History of Sensor-Based Sorting in CIS

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Abstract

History of a sensor-based sorting usage in CIS/USSR starts since 1936 when Mr Bogoslovsky, an engineer of All-Russia Scientific-Research Institute for Mineral Materials (VIMS), had designed the first type of an X-ray luminescence sorter for recovery of diamonds.

In 1960s, at the time of growth in the uranium industry in the USSR, the industry started showing great interest in a sensor-based sorting. At various scientific-research institutes and research-and-development enterprises there were the sensor-based sorting test laboratories organized with focus on the theory and practice for application of the sensor-based sorting (SBS).

From 1970s to 1990s, these laboratories had closely worked with various geological prospecting enterprises. As a result of the work, a large amount of data was gathered from different deposits all over Russia related to the sensor-based sorting parameters for various types of ores, coal and industrial minerals. At the same time, the test work standards were developed to study amenability of ores to treatment by the sensor-based sorting that should be carried out during geological prospecting activities.

One of the distinguishing features of soviet times was use of only home-produced equipment in the industrial-scale operations. So, it resulted in the use of solely domestic sorting equipment based on the SBS, X-ray fluorescence (XRF), X-ray luminescent (XRL) and neutron-absorption sorting. Large-scale test works and application of optical sorters, X-ray Transmission (XRT) technology and electromagnetic high-capacity sensors have started in Russia only after 2000s.

At present, the SBS technique is being used in CIS countries, including Priargunsky Industrial Mining and Chemical Company (Russia) and Vostochny Mining and Metallurgical Company (Ukraine), applying sorting and separation for uranium ores; in Kokpatas and Daugyztau deposits (Uzbekistan) for batch sorting and separation of gold ores; Svyatogor Company (Russia), separation of copper-zinc ores; and ALROSA Corporation, XRL sorting of diamond ore.

Introduction

According to Russian specialists dealing with SBS issues, different types of radiation for treatment of minerals were proposed and implemented by an engineer of VIMS (All-Union Scientific-and-Research Institute of Mineral Resources named after N.M. Fedorovsky, Moscow) M.E. Bogoslovsky who developed engineering prototypes of XRL and Gamma-Absorption sorters with manual operation unit in 1939 for recovery of diamonds [1, 2]. Growth of the uranium production industry in 1950s gave an impulse to development of the SBS technique in the USSR. Further development involved test works on various processing techniques for treatment of other types of raw materials. There were laboratories set up based on scientific-and-research institutes in the USSR in order to develop methodology of the SBS, carry out process studies and design the sorting and separation equipment. It should be noted that this resulted in high level of knowledge over Russian deposits related to amenability of their ores to the SBS. However the majority of test works was carried out using only X-ray radiometric or neutron-absorption sorting techniques, which use is limited.

This paper considers the USSR's (CIS) development and application experience in the SBS techniques, as well as it gives brief description of sorting equipment manufacturers. Given that this paper examines the period of time over 60 years, during which the Soviet Union/CIS undergone significant changes, names of cities, institutes and enterprises may have changed. For example, Leningrad now called St. Petersburg; and the scientific-research institutes that had 'All-Union' in their names now are named as 'All-Russian' or 'Leading', etc.

Development of Sensor-Based Sorting in the USSR

As it was mentioned above that increased attention of Soviet leaders to the uranium industry or more accurately to atomic power and nuclear weapons gave a stimulus to the development of the SBS in the USSR.

At the end of 1950s, the first Russian SBS plant was commissioned on the basis of Vostochny GOK (Zheltye Vody, Ukraine) that produced and treated uranium ores [1, 2]. A specialized department later named as NPK Automation and Mechanics was set up at the enterprise to develop equipment on its base. At scientific-research institutes, VIMS and VNIIIKhT (All-Union Scientific-Research Institute for Chemical Technology, Moscow), there were laboratories established that dealt with methodological support and practical application of SBS methods. Selection of these institutes was stipulated by the fact that VIMS was involved in prospecting and exploration work of uranium and rare-metal ore deposits and VNIIKhT dealt with processing and hydrometallurgy of the given ores.

From 1960s to the end of 1970s, soviet era specialists suggested the neutron-radiation-based separation methods. Experimental models of such equipment were used during metallurgical test work of the ores while evaluating of deposit reserves. However because of safety requirements to work with of neutron-radiation sources, this technique was not widely spread.

