Improved efficiency of copper, iron and nickel ore processing with MAYA online elemental analyzers

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ABSTRACT

Variations in mineralogy and the presence of impurities, not only influence on the effectiveness of the processes, but also increase production costs. Online chemical analysis of material streams directly on site is critical for timeous interventions to improve process performance, remove impurities at earlier stages, decrease consumption of raw materials, water, reagents and energy, as well to reduce the time and labor costs normally associated with the conventional laboratory analysis.

Lyncis, using knowledge and experience accumulated in the mining and industrial applications, offers the solution for stable accurate online measurements of ores and minerals under production conditions, where many factors such as mineralogy, grain size, moisture, etc., influence results. The wide range of chemometric and optimization techniques are used to ensure stable accurate measurements in a real-time mode.

The MAYA analyzers are based on safe LIBS technology (Laser Induced Breakdown Spectroscopy) and require easy and low-cost maintenance. Besides, the processing plants receive the additional environmental benefit and savings, as no hazardous ionizing radiation is produced. The analyzers operate 24/7/365 in automatic mode in severe industrial conditions for over 10 years in metals, fertilizer, refractories and industrial minerals applications.

INTRODUCTION

To keep pace with Industry 4.0, while initiating the digitalization and advanced automation projects, mining and mineral processing companies have to ensure that they have all necessary data in real time. Online elemental analysers that can continuously measure the chemical data of ores and minerals in real time directly in the process (on the conveyor belt or in the pipe) is one of the initial drivers towards Industry 4.0 implementation.

As raw materials often come for processing with significant variation in chemical and mineralogical composition, this decreases the stability and efficiency of any subsequent beneficiation or processing steps, potentially deteriorates the quality of final products, and decrease production efficiency in general. Online measurement will help to solve these challenges and allow the mining companies to empower the process efficiency in automated sorting of crushed ore and concentrate, stockpile formation and dosage of flotation regents optimized according to the actual ore quality of the flotation feed (Figure 1).

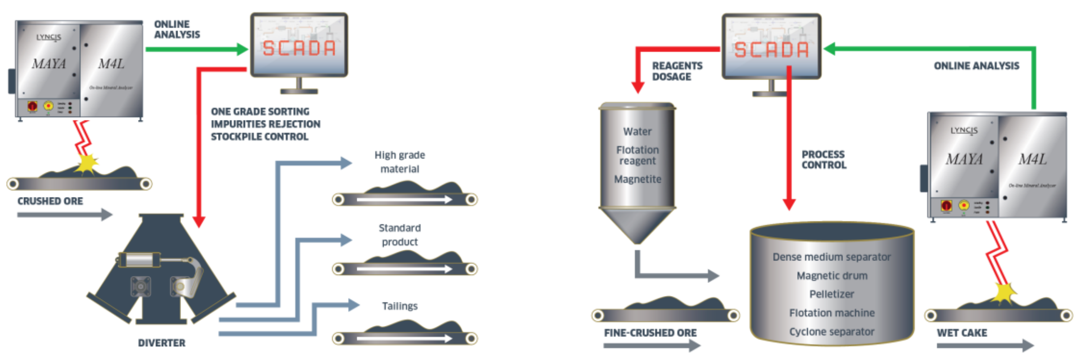

Figure 1 General scheme of automated ore sorting and dosage of reagents based on the assay provided by the MAYA online elemental analyzer

The process control requires the chemical data every minute to improve performance, while conventional collection, preparation and analysis of samples is inherently time consuming, labor intensive and always susceptible to human factor, being unable to represent the real quality variation in the process.

Even though good progress has been made in online elemental analysis, yet very few solutions can demonstrate high performance and robust calibration while also ensuring safety, simplicity and low cost of ownership. The MAYA online elemental analyzers based on LIBS (Laser Induced Breakdown Spectroscopy) was developed to align with the market expectations and has been already proven 24/7 in different applications, including steel, fertilizer, refractory, industrial minerals and coal.

In this paper, the application of LIBS online elemental analyser is studied to measure the assay of the copper and nickel ore, and magnetic iron ore (copper mining tailings). The special focus in the measurements was on the measurement of Sulphur, which was considered challenging for LIBS in the past.

METHODOLOGY

LIBS Technology

Laser Induced Breakdown Spectroscopy (LIBS) is an advanced spectroscopic technology for elemental analysis that is actively used both on Earth and in space.

