

Online XRF Analysis of Industrial Sand Impurities on a Conveyor Belt

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Abstract

The paper is devoted to results of the online XRF method development for analysis of impurities in industrial sands (quartz sand, nepheline syenite, feldspar) on conveyors of mining enterprises. Typical problems of impurity concentration control (Fe_2O_3 , Al_2O_3 , TiO_2 ...) in dry and wet sands are presented. This work examines technical solutions that enabled achieving a required measurement accuracy in an online mode using an industrial XRF CON-X analyzer on conveyors of enterprises. The paper presents results that have been reached in detection of impurities, the estimation of statistical accuracy of concentration values obtained, and sensitivity of measurements in various applications. Results of the online XRF analysis are compared with the results obtained in factory laboratories.

Keywords: Industrial sand; X-ray fluorescence analysis; Online elemental analysis; CON-X

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Introduction

Industrial sand is one of the most used raw materials in the world. With its high quartz content, industrial sand has a wide range of applications depending on its chemical composition. In the case of quartz sand, 99.1 - 99.4% is SiO_2 [1], whereas other types of sand such as feldspar and nepheline syenite have a quartz content of 68.4 - 76.8% [1] and 52.73% [2], respectively. The remaining percentage corresponds to various oxides that are present in industrial sand in different concentrations [3,4]. In many cases, the application of sand is completely dependent on the quartz content. The industrial sand market is large due to its numerous applications and uses. For mining and processing of quartz sand, the market is huge. It is projected to grow from USD 22,098.23 million in 2023 to an estimated USD 35,748.61 million by 2032, at a Compound Annual Growth Rate (CAGR) of 5.49% from 2024 to 2032 [5]. The global nepheline syenite market size was valued at USD 79.7 million in 2019 and is projected to reach USD 87.6 million by 2027 [6]. The global feldspar market size was valued at USD 1.61 billion and is expected to grow at a Compound Annual Growth Rate (CAGR) of 4.9% from 2020 to 2027 [7].

The main consumers of quartz sand are glass, semiconductor, construction, metallurgical and chemical industries [5,8-12]. The main fields of application of nepheline syenite and feldspar are ceramics and glass production. In all these fields, the quality of quartz sand is crucial as it directly affects the physical properties and characteristics of the final product. The quality of sand is mainly determined by the presence of impurities in it, among which are iron, aluminium and titanium oxides (Fe_2O_3 , Al_2O_3 and TiO_2) [3,4]. The high content of these oxides can make any type of sand unsuitable for a particular application. For this reason, every mining or processing plant should be able to control the quality of sand and enrich it in a timely manner. Today, most companies rely on chemical analysis as quality control. However, this method has several disadvantages, which include sample destruction during analysis, which makes it impossible to verify the analysis results, and long processing time of several hours [13]. In

addition, chemical analysis requires a proper laboratory, expensive analytical equipment, qualified personnel, and a large volume of chemical reagents for such analysis. The analysis produces a large amount of chemical waste that is disposed of in the environment.

Due to the disadvantages of chemical analysis, online, real-time, direct-to-conveyor material composition analyzers are being increasingly used in various processes in the mining industry [13,14]. Such online analysis can be based on various nuclear physics techniques (e.g., radiometric, neutron-activation, gamma-activation, and X-Ray Fluorescence (XRF)) [13-16]. Of course, online analysis methods are generally less sensitive and accurate than chemical analysis methods. However, they provide near real-time analysis results, allowing for rapid technology adjustments, process automation, and the elimination of significant human labour. Real-time quality control directly on the concentrator conveyor belt is a step toward automation, which significantly improves production efficiency. Each of the nuclear physics methods used for elemental analysis of the composition of materials has its own advantages and disadvantages and solves a certain range of applications [14-17]. X-Ray Fluorescence analysis (XRF) is one of the most accurate and simplest analytical methods for analysing a substance to obtain its elemental composition [14,16]. Various elements from aluminium (Al) to uranium (U) can be detected using this method. Operational analysis of materials on mining conveyors does not require sample preparation, which eliminates the influence of human factor and unpredictable accidents on the analysis results [13].

In [17] we have shown that the online XRF method allows us to solve rather non-standard problems of controlling the content of elements in ore materials (lump, ore, charge, cake, slag) on conveyors of mining and processing enterprises. This paper is devoted to the analysis of the online XRF method's application features on the sand, the results of development of the online XRF method for impurities control in various types of industrial sand, and the implementation of this method on conveyors of mining and processing enterprises. We present technological applications that require determination of impurities in industrial sands and in which we successfully implemented the online method, and analyse the metrological performance achieved in these applications.

Method

Online XRF method

Unlike laboratory applications, the online use of XRF equipment for the analysis and calculation of the concentration of elements in the material does not require sample preparation [13]. The industrial online XRF analyzer (1) (Figure 1) is mounted on a special suspension (2) above the conveyor belt (3) with minerals (4), usually moving at a speed of a few m/s. XRF analyzer contains an X-ray tube (5), an X-ray detector (6), electronics for amplification and shaping of signals from the detector (7), a computer (8), equipped with software for the analysis of X-ray spectra and the calculation of the concentration of the required elements. Passing under the analyzer, the material is irradiated by X-ray radiation (9)

from the X-ray tube and emits secondary characteristic radiation (10), which is registered by a semiconductor X-ray detector (6). The recorded spectra contain energy peaks of all the elements contained in the material with energies below the excitation energy of the X-ray tube. The spectra are analysed and calculated by a computer software (8), calculation results are displayed on its monitor and transmitted to the Automated Process Control System (APCS) of enterprise.