At the same time I. Ostapenko headed team of Central Scientific-Research Institute for Tin (TsNII-Olovo, Novosibirsk) worked on development of prototype photometric sorters with studies mainly focused on gold ores. In late 1970s, processing department of Sverdlovsk Mining Institute (now Ural State Mining University, Yekaterinburg) also began studies of photometric sorting issues. Developments of XRL sorters for diamond industry were carried out by Burevestnik Research and Production Enterprise (Leningrad/St Petersburg) and Yakutia Scientific-Research and Design Institute for Diamond Industry (YakutNIIPROAlmaz).

To meet demand for reading materials devoted to engineering and technique of the SBS, apart from routine scientific-research articles published in scientific journals (as a rule, about 20 articles per year on the topic), there were various Ph D monographs published in USSR, including V. Mokrousov [2, 3], A. Tatarnikov [4], I. Koshelev [5], and L. Pukhalski [6]. All-Union conferences of specialists dealing with the SBS were held in 1978 and 1985. Moreover, it should be highlighted the specific features of these research articles monographs published in the USSR. Since the most of the studies were focused on uranium and rare metal ores preventing disclosing of research results or when the research results were given without names and characteristics of the deposits under study.

To summarise the Soviet era developments in the SBS, the following two features can be distinguished that largely determine the current position of the SBS techniques in the CIS.

- Firstly, because the studies were conducted by specialists of scientific-research organisations, so the considerable attention was given to theoretical issues: they proposed classification methods and techniques for the SBS; specialists developed techniques for conducting of test works, etc.
- The second feature was related to the actual ban to purchase the relevant sorters abroad during Soviet era. Such equipment was bought in exceptional cases and in small quantities only for research institutes. Along with this, the lack of such equipment producer in the USSR, for example photometric sorters, became an obstacle for application of this method. This was despite the fact that ores of many deposits undergone processability tests using this method. This fact explains the prevalence given to the X-ray radiometric sorting method in many deposits of the CIS, as well as because the equipment for this method was produced since late 1980s.

Methodological Issues Related to the Sensor-Based Sorting

Since late 1960s, there were discussions between experts of two major relevant research institutes (VIMS and VNIIKhT) about name and classification of the sensor-based sorting. However, from the 1980s to the present day, VIMS proposed terminology is being used in all the official documents and standards of the Ministry of Natural Resources.

According to this terminology, in general, this processing technique is called as ‘sensor-based sorting‘ since all the methods are based on the interaction of various radiations (*radio* (*lat*)- ‘emission‘) with material. A classification of sorting techniques is based on the interaction peculiarly of radiation with material. For example, XRT method in this classification is called XR-absorption and separation of ores by their natural radioactivity is called auto-radiometric method.

At the end of 1970s, a technique of test works on amenability of ores to processing using the SBS was developed that included identification of the following:

- Grain-size composition of ore.
- Study of the material composition of ore.
- Assessment of commercial components' distribution irregularity in ore lumps or rock mass batches.
- Develop and determine the separation parameters' effectiveness.
- Laboratory testing using a sorter/separator.

According to this technique, at the beginning the work can be conducted using only a 'separation feature' unit that is a device having a signal exciter part (X-Ray tube, light sources, etc.) and a signal detector which allows field studies. Moreover it is recommended to conduct studies on two and more methods. For example, studies of optical and sensor-based sorters for gold ores. After identification of an optimal feature for separation and a separation method, the actual separation operation using a separator is carried out.

Application of this methodology makes it easy to determine reasons of poor performance of the process during separation; identify grain-size and material compositions; and to understand if selection of a separation method is incorrect or that modern detectors are imperfect. It is obvious that if poor indicators of the process are stipulated by insufficient development of the sorting equipment, for example, insufficient sensitivity of a detector, this problem can be solved with time and ores of the deposit under study can be tested using the SBS.

At present it is compulsory requirements of the State Commission on Reserves of the Russian Federation, the body for state control over rational use of mineral resources, to carry out the ore processability test works using the SBS techniques for the deposits which exploitation is just starting.

Sensor-Based Sorting Techniques

There are two fundamentally different processing method distinguished in the SBS: lump-by-lump separation and 'batch sorting'. Having the lump-by-lump separation widely known to the specialists dealing with the SBS, however the batch sorting is only a local-scale phenomenon with the use experience noticeable only in the USSR enterprises and the Eastern coalition of countries like Czechoslovakia, German Democratic Republic.

Batch sorting is a process of separation by types of broken rock mass, as a rule, into rich, ordinary, low-grade and tailings; or, if the ore is represented by several process types, the ore is divided into, for example, lead and zinc ores. There are usually two or three types of ores allocated.