Astronomers identify molecules in space by observing their spectral features – the particular wavelengths of light they absorb and emit. Each molecule has a unique spectral signature based on its particular chemistry. Several recent breakthroughs in this field are changing how we understand chemistry in space [1]. LIBS was selected by NASA for its rovers to identify the chemical and mineral composition of rocks and soils on Mars. First, in the ChemCam launched in 2011 and now in the SuperCam 2020 [2, 3].

The operating principle of LIBS is based on focusing of a laser beam on a small spot on the material to create a plasma that emits light while cooling (without any type of neutron, gamma and X-ray emission). The plasma is practically electric neutral, but heavily ionized gas contains the molecules, atoms and ions of the chemical elements being in the material and free electrons as well. The process of recombination of positively and negatively charged particles begin in the plasma immediately and is accompanied with the emission of photons – «glow» of the plasma occurs. The atom of every chemical element emits the photons with strictly defined wavelengths, and the emission intensity relates to the concentration of this element in the material analyzed [4, 5].

Online analyzers based on LIBS has the measurement rate from 1 to 20 Hz. Analytical frequencies up to 100 Hz and higher are also possible. The optical radiation of the plasma within a wide optical range from 190 to 1000 nm is measured with special spectrometers transferring the digital information on the spectrum composition to the computer of the analyzer and SCADA system (Figure 2).

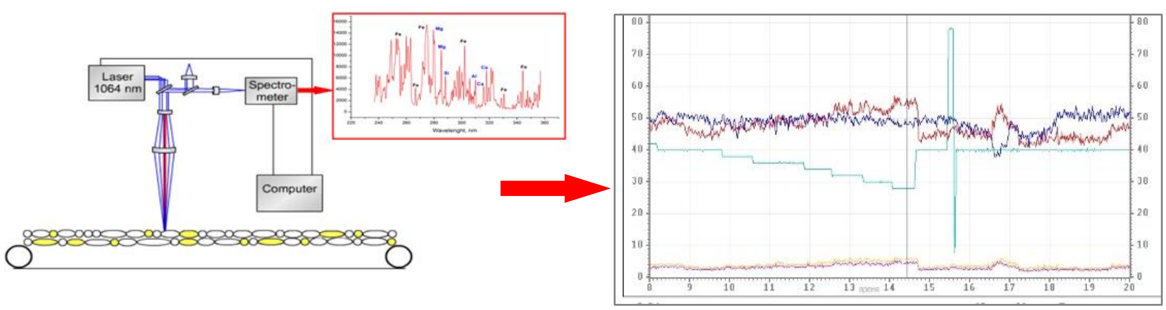

Figure 2 Principal scheme of a LIBS system integrated into SCADA

Concentration of the constituents in the material being analyzed is calculated after the statistical processing of a spectra set for the period required to resolve the process task. LIBS is capable to analyze in online mode all elements of the Periodic Table and provide accurate quantitative results immediately.

Industrial LIBS Analyzers

LIBS is successfully utilized in many applications. However, the majority of them is limited to the laboratory scale. The MAYA online analyser was specially designed for the industrial applications. Unlike the other online analyzers offered on the market, the challenge was not only to detect variations in ore feed in real time, but also to ensure the safety environment for the personnel without hazardous radiation.

The first MAYA analyzer was installed in 2008 and since then LYNCIS has gained the unique experience to guarantee the LIBS application in the industrial environment. MAYA analyzers are currently used in the steel, refractory, potash and phosphate industries [6-10]. It has also been successfully tested in coal, non-ferrous and cement industries and in the production of various industrial materials (lime, limestone, quartz, boron, base metals etc.). The analyzers were designed to operate in automatic mode 24/7 under very harsh industrial conditions (high humidity and temperature variation, vibration, dustiness, etc.). They can be easily integrated with any customers' SCADA and sorting/crushing/dosage equipment for process control. According to the customers' feedback, a typical payback period for the MAYA system is only a few months thanks to the improved grade sorting, optimized consumption of raw materials, reagents, water, and energy and reduced penalties.

The main advantages of the LIBS systems compared to the other analytical methods are the following:

- high accuracy, low detection limits and high sensitivity due to clear spectral lines of most elements within a wide optical range with no interferences;
- the ability to analyze simultaneously all elements of interest, including light elements (H, Li, B, N, Na, Mg, Si, Al, C, P etc);
- no ionizing radiation (neutron, gamma and X-ray) risk for production personnel, no requirement for special permits or regular inspections by the regulatory bodies dealing with radiation monitoring;
- good accuracy regardless of bulk size, surface quality, thickness of the material layer on the belt;
- stable long-term calibration;
- simple and safe operation and maintenance;
- low cost of ownership.

