POSSIBLE USE OF URANIUM ORES BUCKET HOISTING IN "GLAVNYI" SHAFT OF NOVOKONSTANTINOVSKAYA UNDERGROUND MINE AT SE "VOSTGOK"

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Aim. The aim of the paper is to determine a possible level of air pollution with dust in "Glavnyi" shaft of Novokonstantinovskaya underground mine of the State Enterprise "VostGOK"

Methods. The dust pollution level is determined through the laboratory physical modeling of the process.

Findings. The size analysis of the rock to be hoisted by buckets in Glavnyi shaft has been performed and the process of dust formation has been modeled on the laboratory bench. It has been determined that the dust level is significantly impacted by moisture of rocks, additional binding of ore fines in the upper layer by surface-active materials and the fines distribution in the bucket resulted from the loading method. Loading the bucket by a vibrating feeder requires just natural moisture of rocks to provide the below-norm level of dust pollution whereas application of belt or plate feeders require additional treatment of the surface of the rock in the bucket with surface-active materials (bischofite-water solution) to achieve the permissible dust pollution rate (0.3-0.4 mg/m^3, which is 0.5-0.67 of the current norms).

Scientific novelty. It is proved that the integrated dust index is in polynomial-logarithmic dependency on rock mass moisture and, if ore moisture is 4%, decreases the dust pollution level to 0.4-0.45 mg/m^3 which is 0.67-0.75 of the current norm.

Practical relevance. The obtained results confirm possible use of a bucket in *Glavnyi* shaft to hoist uranium ores onto the daylight surface at Novokonstantinovskaya underground mine without exceeding the dust pollution norms if the suggested recommendations are observed. As a result, production of the strategic raw material will grow considerably.

Keywords: *bucket hoisting, dust pollution, dust suppression measures*

Introduction. Novokonstantinovskaya underground mine is part of the SE “VostGOK” and ranks first in Europe in terms of uranium ore reserves. Uranium has been mined by three shafts (*Glavnyi*, R*azvedyvatelno-Ekspluatatsionnyi #6* (RE-6) and *Ventilatsionnyi*-1 (V-1) since 2011 at the depth of 180 to 300 m. With the designed output of the startup complex of Novokonstantinovskaya underground mine of 250 thousand t and the total designed capacity of 1500 thousand t, the current outputs of uranium ore are limited by hoisting capacity of the shafts RE-6 and V-1 and make about 330 thousand t a year.

To increase output of uranium ores at this mine, use of the shaft *Glavnyi* for bucket hoisting of the mined ore onto the daylight surface is now under consideration.

However, the shaft is simultaneously used as a ventilating one and this causes a problem of dust pollution. The current safety rules [1] allow for permissible concentration of dust not exceeding 30% of the maximum allowable concentration (MAC). With the current MAC of 2 mg/m^3 (for uranium ores with 10 to 70% of free silica), the dust pollution norm is 0.6 mg/m^3. Possible excessive dust pollution will violate the safety rules and become a potential source of corresponding occupational diseases.

In case of exceeding the allowable level, additional watering of the rock surface [2,3] or treating it with surface-active materials (SAMs) can suppress the dust. Due to SAMs’ ability to increase dust wettability and prolong this effect, they are widely used at many mining enterprises of Ukraine. Also, practically tested high efficiency of some chloride-water solutions (e.g. particularly bischofite [4,5] which is a diluted electrolytic solution) provides high capillary autoadhesion of dust, i.e. binding (adhesion) of dust particles and their adhesion with larger particles/ones. Maximum efficiency of fines binding can be reached by the density of such solution which should be not less than 1170 kg/m^3 and its specific consumption should make 0.5-1.0 liter per 1 m^2 of the treated surface [5]. This results in considerable dust pollution level decrease due to counter air flows not blowing fine particles off the loaded bucket surface.