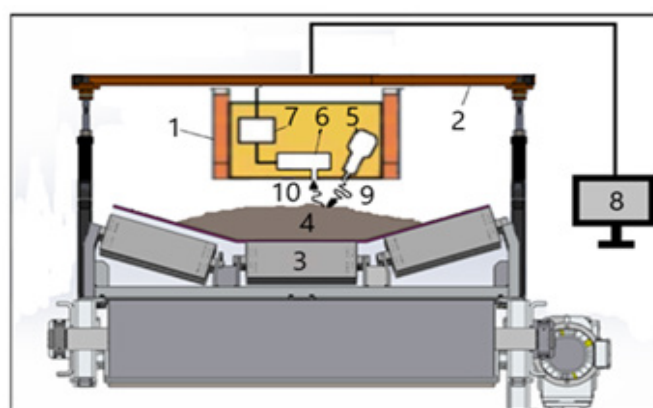


Figure 1: Drawing of an online XRF analyzer installation on a conveyor belt.

It should be emphasized that with the online measurements, results depend on many factors, such as the distance between the surface of measured material and the analyzer; the size of material pieces, the degree of in homogeneity of the controlled material, unknown and variable amounts of light elements invisible to the analyzer; humidity of the measured material, dustiness of the air, etc. [13]. All these factors should be considered in the algorithm of software calculations to ensure reliable results of the online XRF analysis. As can be seen from description of the online XRF analyzer; another important distinguishing point of the method is the fact that during the online XRF analysis the analyzer practically becomes part of the technological equipment for material processing and an automatic control of its quality. A computer can be connected to the company's APCS via Ethernet. Since the analysis results are provided in near real time, there is a possibility of operational influence on the technological process, for example, adding some components to the material on the conveyor. Such increase of functional role of the online XRF analyzer imposes serious requirements on its operations stability and reliability, since such an analyzer must work continuously for years in quite difficult industrial conditions (operating temperatures from $-40\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$, a wide range of electromagnetic interference, vibrations, dust, humidity, etc.).

Features of online sand analysis on a conveyor

Each application of the online method for determining the concentration of elements in various minerals on a conveyor has its own design, technological and methodological features [17]. Understanding the specific features of the problem to be solved and analyzing various decisions made in other tasks ensure its

successful solution to a large extent. The extracted industrial sand is usually 0.1-2.0mm in size [18]. The sand on the conveyor is a fairly soft loose substance and is transported along the conveyor belt in a strip that's a few centimeters high with slight fluctuations in height. Large and heavy objects such as pieces of ore, like in the analysis of mining ore materials, are not found on the conveyor with sand. This eliminates the need to develop and use complex dynamic suspensions in this application to change the position of the analyzer when a dangerous object is approaching [17]. Therefore, in applications on sand, the simplest designs are usually used (see below), fixing the online analyzer in one position above the surface of the analyzed sand.

Ideally, the surface of the sand to be analyzed should be completely flat so that the lower surface of the XRF analyzer with the X-ray detector inlet window can be as close to the sand surface as possible. To ensure a constant gap between the sand layer and the analyzer, it is enough to install a simple leveling mechanism that smooths out the irregularities of sand that appear on its surface. In addition, this air gap between the sand surface and the bottom of the analyzer must be minimized in order to maximize the sensitivity of the characteristic emission of the elements, especially in the low energy region. Since virtually all lines (L-series) of the characteristic X-ray emission of elements from aluminum (Al) to uranium (U) lie in the energy range of 1-30keV, such a low-energy radiation is easily absorbed in the air gap, resulting in a decrease in the sensitivity of the method.

A specific feature of processing the industrial sand on a conveyor is that in its final result the sand of different quality is used for application in different products. The task of sorting sand by quality is usually solved by switching the entire sand flow on the conveyor to various technological lines for its further processing according to the overall quality assessment. As a rule, an industrial online XRF analyzer has outputs of control signals to the actuators, which makes it possible to organize a more accurate sorting of individual sand lots on the conveyor by quality and quickly control the technological process in automatic mode [17]. Even more features of online sand analysis on the conveyor can be found in section 3 in specific applications.

Results and Discussion

Implementation of the online XRF method

To develop online XRF methods for controlling impurities in sand on conveyors of mining enterprises, we used the industrial online XRF CON-X analyzer [19], which has already undergone several upgrades to meet the increasing level of requirements of the developing online analysis [20]. The CON-X analyzer is equipped with a modern software package that provides the analyzer not only with empirical correction (i.e., using a reference sample), but also with the use of the fundamental parameter method. This software package provides the possibility of convenient processing of the obtained spectrum, including deconvolution, smoothing, background subtraction, the use of the spectral ratio method and

the standard-background method [16,21]. This allows solving a wide range of technological problems in the mining industry. In addition to counting the concentrations of mineral elements, the software also calculates the detection limit for determining the concentration of the analyzed elements, the estimation of the statistical accuracy of the obtained concentration values and the sensitivity of measurements from the recorded spectra [15]. The Detection Limit (DL) is the minimum concentration which can be detected with certainty in a given measurement time. It is determined from the equation

$$DL = \frac{3 * \sqrt{S_b}}{S_p} * C,$$

where S_p and S_b are numbers of photons, detected in the spectral line and its background, and C is the concentration of the corresponding element. The statistical accuracy (σ) shows the achievable repeatability of determination of the element concentration at a fixed sample position. It is determined from the equation:

$$\sigma = \frac{\sqrt{S_p + 2S_b}}{S_p} * C$$

Typically, with online measurements, accuracy is somewhat worse than the statistical accuracy in static conditions. The sensitivity (ϵ) is defined as an increase in the number of photons in the spectral line arriving to the detector in one second, if the concentration is increasing by 1% (in terms of measured element). It is computed from the expression

$$\epsilon = \frac{S_p}{t \cdot C},$$

where t is the measurement time.