The measurement and analysis for this study were carried out on copper concentrate, nickel ore and copper mining tailing, using the MAYA test rig based on LIBS, which is similar to the industrial analyzer, but performs the measurement on the special laboratory device, imitating conveyor belt movement. The test rig is equipped with flash lamp- or diode-pumped lasers operating at the wavelength of 1064 nm and at the repetition rate of 3-20 Hz. Spectral data was received using some high-resolution ultraviolet and visible range spectrometers (λ = 190 - 1050 nm) for detection of elements of interest.

Data Analysis

The focus of this study is to assess the LIBS applicability to measure Cu%, S%, Mo%, Fe%, as variations in the content of these elements significantly affect the downstream process for copper and nickel mining companies.

To measure Sulphur by LIBS under ambient conditions, Lyncis applied chemometrics and optimization approaches in this study. Many works in the field of LIBS use the PCR (Principal Component Regression) method for calibration at the laboratory scale. At the industrial scale, PCA (Principal Component Analysis) can be used to pre-process data. The key advantage of this method is that it does not require tags (lab data) at all. Therefore, the training set can be formed not by the averaged spectra of the samples (there are few of them), but by the single spectra (it does not take long to get 10,000 spectra of the material, and the data volume already fully corresponds to the methods of Machine Learning).

At the same time, it is possible to use a PCA decomposition not only for regression purposes (this usually does not allow achieving the required accuracy), but also for the purpose of data normalization. The issue is that with the PCA decomposition, the first one or two components describe not the required concentration fluctuations, but those undesirable effects mentioned above. Therefore, the following method is quite meaningful: obtaining a PCA decomposition for all available spectra, zeroing out the first 1-2 components in the diagonal matrix, and the subsequent inverse transformation. The spectra obtained at the output are qualitatively differentiated in intensity and in the influence of moisture and non-focus. In view of the fact that PCA is a technique of linear transformations, and many effects of plasma physics are fundamentally nonlinear, it also looks promising to replace PCA with Autoencoder, which, with a very similar ideology, uses more complex nonlinear models.

Machine learning models usually operate with the number of samples (or records) starting with hundreds of thousands. It is clear that such number of samples for calibration of the online analyzer is completely unattainable. Nevertheless, the number of spectra in industrial LIBS applications is quite big and actually fits into the concept of conventional machine learning models. The main problem here is in the absence of labels (desired output value) for each spectra. Consequently, they are not suited for supervised learning. Therefore, to calibrate LIBS systems on several dozens of samples, the actual model should use a complex reinforcement learning where only samples (and each sample corresponds to relatively big batch of spectra) have labeled data. Naturally, unsupervised learning (in particular, already mentioned PCA decomposition) can be applied for LIBS data structuring and preprocessing.

RESULTS AND DISCUSSION

The big number of the spectral data obtained with the MAYA system enabled a very good correlation between online LIBS and traditional laboratory results for Cu, Mo and Fe in copper concentrate.

Typical LIBS spectra of copper bearing ores (Figure 3) allows to clearly identify the analytical lines of all the necessary elements.

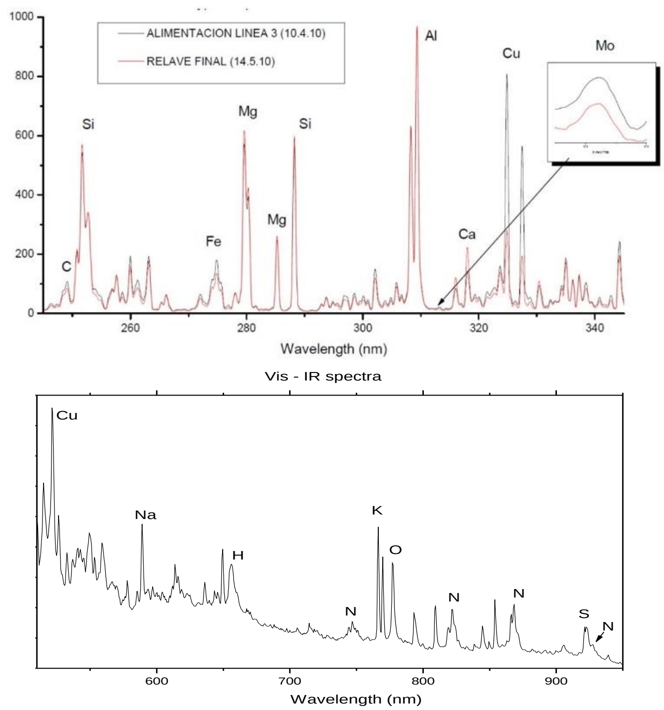

Figure 3 Example of LIBS spectra for copper ore

Particularly, Molybdenum lines were confidently detected even with Mo concentrations in the less than hundreds of ppm range. Correlation with laboratory data (R2) of Cu, Mo, and Fe (Figure 4) is between 0.92–0.98 ensuring its applicability to control the process at the industrial scale.

