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WAYS TO REDUCE ORE LOSSES AND DILUTION IN IRON ORE UNDERGROUND MINING IN KRYVBASS

Introduction. *Ukraine's economic potential greatly depends on efficient operation of the national mining and metallurgical complex that provides 30% of GDP. One of the essential structural branches of the mining and metallurgical complex is iron ore mining industry. The quality of iron ore materials is the primary indicator ensuring their competitiveness in domestic and foreign markets. The quality of iron ore products is formed in the course of ore mining and processing into marketable products.*

Problem Statement. *Worsening ore quality and losses is a serious problem in iron ore underground mining. It is caused by incomplete extraction of iron ore reserves (72—75% of the producing reserves) while breaking and drawing as well as by ore dilution with waste rocks, which causes an iron content reduction by 1.5—12% as compared with the initial iron content in the massif.*

Purpose. *The research aims at analyzing reasons for high ore losses and dilution in underground ore mining at Kryvyi Rih iron ore basin and at searching ways to reduce them.*

Materials and Methods. *Analysis of known methods for solving the given problem has revealed that it is quite efficient to create an organizational and technical system that enables to forecast, to detect, and to promptly solve the reasons causing excessive ore losses and dilution.*

Results. *To efficiently control qualitative and quantitative parameters of ore at all stages of mining, transportation, and processing, an automated working place, Quality AWP, which provides data collection and representation at all stages of mining production at the central server is suggested to apply for continuous monitoring and analysis of ore quality characteristics.*

Conclusions. *Introduction of the complex of technical means and Quality AWP automated system enables tracking the ore qualitative characteristics on a continuous basis and reducing ore losses by 3% and dilution by 2%.*

Keywords: analysis, losses, system, and Quality automated working place.

The analysis of conventional methods for reducing losses and ore impurity has shown that the creation of an organizational and technical system is a very effective direction. This direction has been implemented by designing anengineering, software and hardware complex. The complex is a single integrated system for monitoring and accounting the qualitative and quantitative parameters of iron ore raw materials at all major

Table 1

Mining of Extractable Resources in 2012—2016 by *Kryvbaszhelezrudkom* Public JSC Mines

	Unit	Year				
		2012	2013	2014	2015	2016
Ternovska Mine						
ore production	Thousand tons	1276	1661	1840	1892	1532
losses	%	19.3	16.79	19.97	19.03	17.86
impurity	%	14.5	17.72	14.09	8.65	11.6
Hvardiiska Mine						
ore production	Thousand tons	1608	1437	1654	1674	1550
losses	%	17.4	20.03	20.01	19.78	18.61
impurity	%	19	23.73	15.40	18.32	10.24
Oktiabrska Mine						
ore production	Thousand tons	1329	1348	1401	1646	1590
losses	%	18.3	17.18	18.87	17.72	17.73
impurity	%	17.3	16.79	11.19	12.46	12.26
Rodina Mine						
ore production	Thousand tons	2100	2144	1905	1248	1483
losses	%	19.6	20.08	20.14	20.00	18.58
impurity	%	13.1	12.00	15.56	11.91	12.86

Table 2

Mining of Extractable Resources in 2012—2016 by *Euras Sukha Balka* Private JSC Mines

	Unit	Year				
		2012	2013	2014	2015	2016
Frunze Mine						
ore production	Thousand tons	1100	1269	1300	1210	1150
losses	%	11.4	12.0	13.7	11.5	11.2
impurity	%	10.6	11.3	12.4	12.5	12.35
Yubileina Mine						
ore production	Thousand tons	1900	2100	2169	2200	2045
losses	%	14.4	15.6	14. 7	14.3	14.35
impurity	%	12.6	12.2	14. 4	14	12.3

stages of its extraction and processing using nuclear-physical and geophysical methods [1, 10–13].

The proposed system is based on developments of the research laboratory for industrial problems of the Kryvyi Rih National University. From 1993 to the present, devices and methods designed by the laboratory have been used for operational quality control at the main stages of underground mining.

The experience has shown that attempts to solve this problem by controlling the quality of raw materials at individual stages of mining does not enable efficient management of extraction indicators to reduce losses and ore impurity [5—8]. The comprehensive approach is more rational, the implementation of which requires a detailed study of all factors affecting the extraction of minerals and the formation of its qualitative indicators [14—17].