The sorting process is usually done in ore control stations directly inside the transportation vehicles as follows: a rail car or a dump truck that is loaded with rock mass pulls into the ore-controlling station where ores are checked for their commercial mineral composition by auto-radiometric or SBS method if ores are radioactive and by XRF method if ores are gold-bearing for gold and non-ferrous ores. Further a transportation vehicle is directed to an appropriate stockpile: high-grade ore and/or middle-grade ore sent to a processing plant; off-grade ore to a stockpile or to a lump-by-lump sorting unit; and tailings, to dumps.

This technique is more efficient and much cheaper compare to the lump-by-lump separation. One ore control station can serve a whole open pit or one working level in an underground mine. However, this method is less selective and largely determined by mining method. For example, this sorting method is not suitable for the mining method with high likelihood for blending of broken rock mass. Positive feature of this technology is the ability to remove 3 to 7 % of waste rock before crushing and screening operations that are required for the lump-by-lump sorting. This also, provides operational quality control of ores and involvement of very low-grade ores in concentration, examples of which will be shown below.

Equipment Producers in the CIS

Currently, IR, XRL, XRF and auto-radiometric sorters are manufactured in the CIS. Auto-radiometric sorters are made by NPK AiM (Ukraine) and being supplied only to Vostochny GOK.

XRF separators are manufactured by the following companies: Rados; SibRados that is spin off of Rados; Tekhnoros, a partner of Rados; Integra and its spinoff company Inkorgeotekh; and NPK AiM. These companies produce equipment and software for XRF for batch sorting. It should be noted that Rados dominates in this market.

IR sorters are manufactured by Promtekhnologii (Ukraine); and XRL sorters, by Burevestnik company that is now a major supplier of processing equipment to ALROSA diamond mining corporation.

Mining Companies Using Sensor-Based Sorting Technique

Below are current application examples of the lump-by-lump sorting and batch separation in mining enterprises of the CIS.

Uranium Ores

While applying the sensor-based sorting in the USSR mines production uranium ores, the traditionally used method was auto-radiometric sorting and separation. However with establishment of Rados from the end of 1990s, XRF became a widely method.

At present the SBS of uranium ores in Russia is used in Priargunsky Mining and Chemical Association.

In 1982, various mines implemented the SBS that included a sorting unit installed close to a production face, further sorting in transportation vehicles in the ore control stations and the lump-by-lump separation using auto-radiometric method in a SBS plant with various separators installed (made by VNIIKhT, NPK AiM and plants' own designs). For a number of reasons, including imperfect equipment used, as well as inconsistency in a separation parameter due to application of speeded ore breaking that led to violation of radiological equilibrium, so in 1993 operation of the SBS plant was stopped. However in 2006 the SBS processing plant was equipped by X-ray radiometric separators of Rados, and they are in operation to date.

The existing combined technology includes pre-concentration large-size batch sorting of ores inside rail cars or dump trucks in the ore control station with separation of rock mass into on-grade and off-grade ores. On-grade ore is then fed to the lump-by-lump sorting unit. Off-grade ore is directed to a heap leaching site. As a result of such separation, yield of final tailings amounts to 45-88 % [7]. In 2013, Priargunsky Mining and Chemical Association commissioned a mobile ore sorting facility to treat its uranium ore dumps.

Significant experience in application of the auto-radiometric separation method exists in Vostochny GOK (Ukraine, the town of Zheltye Vody). In 2005, the company adopted "Programme for Development of Alternative Sources of Uranium" that stipulated use of ore sorting plants to reduce uranium content in the off-grade ore dumps, as well as for land reclamation. To meet the challenges of the programme, the company specialists developed a mobile screening plant. The source material from the dumps was sent to the ore control station where the material divided into final tailings, low-grade ore and high-grade ore. Then the high-grade ore is fed to a hydrometallurgical process, and the low-grade ore directed to an ore separation complex (auto-radiometric separators) to produce enriched product and the final tailings.

Application of the screening units in Vostochny GOK has reduced the content of uranium in Smolinskaya mine dumps from 0.018 % to 0.011 %, and in Ingulskaya mine dumps, from 0.02% to 0.015 %. The use of the combined SBS technique allowed mitigate negative impact of the mine to the environment, site restoration, as well as to produce additional saleable products [8].

Gold-Bearing Ores

Large-scale test works for separation of gold-bearing ores in the USSR started in 1960s. Moreover, they were based on photometric sorting but due to shortcoming in home-made equipment their use in USSR rarely extended beyond the test work scales. At present, the photometric sorting is being used in Karalveem deposit. Since middle of 1980s, X-ray radiometric sorting of gold-bearing ores is actively used in Russia.