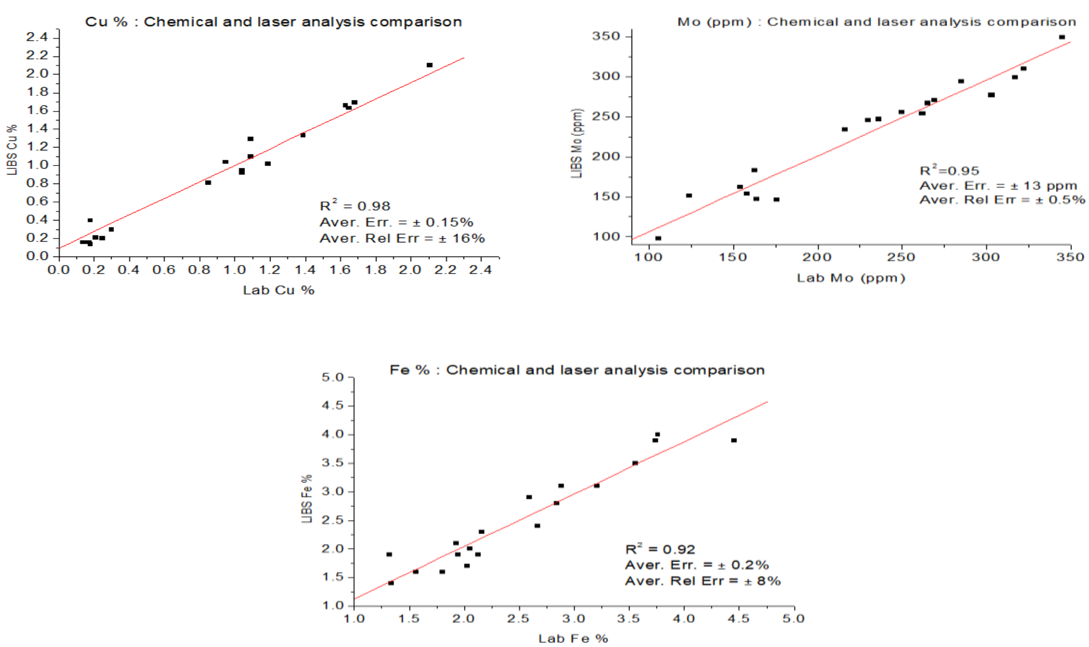

Figure 4 Correlation between online LIBS and traditional laboratory data on Cu (a), Mo (b), and Fe(c) in copper concentrate

The estimation of Sulphur content using the MAYA online LIBS system was made on nickel ore samples. As only a few spectral lines of Sulphur are suitable for its detection and quantification, the main focus in the data analysis was made on the advanced analytical approaches that helped to receive the good correlation for Sulphur even for low concentration (starting from 1.6%) with the corresponding XRF assay provided by the traditional laboratory analysis. Figure 5 shows the correlation between LIBS and XRF assay for Cu and S.

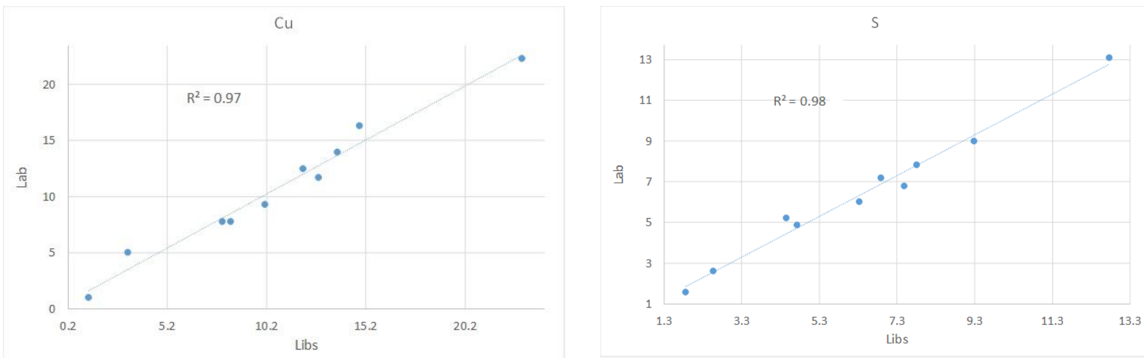

Figure 5 Correlation between online LIBS and traditional laboratory data on Cu and S in nickel ore

The Sulphur measurement was also estimated in the task to control the copper mining tailings (fine dry magnetic iron ore was provided for testing).