Below, there are summary data on production, losses and ore impurity for 2012—2016, by the Kryvbas mines.

Since 2013, ore mass impurity has been reduced; the highest losses for *Kryvbaszhelezrudkom* are reported for 2014; since that time the losses started to decrease.

The analysis of production activity of the underground iron ore mines in Kryvbass has shown that the main causes of ore losses and impurity are as follows:

1. The deviation ofdirection of theblast holes (Fig. 1), which can reach 10—18% of their length, andtheir out of contour space leads to destruction of dead rocks beyond the contour of the ore body, the subsequent impurity of the ore mass, and a reduction in the content of the useful component by 2—12%.

2. Underdrilling as a result of curvature of blasting holes leads to incomplete breakage of the ore massif, which causes quantitative losses of ore when it is discharged from the extraction space, as well as because ofshutdown of the discharge process when the iron content in ore reaches 45%.

It should be noted that the minimization of ore losses and impurity is one of the key requirements for the second mining technologies [2—4].

A complex of technical means for reducing iron ore losses and impurity during underground mining has been developed (Fig. 2).

The offered complex includes the following stages of mining production technological process:

- preparatory and blasting operations;
- ore discharge from box holes;
- transportation of ore by mine carts;
- crushing and sorting factory (CSF).

The electronic inclinometer is designed for monitoring the position of blast holes in the ore massif, which enablesmeasuring the zenith and azimuthal angles and exercising the operative control of the well position in the massif. In this case, the hole curvature is fixed, which, according to statistics, makes up to 15% of the hole depth.

The total information obtained from inclinometers and depth-gauges enables to develop 3D models of the ore massif, which makes it possible to predict the qualitative and quantitative parameters of the exploded ore mass and to determine the amount of blast holes deflectedbeyond the contact zone towards the area of «dead rocks». In addition, in the case of a large distance between the holes, the need to drill an additional well forpreventing ore losses and above-limit release of oversize material is determined.

The logging probe is designed for operational control of iron content throughout the depth of blast holes.

The software complex is used to create 3D models of the ore massif.

The miner radiometer (PACS device) is used for operational control of the ore mass quality during the ore discharge from box holes. It should be noted that until now, the problem of ore ongoing quality control ore at this stage has not been solved. At the Kryvbass mines, the quality control of exploded ore mass during discharge from box holes was previously carried out by sampling with the use of chemical analysis method. The durationof analysis was 2 hours. Currently, the rapid analysis of samples is carried out by PACS radioisotope devices and lasts for 60 s. The ore discharge from box holes ceases as the iron content becomes less or equal to 45%, which prevents contamination of the ore mass.

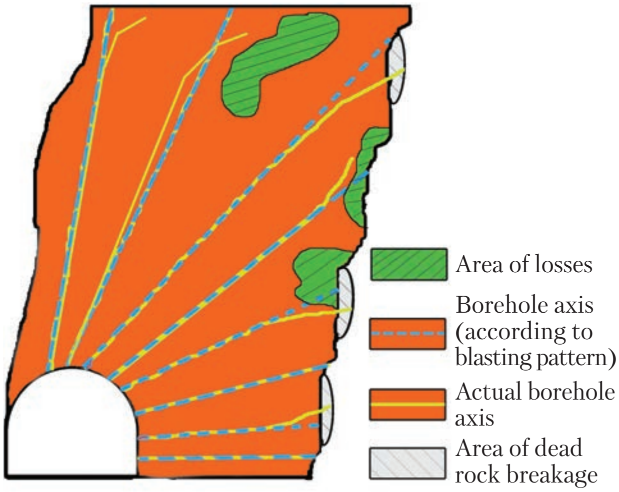

Fig. 1. Schematic drawing ofborehole curve

The quality of exploded ore mass during the transportation of ore by mine carts can be controlled in the two ways:

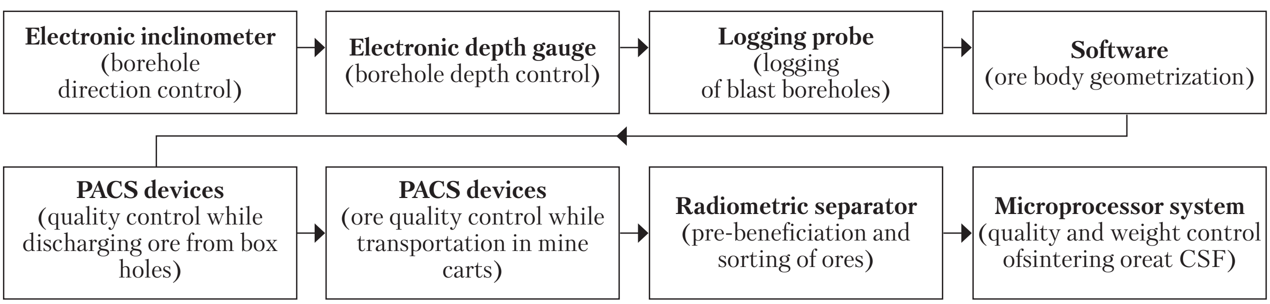

Fig. 2. Complex of engineering facilities to reduce iron ore losses and impurity

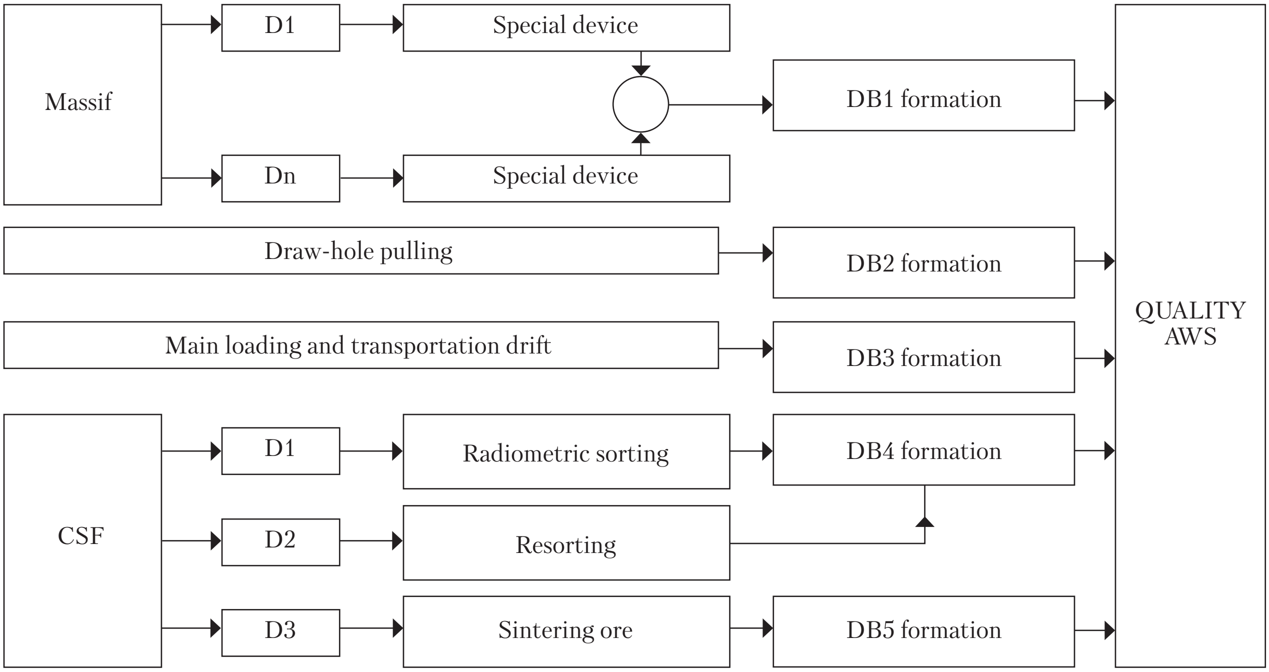

Fig. 3. Quality AWS functional scheme

1) the discrete method, by sampling from mine carts and carrying out rapid analysis by PACS radioisotope device;

2) the ongoing method, by using a radiometric sorting complex (RSC) for automation of rolling and sorting of mine carts with ore mass [3].

In the case of crushing and sorting factory, the operative control of ore weight and content on the conveyor is carried out using a microprocessor system; the ore is sorted with the use of radiometric separators. At the same time, the dead rock is separated from the total mass, which leads to a decrease in the impurity of commercial ore and to improvement of its quality.

Table 3 shows the results of experimental and industrial tests of a radiometric separator in the conditions of the CSF of *Artem-2* mine.

