Online X-Ray Fluorescence Monitoring of Coarse Ore for Silver at the Process Conveyors at Kazakhmys Corporation LLC

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Abstract

This paper examines the process and methodological aspects of implementing online X-ray fluorescence monitoring of ore in terms of its silver, cadmium, zinc, lead, molybdenum, and iron grade at the process conveyors at Balkhash and Karagaily Concentrators and the main conveyor of the Nurkazgan underground mine operated by Kazakhmys Corporation LLC. The research was complicated by the need to: a) ensure reliable measurement of silver and cadmium in the range of 1+ ppm, molybdenum in the range of 10+ ppm, as well as copper, zinc, lead, and iron in the ore size class –300 mm; b) implement monitoring of the grade of these elements (except molybdenum) at Balkhash Concentrator in the waste slag of Balkhash Copper Smelter, characterized by a very complex elemental matrix. A modification of the ore monitoring station RLP-21T (by Aspap Geo LLC, Alma-Ata) was developed, implemented, and thoroughly tested for online monitoring of low-grade silver ore flows. Energy dispersive X-ray fluorescence method was adopted for ore assays. Instrument spectra were measured every second. Silver, cadmium, and molybdenum grade was calculated based on 40 measurements, copper, zinc, lead, and iron grade – based on 20 measurements.

Keywords: *X-ray fluorescence method, RLP-21T ore monitoring station, copper, silver, cadmium, molybdenum, online monitoring of ore grade, process conveyors*

Introduction

The existing literature on the implementation of effective online monitoring of silver, cadmium, copper, lead, zinc, and iron in the run-of-the-mine ore from the copper sandstone deposits Zhezkazgan and Zhaman–Aibat fed to the Zhezkazgan Concentrators 1 (ZC–1) and 2 (ZC–2), using energy dispersive X-ray fluorescence (EDRXF) ore monitoring stations (OMS) at on belt process conveyors, was reviewed in detail in [1–3]. As a result of the studies conducted at ZC–1 and ZC–2 from October 2016 to January 2017, for the first time in Kazakhstan the most pressing production problem was solved: highly effective online monitoring was implemented of primary (Cu, Pb, Zn) and secondary (Ag, Cd) commercial elements in ores of the size class -300 mm with a low (5+ ppm) silver grade, transported by heavy-duty belt conveyors at concentrator plants.

Zhezkazgan industrial site and the Zhomart mine now have access to: a) real-time information on the grade of the ore fed to the concentrator plants during the shift, day, and since the beginning of the month and can quickly make the necessary adjustments to the mining and concentration process; b) reliable evidence for the purposes of substantiating their proposals concerning ore grade when the concentrator's output is allocated at the end of the calendar month.

The research goal was to develop a single high-performance system for online monitoring of the chemical composition of the salable copper polymetallic ores at the mining operations of Kazakhmys Corporation LLC, focused not only on the core element (copper), but also secondary elements (silver, cadmium, molybdenum). The goal was achieved at some of the operations at the Zhezkazgan industrial site.

But Kazakhmys Corporation LLC also controls the deposits developed by the mining operations at the Karaganda and Balkhash industrial sites: the gold and copper porphyry deposit Nurkazgan (Cu, Au, Ag, Mo, Se, S), the pyrite-copper-lead-zinc deposits Kusmuryn (Cu, Zn, Pb, Au, Ag, Cd Se, Te, S) and Akbastau (Cu, Zn, Pb, Au, Ag, Cd, Se, S, Te), the gold-pyrite-copper-lead-zinc deposit Abyz (Pb, Zn, Cu, Au, Ag, S, Se, Te, Cd, In, Hg), the Sayak group of copper skarn deposits (Cu, Mo, Fe, Au, Ag, Co, Bi, Te, Se, Re), the porphyry copper deposits Shatyrkol (Cu, Mo, Au, Ag, Te, Se, U) and Konyrat (Cu, Mo, S, Au, Ag, Re, Se, Te), as well as the concentrators (Balkhash (BC), Karagaily (KC), Nurkazgan (NC)) processing the ores.

The research goal was to deploy a single high-performance system for online monitoring of the chemical composition of salable copper polymetallic ores at the mining and processing operations of the Karagandy and Balkhash industrial sites controlled by Kazakhmys Corporation LLC.

The ores of the deposits listed above are characterized by a broad grade range of the primary and associated elements, a very low (1+ ppm) silver grade, and a large number of process ore grades, i.e. are more challenging in terms of implementing an X-ray fluorescence online monitoring of the ore grade at the process belt conveyors compared to the ore coming from the homogeneous (copper sandstone) deposits Zhezkazgan and Zhaman–Aibat.