The investigations fulfilled the following tasks:

- determination of the particle size distribution in the rock mass to be hoisted in order to determine the size distribution of fines;

- study of the dust formation process at bucket hoisting on the laboratory bench and determination of the impact of ore fines distribution in the bucket and ore moisture on dust formation;

- in the case of exceeding of possible level of dust-ladenness of air to work out measures for her decline and coersion to the operating norms.

- development of measures for reaching the current dust pollution norms in case they are exceeded.

Methods. To study the process and determine the possible dust pollution level the laboratory physical modeling of the process was conducted on the laboratory bench in the wind tunnel АТ-2К-250/500 with the open flow and the closed test section, an aspirator with a drive and hoses for air and its filtration.

Physical modeling of the dust formation process was performed on the laboratory bench consisting of the wind tunnel АТ-2К-250/500 with the open flow and the closed test section, an aspirator with a drive and hoses for air and its filtration.

Results and discussions. Modeling the dust formation process requires information on the number of fine fractions in the rock mass which are intended for the process. For this purpose, the particle size distribution of the rock mass sample of about 70 kg was determined. The sample with size-sorted fractions is given in Fig. 1.

Fig. 1. The rock mass sample with size-sorted fractions

When sizing, separate lumps were measured and weighed; parameters of fine fractions (-15÷+0 mm) were determined by sieve analysis (apertures of 15, 10, 7, 5, 3, 2 and 1 mm) and weighing. The results of the size analysis of the sample investigated are given in Table 1.

Table 1

The results of the granulometric analysis of the sample investigated

Fraction sizes, mm	Fraction weight, g	Fractions in the sample, %
-200÷+100	47050	67.64
-100÷+50	19554	28.13
-50÷+5	1880	2.70
-15÷+0. incl.:	1063	1.53
-15÷+10	813	1.170
-10÷+7	84	0.121
-7÷+5	67	0.096
-5÷+3	31	0.045
-3÷+2	29	0.042
-2÷+1	18	0.026
-1÷+0	21	0.030
Total:	**69512**	**100.00**

As is seen, -1÷+0 mm fraction makes just 0.03 %. The БПСМ-4 bucket may contain about 7-7.5 t of rock mass with 2-2.3 kg of -1 + 0 mm fraction which is a potential source of dust formation while the bucket is moving along the shaft. But random character of size distribution in general and in the bucket in particular implies that the actual weight of this fraction in a bucket may make from 1-1.5 kg to 3.5-4 kg.

Distribution of ore fines in the bucket impacts the dust pollution level significantly and depends on the loading method. The impact of the loading method on the ore fines concentration was also investigated as dust-like and fine particles are only blown off the upper layer of the loaded rock mass. The rock mass loaded by a belt or a plate feeder is distributed more evenly due to its size composition and considering its natural fluctuations near the mean value.

A vibrating feeder causes segregation of the material on its surface according to its size: fine particles move to the lower layer, larger fractions that do not participate in dust formation are gathered in the upper layer. This size distribution is observed in the upper layer of the rock mass in the bucket as well and causes 3-4-fold decrease of the number of ore fines. Considering this fact, separate investigations into distribution of the material according to its size and with smaller concentration of ore fines in the upper layer caused by application of a vibrating feeder were conducted.

As mentioned above, the dust formation process was modeled in the wind tunnel AT-2K-250/500 with the open flow and the closed test section and an aspirator with a drive and hoses for air and its filtration. The laboratory bench and the aspirator for polluted air bleeding from the wind tunnel are given in Fig. 2 and 3.