The results of long-term industrial tests have shown the expediency of using radiometric separators to cut off the undersized rock mass. The use of such devices in the technological chain enables solving the problems of reducing impurity and increasing the content of useful component in the extracted ore mass.

For operational control of the qualitative and quantitative parameters of the ore at all stages of extraction, transportation, and processing, it is suggested to use *Quality* automated workstation (AWS) (Fig. 3) that provides collecting and displaying on the central server the information from all mining sites for ongoing monitoring and analysis of ore qualitative characteristics.

The tasks of the *Quality* system are conventionally divided into the four stages:

Stage 1: Operational control of the useful component content in the massif and the borehole deviations from the design, which includes:

- measuring the zenith and azimuth angles of borehole direction deviation from the design values;
- measuring the borehole depth;
- determining the ore quality in the massif;
- developing 3D model of the ore body;
- making decisions to eliminate the detected deviations of parameters of the scheme for hole drilling in the massif from the design values of the blasting pattern (BP).

Table 3

Results of Experimental and Industrial Tests of Radiometric Separator

Initial ore		Concentrated ore			Tailings		Fe extraction to concentrate	Increase in Fe content, %
Fe, %	SiO_2, %	Yield, %	Fe, %	SiO_2, %	Yield, %	Fe, %		
42.2	23.3	70.5	54.0	10.7	29.5	14.0	90.2	11.8
41.7	35.7	34.0	58.5	8.5	66.0	33.0	47.7	16.8

Stage 2. Control of the quality of the blasted ore mass during the ore discharge and transportation to the main loading and transportation drift.

Stage 3. Radiometric sorting of ore in CSF.

Stage 4. Quality control of commercial ore while shipping to consumers.

Within the framework of the *Quality* system, a program for interaction of the server module with each separate device has been developed to collect and to store the collected data in the local database and then to process them (plotting, block sections, etc.).

The central server receives data from inclinometry, depth-gauge and log measurements of blast boreholes of the ore massif and generates a database DB 1 that includes indicators of the content of useful component for each borehole. According to these data, 3D models of the ore massif are developed, which enables to predict the total volume and content of iron in the massif.

The information obtained from the discrete analysis of samples from the box holes forms a database DB 2, the analysis of which makes it possible to estimate the actual degradation of quality in the blasted ore mass in comparison with the DB1 data. Comparison of DB 1 and DB 2 data allows technical personnel to develop measures to minimize the degree of impurity of the blasted ore mass.

The blasted ore mass is transported to the main loading and transportation drift of the mine, with samples taken from the vehicles. Based on the data of discrete quality control a database DB 3 is created and sent to the *Quality* AWS server. According to this information, both the volume and the quality of the ore at the CSF inlet are determined.

At CSF, after the second stage of crushing, a radiometric sorting of 100 mm grading ores is done in order to reduce impurity and to improve the quality of raw materials. Based on the qualitative and quantitative data of radiometric sorting, a database of lump fraction of commercial ore for blast furnace production (DB 4) is formed. In the case of production necessity, the resorting is done, with the results transferred to DB 4.

The ongoing assurance of the sintering orequality on the conveyor in the CSF conditions is carried out by the microprocessor system, with database DB5 formed. Information from DB 4 and DB 5 is used by personnel of the mine surveying and geological service to assess the qualitative and quantitative parameters of the commercial ore for both mine's own account and for shipment to consumers.

The introduction of the complex of engineering facilities and *Quality* AWS automated system enables not only to continuously monitor the quality characteristics of the ore, but also to reduceore losses and impurity.

CONCLUSIONS

1. A hardware and software complex incorporating technological and organizational, and engineering solutions has been developed, which enables to reduce losses and impurity of Kryvbas underground mining ores.

2. Full-scale implementation of the *Quality* AWS system enables to reduce the planned degree of ore impurity by 2%; and ore losses by 3%, as well as to increase the iron content by more than 2%.

3. The economic effect of the mentioned reduction in ore losses and improvement in the quality of commercial ore only for PJSC *Kryvbaszhelezrudkom*is estimated over USD 7.7 million.