Below are some typical tasks for monitoring the concentration of impurities in various types of industrial sand in mining enterprises and the technical solutions that have made it possible to achieve the required measurement accuracy online using the CON-X XRF analyzer on conveyors of these enterprises.

Online measurement of iron (Fe) concentration in nepheline syenite

Iron oxide is the main impurity that most often determines the quality of mined sand. The aim of this project was to control the concentration of Fe_2O_3 in the nepheline syenite produced at a plant. Nepheline syenite is a fine gray sand with a grain size of less than 500 μ m. The sand is transported by conveyor at a speed of 1m/s. The controlled range of iron concentrations for this project was 800-2200ppm. The industrial online XRF analyzer was mounted above the conveyor (Figure 2) on a simple four-legged suspension with dampers to suppress vibrations from the conveyor. The distance between the sand surface and the bottom surface of the analyzer was 50mm (varied from 30 to 70mm). The analyzer used an X-ray tube with a Mo anode, which was used in the HV=25kV mode; I=60 μ A. A primary radiation filter (Mo, 50 μ m) was installed in this analyzer between the X-ray tube and the sand surface to monochromatize the radiation. The measurement time was 300 seconds.



Figure 2: Online XRF analyzer measuring iron (Fe) concentration in nepheline syenite.

Prior to its installation on the conveyor, the online analyzer was calibrated under laboratory conditions in the iron concentration range of 800 to 2200ppm using standard calibration samples provided by the customer. Systematic measurement errors were tested and taken into account when installing the analyzer on the conveyor. Typical X-ray fluorescence spectra of nepheline syenite samples with different concentrations of Fe₂O₃ recorded by an online XRF analyzer are shown in Figure 3. Figure 4 shows

the magnification of low-intensity spectral region. Several well-identified X-ray fluorescent lines of elements present in nepheline syenite are observed on the spectra, namely potassium (K), calcium (Ca), barium (Ba), manganese (Mn), iron (Fe), gallium (Ga), rubidium (Rb) and strontium (Sr).

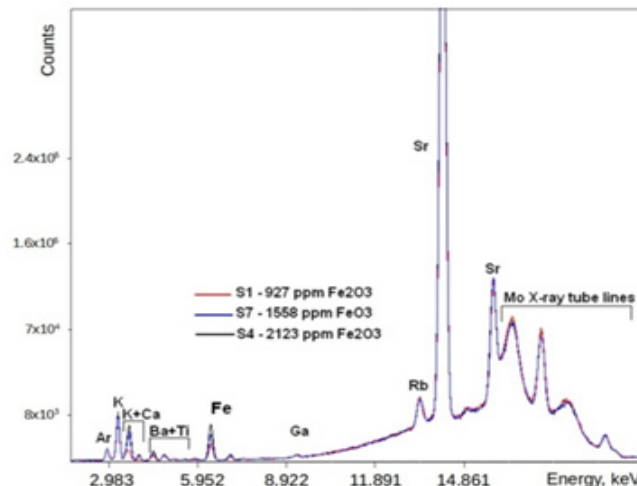


Figure 3: Overview of nepheline syenite spectra. The Mo lines are instrumental; the Ar line is emitted by the Ar atoms in the air between the sample and the analyzer.

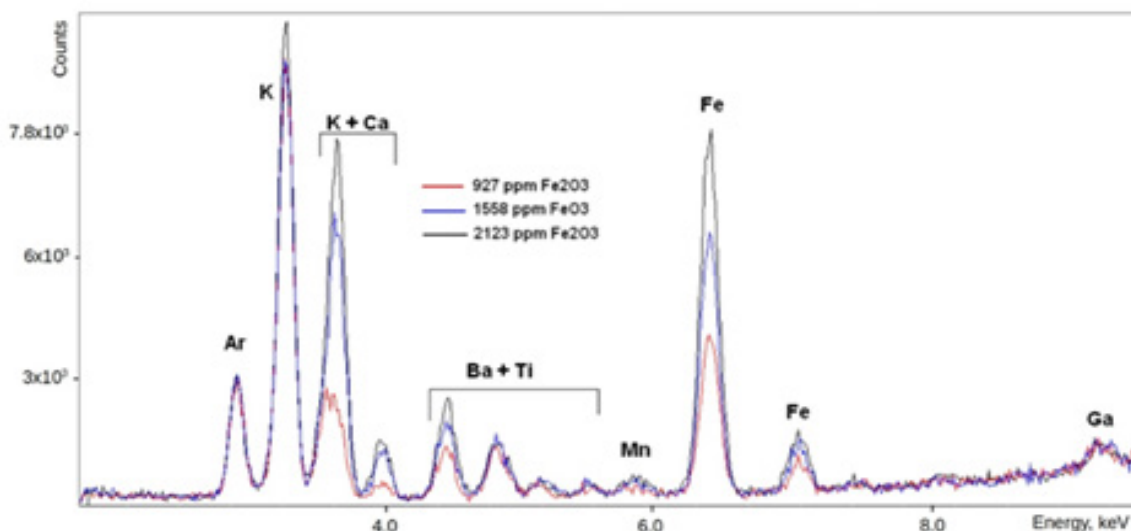


Figure 4: Online XRF analyzer measuring iron (Fe) concentration in nepheline syenite.