Balkhash Concentrator is fed ore from the mines Konyrat, Sayak (Sayak-1 and Tastau), Shatyrkol, Nurkazgan, Akzhal

Fig. 1. RLP–21T at the conveyors 2 and 2A, Balkhash Concentrator. Conveyor gallery with the OMS installed (a) and ore monitoring station RLP–21T (b)

Rys. 1. RLP – 21T na przenośnikach 2 i 2A, koncentrator Balkhash. Galeria przenośników zzainstalowanym OMS (a) i stacją monitorowania rudy RLP – 21T (b)
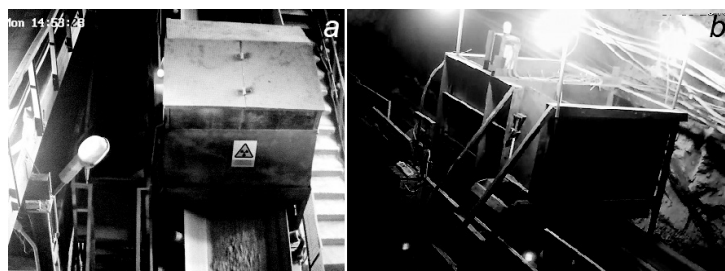

Fig. 2. RLP–21T at the conveyors of Karagaily Concentrator and Nurkazgan mine. Conveyor 4 at Karagaily Concentrator (a) and conveyor at the Nurkazgan mine (b)

Rys. 2. RLP – 21T na przenośnikach w zakładzie wzbogacania Karagaily i kopalni Nurkazgan. Przenośnik 4 w zakładzie Karagaily (a) i przenośnik w kopalni Nurkazgan (b)

and waste slags of Balkhash Copper Smelter. Karagaily Concentrator is fed ore from the mines Akbastau, Kusmuryn, and Abyz. The ore produced by the Nurkazgan underground mine (NM) is processed at NC.

The research task was the most difficult at BC, simultaneously receiving ore from heterogeneous sources, such as deposits, and a virtually homogeneous source, i.e. the slag waste dump at Balkhash Copper Smelter. The copper ores being processed have high (Shatyrkol), medium (Sayak-1, Tastau, Nurkazgan), low (Konyrat), and poor (Akzhal) grades. The waste slags from Balkhash Copper Smelter have a complex elemental composition: Cu — up to 1.15%, Zn — up to 6.0%, Pb — up to 0.70%, Fe — up to 47.0%. Ore grain size: -300 mm. OMS was planned to be installed at the heavy-duty belt conveyors 2 and 2A. Monitored elements: Cu, Pb, Zn, Ag, Cd, Fe.

At KC, one OMS unit was to be installed at the conveyor 4. Ore grain size: -50 mm. Monitored elements: Cu, Pb, Zn, Ag, Cd, Fe. Due to the more favorable ore size distribution, this research task was considered the least difficult.

At NM, one OMS was planned to be installed at the mine's main conveyor. Ore grain size: -300 mm. Monitored elements: Cu, Pb, Zn, Ag, Mo, Fe. Ore properties: a) very low silver grade (the deposit averages 2.9 ppm); b) molybdenum in the ore (110 ppm on average).

Due to the fact that the global non-ferrous metals industry offers no examples of effective online monitoring of the primary and associated ore component grades at an ore size of -300 mm and silver and cadmium grade higher than 1+ ppm using EDXRF OMS, the research problem is of high theoretical and practical relevance.

Study area/Materials and methods

A detailed review of the OMS market is available in [1–3]. Due to the fact that effective online monitoring of the primary

and associated ore component grades at ZC-1 and ZC-2 was successfully implemented with the help of EDXRF OMS RLP-21T, for BC, KC, and NM we chose: OMS RLP–21T, X-ray fluorescence ore assay; an X-ray tube with side end radiation emission coupled with combined targets as the excitation source; silicon drift detector (SDD) with an internal collimator as the radiation detector, which, together with a digital signal processor, provides a high energy resolution (130 eV along the 5.9 keV line).