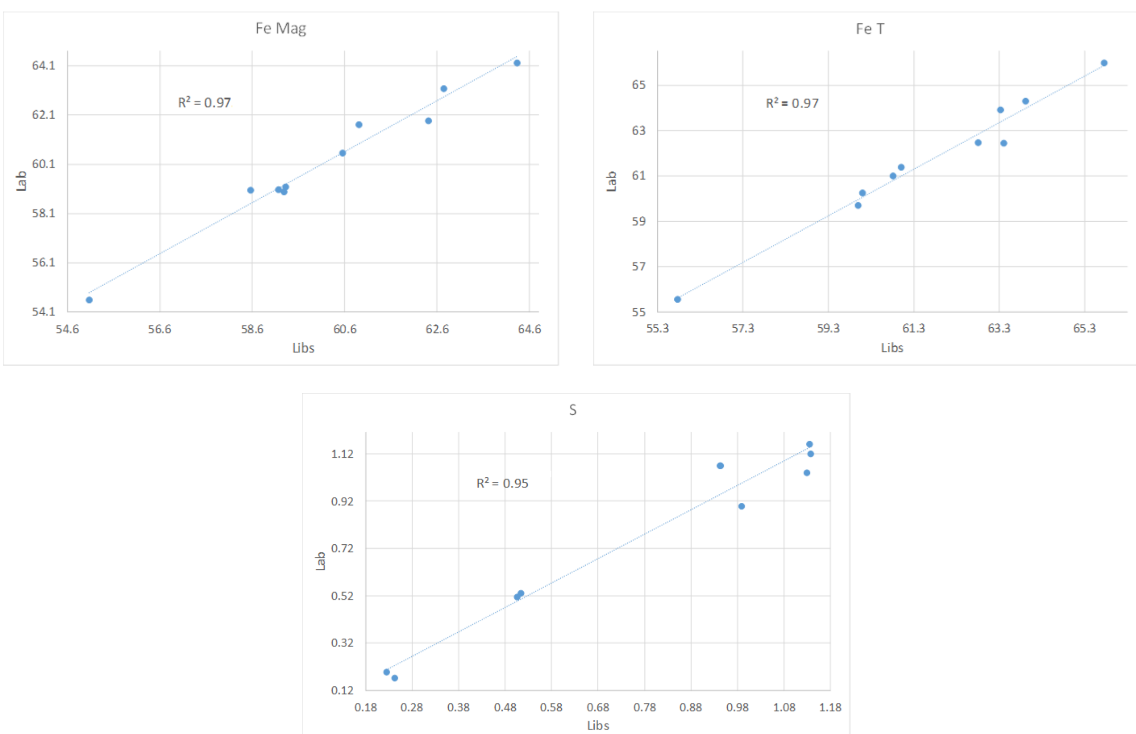

Figure 6 Correlation between online LIBS and traditional laboratory data on Fe Mag and S in copper tailings

In this study, the focus was to know the ore grade of Iron Total, Magnetic Iron (in the range from 20% to 60%) for the recovery, but the analysis of S below 2% was also required due to the customers' quality requirement. Sulphur was contained in such type of minerals as: Sphalerite, Chalcopyrite, Pyrrhotite. The results received at the laboratory scale are presented on Figure 6.

According to our accumulated experience, such result (Figure 6) indicate successful industrial implementation. The results received in the Sulphur measurement under the ambient conditions open more opportunities for LIBS, as before it was considered that only competing technologies using hazardous radiation can detect Sulphur.

CONCLUSION

This study has discussed the applicability of the MAYA online elemental analyzer based on LIBS for real-time measurement of iron, copper and nickel ores directly on a belt, without sampling and any hazardous radiation. Efficient quantitative determination of Cu, Fe, Mo, S with LIBS has been presented in this paper.

Knowing the characteristics of materials prior to processing, not only makes possible a real-time response but also moves control to a more advanced decision-making capability with automated and fast decisions. The critical challenge for this study was to measure Sulphur content using LIBS, which was successfully solved using the advanced of chemometrics methods and optimization approaches.

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