The X-ray lines of lighter components of nepheline syenite, such as magnesium (Mg), aluminum (Al), and silicon (Si), are not visible in the spectra because the measurements were made in the air and the detector was located 50mm from the surface of the sand. X-ray photons emitted by light elements are very weak and easily absorbed in the material being measured and in the air gap. The X-ray iron line is well detectable in all spectra shown in Figure 3 & 4, and its intensity increases in proportion to iron concentration

increase. Studies have shown that Fe₂O₃ detection limit in nepheline syenite with the online XRF analyzer configuration used, was DL=8ppm. The errors in the analysis of Fe₂O₃ in nepheline syenite samples in the specified concentration range do not exceed 1% of the rel. A higher deviation of 2.8% relative was obtained only for the sample with the highest Fe₂O₃ content of 2123ppm. At this time, measurement sensitivity of the method was about 4.1puls/ppm (for measurement time of 300 seconds).

The values of Fe_2O_3 concentration obtained by the online analyzer in the sand on the conveyor were compared with the values of concentration in samples taken simultaneously from the conveyor to determine the concentration in the factory laboratory. Figure 5 shows across-check of Fe_2O_3 concentrations measured by the online analyzer and in the customer's laboratory. This graph shows that the value of the correlation coefficient of concentration values obtained by the two methods is $R^2=0.998$ and the discrepancy in the values does not exceed 3% (relative).

To assess the repeatability of the online analysis results (or their convergence), we repeatedly measured the spectra of the same sample over a period of 16 hours, collecting a total of 200 spectra. The measurement time was 300 seconds. The results of these measurements are shown in Figure 6. The standard deviation for the 300-second measurements was 14ppm, which is 0.8% of the relative deviation ($n=200$). The average measured value of Fe concentration in the tested sample was 1753ppm versus the value of 1761ppm measured in the laboratory.

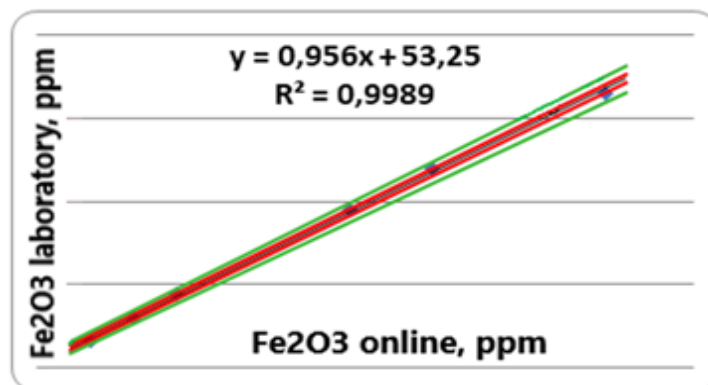


Figure 5: Cross-check of Fe_2O_3 concentrations in nepheline syenite measured by online measurements and data provided by customer's laboratory. Calibration line is shown in blue. Red and green lines correspond to 1% and 3% (relative) error.

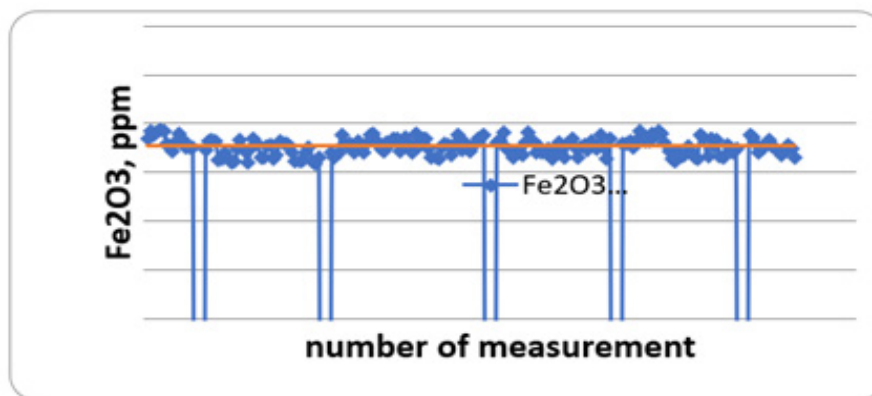


Figure 6: Overnight repeatability of iron concentration measured in the sample with 1761ppm iron.

In general, the measurement results confidently demonstrated the possibility of online measurement of iron concentration in nepheline syenite on a conveyor of mining enterprise. The concentration of Fe_2O_3 in nepheline syenite samples in the range of measured concentrations of 800-2200ppm can be determined online with an accuracy of better than 1-2% (relative). The detection limit for iron in the configuration used was 8.0ppm. The repeatability of the online XRF analysis measured for a 1761ppm Fe_2O_3 nepheline syenite sample was 14ppm (or 0.8% relatively) for a 5-minute measurement ($n=200$).

Online measurement of low concentration of iron (Fe) in wet quartz sand

Industrial sand extraction is carried out in two ways: the first is the open production of natural sand from river bottom off loaded quarries or river channels, the second is the crushing of vein quartz rock. In the first case, the equipment for sand mining is installed on a barge standing in water area of the reservoir. Equipment for quality control of the produced sand should be installed here, too. The goal of the project was to develop a system for automatic monitoring of the concentration of iron oxide Fe_2O_3 in quartz sand extracted

from the bottom of a natural reservoir. The range of controlled concentrations of Fe_2O_3 was from 50 to 200ppm. The mixture of the extracted sand with the water of the reservoir is fed by the dredger to the barge and falls on the drying filter, which moves at a speed of about 0.5m/s, ensuring that the water flows down and moves the sand to the conveyor. To achieve the best statistical parameters in this project with low concentration of controlled elements, high values of Mo X-ray tube voltage and current were used: 39kV and 400 μ A, respectively. The measurement time was 300s. Due to the low iron content of monitored samples we also made some changes

to configuration and parameters of the system to improve the accuracy of detecting low-count elements (low-ferruginous, in this task) and reducing the level of background radiation. In particular, a primary radiation filter of Ti was applied for this purpose, and installed between the X-ray tube and the sand layer. The industrial XRF analyzer in the described configuration was installed above the conveyor immediately after the simplest sand leveling device (Figure 7). The distance between the analyzer and the levelled sand surface was 40 \pm 5mm.