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ШЛЯХИ ЗМЕНШЕННЯ ВТРАТ І ЗАСМІЧЕННЯ ЗАЛІЗНОЇ РУДИ ПІДЗЕМНОГО ВИДОБУТКУ В КРИВБАСІ

Вступ. Економічний потенціал України значною мірою залежить від ефективності функціонування гірничо-металургійного комплексу, який забезпечує 30 % внутрішнього валового продукту (ВВП). Одним з найважливіших структурних підрозділів гірничо-металургійного комплексу є залізорудна промисловість. Якість залізорудної сировини є основним показником, який забезпечує її конкурентоспроможність на внутрішньому та зовнішньому ринках. Якість залізорудної продукції формується в процесі видобутку рудної маси та переробки її в товарну продукцію.

Проблематика. Серйозною проблемою, яка супроводжує процес виробництва товарної продукції при підземній розробці залізорудних родовищ, є зниження якості та втрати руди, що обумовлено неповним видобутком балансових запасів руди (72—75 % від ресурсів видобувного блоку) при її відбиванні й випуску з очисного простору, а також засміченням відбитої рудної маси порожніми породами, що призводить до зниження на 1,5—12 % вмісту заліза порівняно з вихідним вмістом в масиві.

Мета. Аналіз причин високих показників втрат і засмічення руди підземного видобутку Криворізького залізорудного басейну та пошук шляхів їх зниження.

Матеріали й методи. Аналіз відомих методів і способів вирішення зазначеної проблеми показав, що досить ефективним напрямком є створення організаційно-технічної системи, що дозволяє прогнозувати, виявляти на практиці і оперативно усувати причини, що призводять до виникнення наднормативних втрат та засмічення руди.

Результати. Для оперативного контролю якісно-кількісних параметрів руди на всіх стадіях видобутку, транспортування та переробки запропоновано використовувати автоматизоване робоче місце (АРМ) «Якість», яке забезпечує збір і відображення інформації з усіх ділянок гірського виробництва на центральному сервері для безперервного моніторингу та аналізу якісних характеристик руди.

Висновки. Впровадження комплексу технічних засобів і автоматизованої системи АРМ «Якість» дозволить не тільки безперервно відстежувати якісні характеристики руди, але і домогтися зниження втрат руди на 3 % та її засмічення на 2 %.

Ключові слова: аналіз, втрати, система, автоматизоване робоче місце «Якість».

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ПУТИ СНИЖЕНИЯ ПОТЕРЬ И ЗАСОРЕНИЯ ЖЕЛЕЗНОЙ РУДЫ ПОДЗЕМНОЙ ДОБЫЧИ В КРИВБАССЕ

Введение. Экономический потенциал Украины в значительной степени зависит от эффективности функционирования горнометаллургического комплекса, который обеспечивает 30 % внутреннего валового продукта (ВВП). Одним из важнейших структурных подразделений горнометаллургического комплекса является железорудная промышленность. Качество железорудного сырья является основным показателем, который обеспечивает его конкурентоспособность на внутреннем и внешнем рынках. Качество железорудной продукции формируется в процессе добычи рудной массы и ее переработки в товарную продукцию.

Проблематика. Серьезной проблемой, сопровождающей процесс производства товарной продукции при подземной разработке железорудных месторождений, является снижение качества и потери руд, что обусловлено неполным извлечением балансовых запасов руды (72—75 % от ресурсов добычного блока) при ее отбойке и выпуске из очистного пространства, а также засорением отбитой рудной массы пустыми породами, что приводит к снижению на 1,5—12 % содержания железа по сравнению с исходным содержанием в массиве.

Цель. Анализ причин высоких показателей потерь и засорения руды подземной добычи Криворожского железорудного бассейна и поиск путей их снижения.

Материалы и методы. Анализ известных методов и способов решения указанной проблемы показал, что весьма эффективным направлением является создание организационно-технической системы, позволяющей прогнозировать, выявлять на практике и оперативно устранять причины, приводящие к возникновению сверхнормативных потерь и засорения руды.

Результаты. Для оперативного контроля качественно-количественных параметров руды на всех стадиях добычи, транспортировки и переработки предложено использовать автоматизированное рабочее место (АРМ) «Качество», которое обеспечивает сбор и отображение информации со всех участков горного производства на центральном сервере для непрерывного мониторинга и анализа качественных характеристик руды.

Выводы. Внедрение комплекса технических средств и автоматизированной системы АРМ «Качество» позволит не только непрерывно отслеживать качественные характеристики руды, но и добиться снижения потерь руды на 3 % и ее засорения на 2 %.

Ключевые слова: анализ, потери, система, автоматизированное рабочее место «Качество».