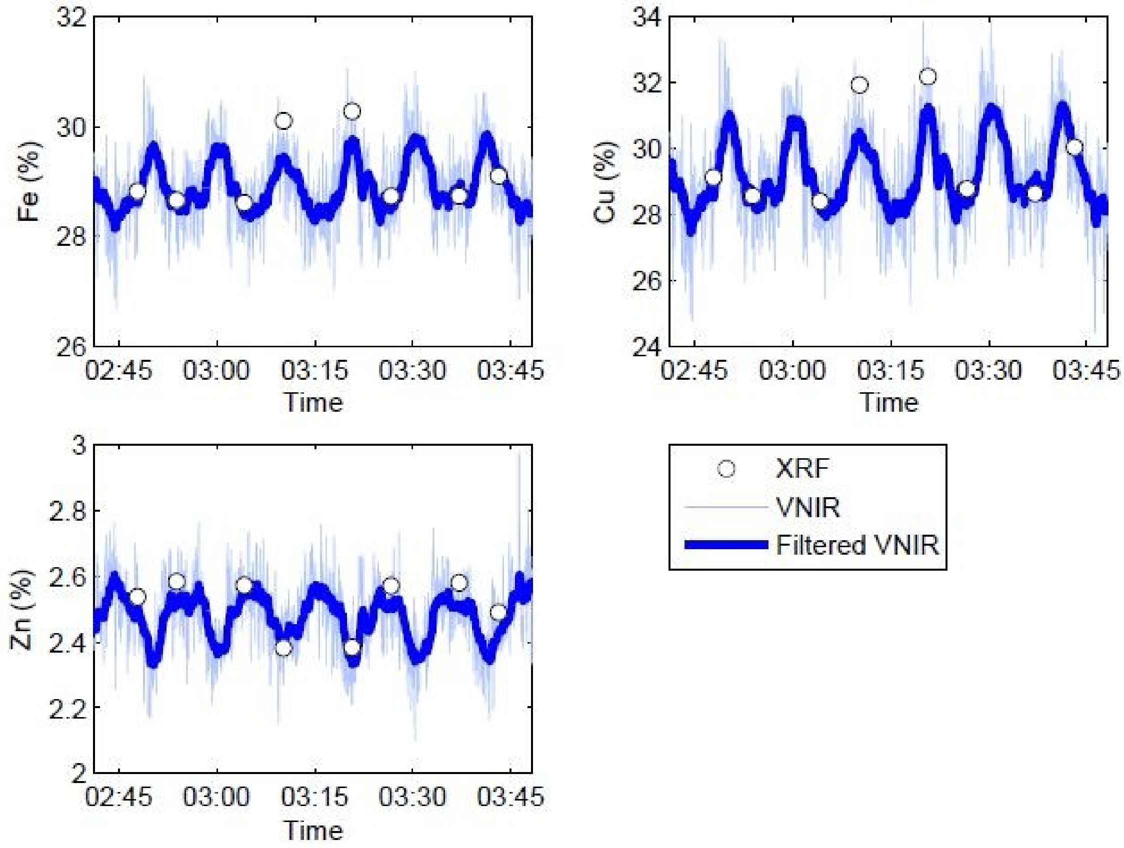

Figure 7.2: The high-frequency VNIR assay reveals well the grade oscillations in the final copper concentrate. (Reproduced from the data used in Publication V)

Feedback from the operators indicates that the most important benefit of the new assay is the reduced sampling interval: for example, the high-frequency assay shows the response to manual control actions more rapidly than the XRF analyzer.

In general, oscillations in industrial processes reduce the process performance and indicate that the process is not optimally controlled. In Publication VI, the applicability of the high-frequency VNIR assay is demonstrated by analyzing the oscillations detected in the copper assay of the final copper concentrate. The target of the research is to pinpoint the cause of the oscillations and to return the process back to steady operation.

The oscillatory analysis was based on the rSSA algorithm which estimates the on-line structure of the process signals. The results show that during the oscillations, structurally the most similar signal to the final copper grade is the flow rate of the final concentrate. However, the same oscillatory structure is found also in other parts of the process. The most probable cause is narrowed down to the level control of the second cleaner stage, where the oscillating slurry level causes periodical grade changes to the feed of the final cleaner stage. Moreover, the oscillations are transmitted to other parts of the circuit by the tailing slurry feedbacks.

Page 59: CONCLUSIONS

This thesis focused on the application of VNIR reflectance spectroscopy to the analysis of mineral flotation froths and slurries. The main objective was to determine if the reflectance spectral information could be used to improve the elemental assaying of the flotation slurries. Mineral flotation is one of the most commonly used concentration methods, and the analyses of the slurry contents in the different parts of the process form the basis for the monitoring and controlling of a flotation plant.

Initially, VNIR spectra of the froth in a final zinc concentrate cell were measured and a data-based model was estimated to connect the spectra to the elemental contents of the final zinc concentrate slurry. The model was able to predict the elemental contents, and slightly better results were obtained with the VNIR measurements than with the RGB data obtained from the froth camera. However, the later study of the slurry VNIR spectra indicated that more accurate modeling would be possible if the quality of the calibration samples could be improved.

The main contributions of the thesis were obtained from the VNIR reflectance spectrum analysis of the flotation slurries. Several on-line measurement device prototypes were developed during the work, and it was shown that in the studied copperzinc flotation process the VNIR spectra of the concentrate slurries accurately correlate with the elemental contents. Since the VNIR spectra can easily be measured with a short sampling interval (five to ten seconds) as compared to the XRF analyzer, where the sampling interval is around 15 minutes, the assay interval of the slurries can be radically reduced by predicting the elemental contents from the VNIR spectra.

It was detected, however, that a fixed calibration model does not adequately capture the changes in the slurries for longer time periods. Instead, adaptive updating of a recursive PLS model with the XRF measurements was necessary in order to utilize the spectral measurement in real process applications. As a result, the developed VNIR slurry analyzer uses both VNIR and XRF measurements to generate a highfrequency slurry assay. The disadvantage of the adaptive calibration is that the VNIR measurement is not capable of operating on its own for longer periods of time. On the other hand, the advantage is that the assay is robust to even large variations in the mineralogy, particle size distribution and other properties of the processed ore which typically hinder the analysis of flotation processes.

End of excerpts

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