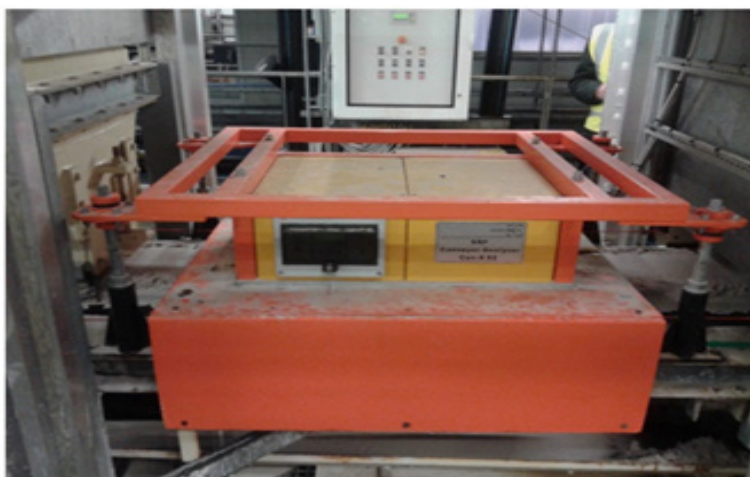


Figure 7: Online XRF analyzer measuring low concentration of iron (Fe) in wet quartz sand.

Prior to its installation above the sand conveyor, the analyzer was calibrated in the laboratory to the range of measured concentrations using standard reference samples. Samples of low ferruginous quartz sands were provided by the customer. The iron content of the calibration samples was determined by XRF in the customer’s laboratory and ranged from 50ppm to 220ppm. Moisture content of the calibration samples was 8 - 10%. Systematic measurement errors were tested and taken into account when

installing the analyzer on the conveyor. Typical common spectrum of quartz sand measured at parameters indicated above is shown on Figure 8. Figure 9 shows the $FeK\alpha$ peak area on an enlarged scale. Figure 9 demonstrates the obvious correlation of the iron spectral line with the concentration of Fe_2O_3 in the sand. The detection limit of Fe_2O_3 according to the calculations of the spectra was 5ppm. The deviation in determining the concentration in the required range did not exceed 6.2% (relative).

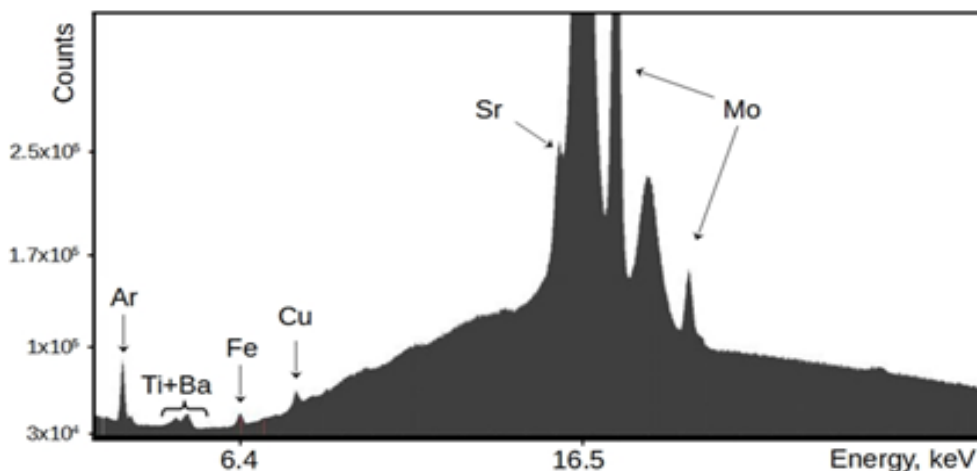


Figure 8: Spectrum of quartz sand sample.

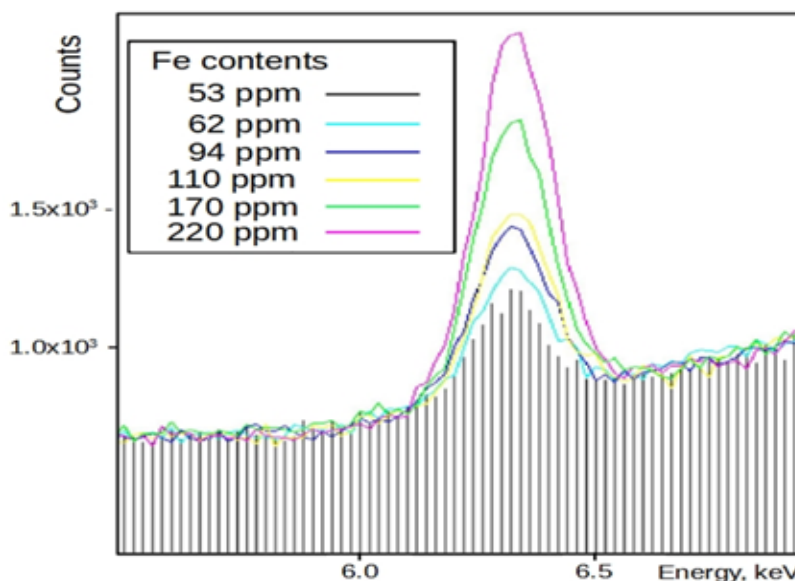


Figure 9: FeK α peak of quartz sand spectrum at different iron concentrations.