Ensuring the stable operation of the OMS in ores with an extremely low silver, cadmium, and molybdenum grade for X-ray fluorescence is an extremely challenging task in terms of instruments and methods. To achieve the set goals, RLP-21T OMS was configured with more powerful X-ray tubes (a significantly higher pulse loading of the spectrometric tract and, consequently, a higher sensitivity of X-ray fluorescence measurements of silver, cadmium, and molybdenum was achieved); large-area silicon drift detectors (FAST SDD® 25 mm² (500 μm/0.5 mil Be/ML) (the detectors are capable of operating at loads up to 1 Gb/s, which is extremely important, because only at such loads RLP-21T OMS can handle ores low in silver, cadmium, and molybdenum); the most advanced (high-speed) electronics; individual collimators of the X-ray tube primary radiation beam tube (clean conveyor belt sections containing zinc should not get into the exposed area of the ore surface).

To reduce the conveyor stopping time for the OMS operability checks, an artificial control sample was added to RLP-21T OMS, which is mounted onto the openings of the X-ray tube and SDD on the side end of the RLP-21T OMS body and held by magnets. Elemental composition of the control sample: Cu – 1.38%, Ag – 12.0 ppm, Zn – 0.05%, Pb – 0.20%, Cd – 1.8 ppm, Fe – 4.65%.

Tab. 1. RLP–21T performance at BC in 2018
Tab. 1. Wydajność RLP – 21T w BC w 2018

Month of 2018	Copper, %				Silver, ppm			
	Underflow	OMS	Δ	σ, %	Underflow	OMS	Δ	σ, %
5	0.85	0.85	0	0				
6	0.93	0.93	0	0				
7	0.93	0.95	-0.02	2.15				
8	0.92	0.95	-0.03	3.26	5.33	4.51	0.82	15.38
9	0.94	0.95	-0.01	1.06	5.35	4.49	0.86	16.07
10	1.04	1.05	-0.01	0.96	5.53	4.60	0.93	16.82
11	0.98	0.95	0.03	3.06	4.50	4.34	0.16	3.56
12	1.11	1.10	0.01	0.90	5.81	6.01	-0.20	3.44
Year total	0.963	0.966	-0.004	0.39	5.304	4.790	0.514	9.69

Tab. 2. RLP–21T performance at BC in November 2018
Tab. 2. Wyniki RLP – 21T w BC w listopadzie 2018

Mine	Copper, %				Silver, ppm			
	Underflow	OMS	Δ	σ, %	Underflow	OMS	Δ	σ, %
Shatyrkol	2.34	2.27	0.07	2.99	3.85	3.70	0.15	3.90
Sayak	1.04	1.00	0.04	3.85	5.59	5.37	0.22	3.94
Nurkazgan	1.05	1.02	0.03	2.86	3.25	3.12	0.13	4.00
Konyrat	0.28	0.37	0.01	2.63	2.88	2.77	0.11	3.82
Slag	0.73	0.72	0.02	2.70	7.88	7.57	0.31	3.93
Total	0.98	0.95	0.03	3.06	4.52	4.34	0.18	3.98

Dedicated research was carried out for the purposes of the more complex analytical tasks, as a result of which major upgrades were made to the OMS RLP–21T software. In the software, in particular, the components were upgraded responsible for the following: compensation for the variable profile of ore loading onto the belt conveyor (variable sensor–ore gap); compensation for the matrix effect; automatic selection of conversion equations for each ore supplier to BC, etc. In addition, Aspap Geo LLC had to deviate from its basic principle: since the online monitoring objects are different, ore types are different, ore processing products are different, they had to switch to custom scales. The scale was selected automatically depending on the content of a group of elements (primarily copper and iron).

Prior to installation on the conveyors, all OMS RLP–21T units underwent mandatory bench tests. The research objects were specially prepared ore sample sets from each of the deposits with a known content of the six elements. Each set included three types of samples: powdered samples, size fraction after the roller crusher (-3 mm), size fraction after the jaw crusher (-10 mm). After each OMS was suspended directly at the conveyors, the entire test cycle repeated, but taking into account the limitations on the stopping time of the conveyors for the tests.

At the OMS intended for the BC, KC, and NM conveyors, the ore assay process tested at ZC–1 and ZC–2 [2, 3] was kept with a single measurement exposure of 1 sec. The only difference was that at BC, copper, lead, zinc, and iron grades are averaged based on 20 single measurements, silver and cadmium grades are averaged based on 40 single measurements; at KC and NM, all grades were averaged over five-minute intervals.

Results and discussion

The main research findings are discussed below.

1. At BC, OMS RLP-21T were installed at the heavy-duty belt conveyors 2 and 2A and put into operation on May 4, 2018 (Figure 1).