There is a very interesting experience in testing and application of the SBS for gold-bearing ores in Kokpatas deposit (Uzbekistan). At the initial stage (1990-2000), the mined ores were of sulphide, oxidized and mixed types which differed not only in terms of material composition but also in colour. Laboratory tests have shown that photometric sorting was potentially suitable for these ores. However, during the pilot tests it was found that the ores required pre-flushing for their effective separation, but this was impossible to do in desert region with significant shortage of water. At present the mine has nearly mined out its oxidized ore reserves, and there is no need any more for sorting of the ores into various process types.

In parallel with the studies on the separation of ores into various process types, the company conducted the work on the development of the ore pre-concentration technique. This research resulted in implementation of a combined technique of the SBS of ores, that included large-size batch sorting of ores inside dump trucks in the ore control station with subsequent lump-by-lump separation using equipment made by IntegraGrupRu. Kokpatas deposit is developed by more than 30 open pits. Ores are difficult to treat. Ore bodies have complex occurrence with multiple intersections of barren rock. Table 1 below shows results of batch sorting and lump-by-lump separation

Table 1: Sensor-based sorting process parameters of Koktapas deposit ores

Product	Yield, ktpa	Yield, %		Grade Au, g/t	Distribution, %
		of total mass	by ore types		
Sorting in Ore Control Station					
On-grade ore					
Ore	4.5	61.01	97.09	2.84	81.19
Waste rock	0.15	1.83	2.91	0.47	0.40
Total	4.65	62.84	100.00	2.77	81.59
Off-grade ore					
Ore	0.9	12.12	55.34	1.84	10.45
Waste rock	0.7	9.78	44.66	0.39	1.79
Total	1.6	21.91	100.00	1.19	12.24
Mineralized rock					
Ore	0.4	5.87	38.50	1.65	4.54
Waste rock	0.7	9.38	61.50	0.37	1.63
Total	1.1	15.26	100.00	0.86	6.17
Total in Ore Control Station					
Ore	5.9	79.01	-	2.60	96.18
Waste rock	1.5	20.99	-	0.39	3.82
Total	7.4	100.00	-	2.13	100.00
Lump-by-lump separation					
Concentrate	2.91	39.00	49.30	4.59	83.80
Tailings	2.99	40.10	50.70	0.66	12.83
Total	5.90	79.10	100.00	2.60	96.18

Application of the large-size batch sorting of rock mass allows to separate the off-grade gold content material from the on-grade ore and, vice versa, to produce on-grade material from the off-grade ores, thus ultimately increasing by about 20% production of metals from the mining sites. The rock mass in the ore-control station is subdivided into three streams: high-grade ore fed to hydrometallurgical plant; ordinary ore, fed to ore-sorting plant; and final tailings to storage [9].

Application of X-ray radiometric method enabled separation of the product with a yield of 30-40% and off-grade gold content. Therefore the gold content in the enriched product fed for further treatment increased by 1.5 to 2 folds. Implementation of the combines SBS in the company allowed to increase the deposit's life because of involvement of the out-off-balance ores in the economically sound concentration, as well as by additional production of commercial products.

The first industrial application of the X-ray radiometric separation of gold ores is dated from 1994 when Rados separators were installed in Holbinsky and Kommunar mines.

In 2000-2005, Eldorado mine (Krasnoyarsk region) exploited an ore-sorting complex equipped with X-ray radiometric separators. These separators were fed by the ore at a gold grade of 1.0-1.8 g/t. While separation process, the ore was enriched to a gold grade of 2.5-3 g/t at the product yield of 40 %, and tailings with a gold content of 0.6-0.9 g/t. Implementation of the pre-concentration allowed to reduce the ore transportation costs and its subsequent enrichment by 47%. This ore sorting complex was dismantled in 2005 because the mine transferred to a heap leaching technology.

In Tokursky mine, X-ray radiometric separation is in use since 2008 for treatment of gold-bearing tailings of manual picking operation. The source material contains up to 1 g/t of gold. This separation results in production of tailings with a gold content of 0.2 g/t. Yield of the enriched production is about 10 % at a gold grade of 5-7 g /t.

Non-Ferrous Metal Ores

In the CIS, non-ferrous metal ores are predominantly treated using X-ray radiometric sorting. Uchalinsky and Gaysky GOKs, dealing with mining and processing of copper-pyrite ores, commissioned two X-ray radiometric complexes in 2003-2004.

In order to reduce the rock mass transportation costs, Svyatogor company has been using the X-ray radiometric sorting since 2006 for copper-zinc ores of Tarnjerskoye deposit (the town of Krasnouralsk). Russian Rados-made SBS separators are being used in Be-Jen deposit (China) for sorting of led-zinc ores, as well as by Techen company for treatment of copper, molybdenum and base metal ores.

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