A comparison of the Fe₂O₃ contents obtained online by the CON-X analyzer and the corresponding values provided by the laboratory is shown in Figure 10. It is obvious that the good correspondence between the results of the online analysis and the laboratory is confirmed by the correlation coefficient R²=0.9981 for data comparison. The relative standard deviation for online and laboratory measurements did not exceed 13%. In general, the results of this project confidently demonstrated the possibility of online measurement of low concentration of Fe in the range of concentrations from 50 to 220ppm in wet quartz sand. The

detection limit of Fe₂O₃ according to the calculations of spectra was 5ppm. The error in determining the concentration in the required range did not exceed 6.2% (relative). A relative standard deviation of the results of online measurements and laboratory measurements did not exceed 13%. As our research has shown, the accuracy and reproducibility of iron in sand analysis do not depend significantly on the water content of the material, as long as the water is less than 10-15%. This result has been confirmed by us in other sand projects.

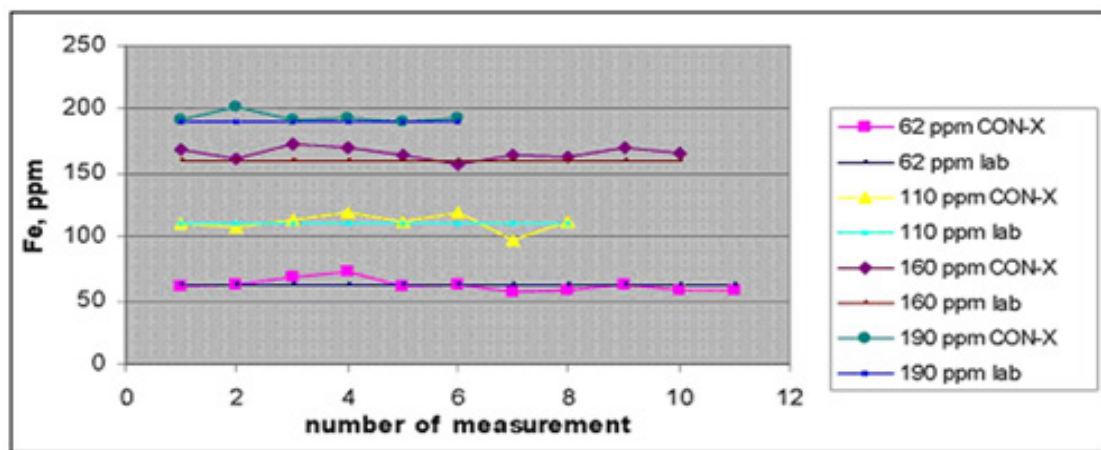


Figure 10: Comparison of online vs laboratory results.

Online measurement of aluminum (Al) and iron (Fe) concentration in quartz sand

The purpose of this project was to organize online monitoring of the concentration of aluminum (Al) and iron (Fe) impurities

in quartz sand on conveyor moving at a speed of 1m/s. To record the characteristic radiation of such a light element as aluminum, we used an online XRF analyzer with a closed geometry of the measuring unit filled with helium He. In addition, an X-ray tube with an Ag anode was used in a mode with supply voltage of 9.0kV and a

current of $400\mu\text{A}$. These technical solutions were chosen to provide better spectral statistics for X-ray lines of light elements such as Al and Si. With a low supply voltage of the X-ray tube, the intensity of some X-ray lines of the test material and the background can be reduced (for example, escape peaks of K and Ar).

The measurement time of 300s was chosen. The distance between sand surface and the detector was 2mm. To ensure such a narrow gap, a sand leveller was installed on the conveyor belt in front of the analyzer. The measurements were carried out by blowing the He flow through a measuring chamber. No intermediate primary radiation filters were used (Figure 11). As an example, Figure 12 & 13 show the spectra of samples measured under the conditions, specified above ($U=9.0\text{kV}$, $I=400\mu\text{A}$, measurement time=300s, flux He). It can be seen from these spectra (Figure 12 & 13) that the qualitative chemical composition of all samples is similar, and it is obvious that the height of the Al line increases with an increase in concentration of Al_2O_3 . The Si line predominates in the spectra of all samples, which is natural. The iron line is also recorded without

problems, which makes it easy and accurate to calculate the concentration of iron impurities. The peak of aluminum, although the smallest of those analyzed, is easily calculated by software, as well. Analysis of the recorded spectra of quartz sand showed that with five-minute measurements, the analyzer at low voltage on the X-ray tube and close geometry is able to quantify the amount of Al in quartz sand samples. The following statistical parameters were calculated from the corresponding spectra: Detection Limit (DL), statistical accuracy and sensitivity. An estimate of these parameters at a measurement time of 300s is given in Table 1. Studies show that the calculated statistical accuracy of measurements for Al and Fe is quite high: the Detection Limits (DL) for Al are better than 0.2%, mass, for Fe it is better than 0.002%, mass. Al can be determined with an accuracy of better than 0.2%, mass, Fe is better than 0.002%, mass. Thus, the online XRF analyzer allows to measure concentrations of light elements such as Al and Si directly on the belt of an industrial conveyor at measurement time of 300s with the accuracy specified above.



Figure 11: Online XRF analyzer measuring aluminum (Al) and iron (Fe) concentration in quartz sand.