The performance of RLP-21T at BC is shown in Table 1 (for silver, the differences in August–October 2018 were due to technical reasons; these were later eliminated, as indicated by the data from November and December). The interpretation of the performance data of RLP–21T in November 2018 is given in Table 2.

In July 2018, the QC testing station at the KKD 1500/180 crusher was shut down. As the data is collected, the grade calculation algorithms for some ore suppliers are being refined.

Attention should be paid to the fact that, over the 11 months of operation, the maximum silver grade in a single train recorded by the OMS was 11.5 ppm (Tastau) and 12.3 ppm (waste slag), and the minimum grade was 1.9 ppm (Kounrad). This is much lower than the silver grade of the ores fed to ZC–1 and ZC–2. Moreover, for the first time in the world practice, an EDXRF OMS was able to detect that low silver grades in ores sized -300 mm.

2. At KC, OMS RLP-21T was put into operation at conveyor 4 on July 27, 2018 (Figure 2a). The silver grades recorded by OMS over one five-minute interval were: 19.6 ppm (maximum) and 6.5 ppm (minimum). This is another evidence of the uniqueness of the methodological approach and numerical models underlying RLP–21T.

3. RLP-21T at the Nurkazgan underground mine. RLP–21T on the main belt conveyor was put into operation on June 14, 2018 (Figure 2b). The grades recorded by OMS over one five-minute interval were: 7.4 ppm (maximum) and 1.1 ppm (minimum) for silver, 0.1105% (maximum) and 0.0008% (minimum) for molybdenum.

Conclusion

1. A system for online monitoring of the primary (Cu, Pb, Zn) and associated (Ag, Cd, Mo) elements in the copper polymetallic ores processed at Balkhash Concentrator, Karagaily

Concentrator, and the Nurkazgan underground mine was developed, thoroughly tested, and commercialized. The system is based on the EDXRF ore monitoring station RLP–21T.

2. Four ore monitoring stations RLP–21T were put into operation: two at BC (heavy-duty belt conveyors 2 and 2A, monitored elements: Cu, Pb, Zn, Ag, Cd, Fe), one at KC (belt conveyor 4, monitored elements: Cu, Pb, Zn, Ag, Cd, Fe), one at NM (main belt conveyor, monitored elements: Cu, Pb, Zn, Ag, Mo, Fe).

3. For the first time at a large-scale mining project in Kazakhstan (Kazakhmys Corporation LLC), a practical solution was implemented for online monitoring of primary (Cu, Pb, Zn) and, most importantly, associated (Ag, Cd, Mo) elements at low (1+ ppm) silver and cadmium and (10+ ppm) molybdenum grades and an ore size of -300 mm at process belt conveyors. Thus, the groundwork has been laid for ore grade management according to the content of the primary and associated elements (most importantly, silver).

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Monitorowanie online za pomocą fluorescencji rentgenowskiej gruboziarnistej rudy srebra na przenośnikach w zakładzie przeróbki w Kazakhmys Corporation LLC

W artykule przeanalizowano proces i aspekty metodologiczne wdrażania zdalnego monitorowania zawartości srebra, kadmu, cynku, ołowiu, molibdenu i żelaza w zakładach wzbogacania Balkhash i Karagaily oraz na głównym przenośniku w kopalni podziemnej Nurkazgan obsługiwana przez Kazakhmys Corporation LLC. Badania były skomplikowane ze względu na konieczność: a) zapewnienia niezawodnego pomiaru srebra i kadmu w zakresie 1+ ppm, molibdenu w zakresie 10+ ppm, a także miedzi, cynku, ołowiu i żelaza w klasie –300 mm; b) wdrożyć monitorowanie tych pierwiastków (z wyjątkiem molibdenu) w koncentracie Balkhash ,w żużlu odpadowym Huty Miedzi Balkhash, charakteryzującym się bardzo złożoną matrycą elementarną. Opracowano, wdrożono i dokładnie przetestowano modyfikację stacji monitorowania rudy RLP-21 (firmy Aspap Geo LLC, Alma-Ata) do monitorowania online przepływów rudy srebra o niskiej jakości. Do fluorescencji rentgenowskiej zastosowano dyspersyjną metodę rentgenowską. Widma mierzono co sekundę. Zawartość srebra, kadmu i molibdenu obliczono na podstawie 40 pomiarów, a miedzi, cynku, ołowiu i żelaza – na podstawie 20 pomiarów.

Słowa kluczowe: rentgenowska metoda fluorescencji, stacja monitorowania rudy RLP-21T, miedź, srebro, kadm,molibden, monitoring online rudy, przenośniki taśmowe