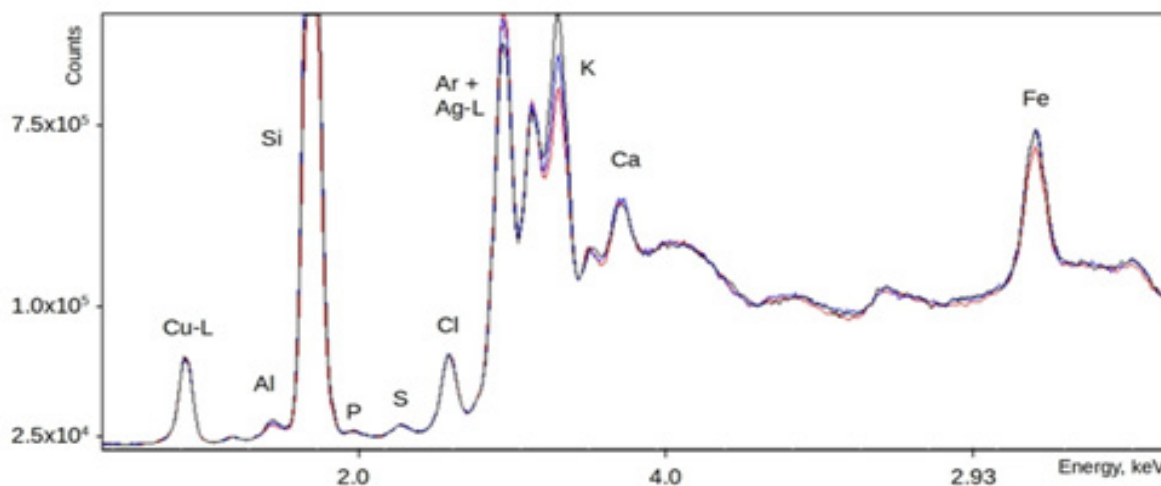


Figure 12: Overview of quartz sand sample spectra. Spectra shown in red, blue and black correspond to the samples with different concentrations of aluminum impurities. The Ar line is arising in the air; the Ag line has an instrumental origin (X-ray tube anode material).

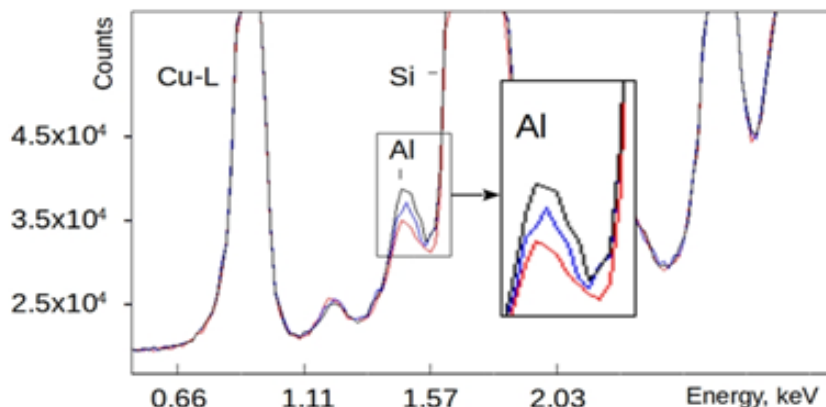


Figure 13: Zoom in to low-intensity lines of sand samples spectra. Colour coding is as on Figure 12.

Table 1: Statistical parameters of Al and Fe determination.

Element	Average per Range, % mass	S _{pb} , counts	S _p , counts	S _p , counts	σ, % mass	DL, % mass	ε, counts/(s*%)
Al ₂ O ₃	2.2	36848	6204	30644	0.2	0.19	10
Fe ₂ O ₃	0.144	730584	168229	562357	0.002	0.002	3900

There are several options to improve the accuracy and sensitivity of measurements. Since accuracy is a function of measurement time, a longer time, such as 900s, can be applied. In addition, to improve the statistical parameters of Al, it is possible to measure only Al without Fe. In this case, a lower voltage, namely below 7.0kV, can be applied to the X-ray tube to excite the sample. This allows the use of a higher current, thereby obtaining a higher intensity of the Al line. On the other hand, higher intensity leads to a better accuracy.

Online measurement of iron (Fe) and titanium (Ti) concentration in dry and wet feldspar

The aim of this project was to analyze the concentration of

iron oxide Fe₂O₃ and titanium oxide TiO₂ in dry and wet feldspar on a conveyor in real time. The sand under study had a known concentration of TiO₂ in the range of 0.032 to 0.169% and a concentration of Fe₂O₃ in the range of 0.008 to 0.100%. Feldspar looks like fine white sand with a grain size of less than 500µm. The conveyor speed was 1m/s, the distance between the sand and the analyzer was 50mm (variable between 30 and 70mm) (Figure 14). The online analyzer contained an X-ray tube with anode made of Mo. The optimal modes of the X-ray tube for solving the task were X-ray tube voltage of 35kV, X-ray tube current of 800µA and measurement time of 300sec. Primary radiation filter (Mo, 50µm) installed between the X-ray tube and the sand layer was used.



Figure 14: Online XRF analyzer measuring iron (Fe) and titanium (Ti) concentration in dry and wet feldspar.

Prior to conveyor measurements, the analyzer was calibrated in the laboratory using 15 standard calibration samples provided by the customer. Samples obtained were taken from 3 different streams of the monitored material and measured in the customer’s laboratory. Individual calibration was prepared for each separate stream. Using 3 kits (samples from 3 streams), each consisting of 5 samples, we calibrated the analyzer in steady-state mode for each fraction with both dry and wet samples, respectively. For each flow and moisture state (dry and wet), individual calibration curves were constructed. Samples of each stream were measured in the dry and wet state (~20% of the water mass was added to each individual sample). Calibration dependencies were linear for all cases studied. Regression equations were calculated for each fraction and moisture level. The regression coefficients corresponding to a particular flow were taken into account in the construction of 3 individual methods, which were used by the software for automatic flow analysis. The calibration (regression) coefficients for the first

stream, for example, were $R^2=0.991$ (dry, Ti); $R^2=0.995$ (dry, Fe); and $R^2=0.9626$ (wet, Ti); $R^2=0.9448$ (wet, Fe).

A typical X-ray spectrum measured for feldspar samples during subsequent conveyor measurements is shown in Figure 15. The magnification of low-intensity lines is shown in Figure 16. Several well-identified XRF lines are observed in the spectra, namely calcium (Ca), titanium (Ti), iron (Fe), copper (Cu), zinc (Zn) and strontium (Sr). XRF lines of light sand components such as magnesium (Mg), aluminum (Al) and silicon (Si), are not visible in spectra measured in air and with the measuring head located 50mm from the sample surface. XRF photons emitted by light elements are very weak; these are easily absorbed in the material being measured and in the air gap between surface of the material and the analyzer. The spectra of all samples are identical. The intensity of XRF spectra lines of the $TiK\alpha$ and $FeK\alpha$ target elements increases in direct proportion to the concentration of the components.

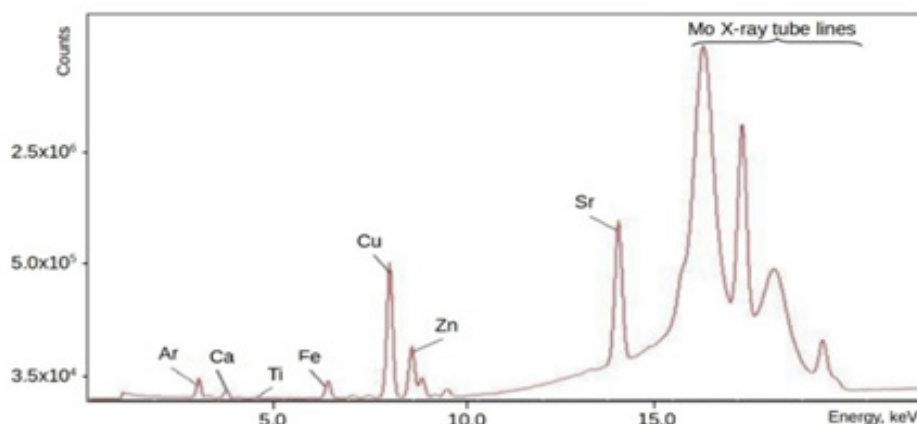


Figure 15: Overview of feldspar spectrum. The Mo lines are instrumental; the Ar line is emitted by Ar atoms in the air between the sample and the analyzer.

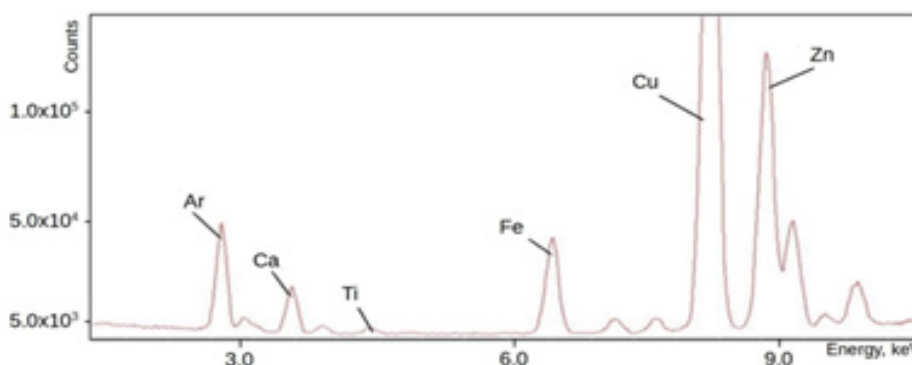


Figure 16: Zoom into low-intensity lines of feldspar spectrum shown in Figure 15. The Ar line is emitted by Ar atoms in the air between the sample and the analyzer.

Calculations of the studied spectra showed that the detection limit for TiO_2 was 0.009% for Fe_2O_3 - 0.005% during measurement time of 300 seconds. The concentration of Fe_2O_3 in feldspar samples can be determined with an accuracy of better than 10% (relatively)

in all fractions (flows). The TiO_2 content in feldspar samples can also be measured with an accuracy of ~10% (relatively). The repeatability of XRF analysis was measured for the 3 studied fractions and turned out to be 1-2% relative for the 5-minute

measurement ($n=200$ in continuous automatic mode). Thus, the test results showed that the online XRF analyzer is able to measure Fe_2O_3 and TiO_2 content in dry and wet feldspar streams that are transported by a conveyor. The detection limit for TiO_2 was 0.009%, for Fe_2O_3 - 0.005% over a measurement time of 300 seconds. The concentration of Fe_2O_3 and TiO_2 in feldspar samples can be determined with an accuracy of better than 10% (relatively). The repeatability of the analysis is 1-2% relative for a 5-minute measurement ($n=200$ in continuous automatic mode).

Conclusion

As the results of this work show, the online XRF method allows to reliably solve problems of controlling the concentration of impurities in industrial sands on the conveyor of mining enterprises. The detection limits of various impurities (Fe_2O_3 , Al_2O_3 , TiO_2 ...), as well as the statistical accuracy of the obtained concentration values fully meet requirements of enterprises. The online analysis results obtained on the conveyor are consistent with the results of the analysis in factory laboratories. The main difference is that laboratory measurements require taking samples from the conveyor for analysis and take several hours of work by specialists in the laboratory. Online analysis of impurities on the conveyor does not require the participation of specialists and provides analysis results in almost real time, whilst opening up prospects for the automation of technological reprocessing of the extracted industrial sands as part of the Automated Process Control System (APCS) of enterprises.

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