Fig. 2. The wind tunnel AT-2K-250/500 with the open flow and the closed test section

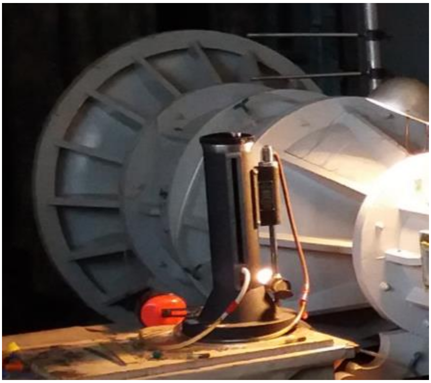

Fig. 3. The aspirator

The air flow rate in the test section was established by a diffuser of a required diameter. The fan activated by an electric motor sucked down air through a nozzle with a straightening grille to the test section. In the section the bucket model was placed with a pipe for air sampling. The hoses delivered the air to the aspirator. Samples of the air from the test section went through a previously weighed filter in the sampler. After each sampling the filter was changed. Before and after the experiments the filters were weighed on the electronic scales ВЛР-200 with weighing accuracy of 0.05 mg.

As during physical modeling of the process observance of similarity criteria (particularly geometrical sizes of rock mass particles, the air flow rate and the kinematic coefficient of viscosity of the medium) is of considerable importance, the modeling scale change causes a problem of agreement of the above factors for the result of the modeling to correspond to the data in real conditions. The diameter of the wind tunnel cannot be changed but the air flow rate can be regulated. The actual material (rock mass) of the size composition characteristic of the underground mine was put in the model bucket and the bucket was placed in the wind tunnel for a series of experiments. The air flow rate in the test section of the tunnel should correspond to the speed of blowing off ore fines from the surface of the bucket.

The obtained data on dust pollution of the air in the model should then be corrected considering the relation between the БПСМ-4 bucket surface and the bucket model areas (treating this regularity as linear) and the actual amount of the air moving along *Glavnyi* shaft and in the air tunnel per time unit during the experiment. Due to this correction the obtained data are close to those in real conditions and enable forecasting the possible dust pollution level which may occur at bucket hoisting in *Glavnyi* shaft.

According to the information provided by the engineers of the enterprise, the section area of the shaft *Glavnyi* is S_{shft}=44 m^2, the amount of the air delivered through this shaft into the underground mine is $Q_{air\ shft}$=160.4 m^3/s, the rate of hoisting rock mass by the БПСМ-4 bucket is to be V_{buc}=6 m/s. Thus, the rate of the air flow which is to blow ore fines off is equal to the resultant of two counter rates: the rate of the downcast air delivered through the shaft and that of the loaded bucket hoisting speed.

The rate of the air flow along *Glavnyi* shaft can be determined from the expression, m/s

$$V_{air\ shf}=Q_{air\ shft}/S_{shft}=160.4/\ 44\approx 37.$$

Thus, the resultant speed of interaction of the air flow with the surface of the rock mass loaded into the bucket makes, m/c

$$V_{air\ flow}=V_{air\ shft}+V_{buc}=3.7+6=9.7.$$

The rate of the air flow in the wind tunnel close to the one stated (10 m/s) was obtained with the help of a diffuser of the required diameter (140 mm). The difference between the obtained rate and the required one makes only 3.1% which is quite permissible in our opinion and does not produce any considerable impact on the results of the process modeling.

A small plastic bucket (the upper diameter of 120 mm and height of 115 mm) used as a bucket model was filled with the crushed rock mass of the sizes corresponding to those of ore fines (i.e. -1+0 mm fraction) which are a potential source of dust formation. During the first set of experiments when modeling loading the bucket by a belt or plate feeder, the amount of the mentioned fine fraction in the upper layer corresponded to the even distribution of the fines (i.e. 0.03%). When modeling the bucket loading by a vibrating feeder and determining dust pollution of the air, the amount of fines was decreased to 0.01% which corresponded to the determined segregation of the material loaded by this method.

The total time of hoisting the bucket from the 330 m level to the daylight surface (Fig.1) at the speed of 6 m/s and considering unevenness of its movement (acceleration at the start and deceleration at the end of hoisting) makes about 1 minute. The modeled process of fine particles blowing off demonstrated that the maximum intensity of the process at the beginning decreases as the bucket moves towards the shaft mouth due to fine particles blowing off at the previous part of the shaft, i.e. blowing off depends on the time factor. Due to this, dust pollution changes, too. To track this process, the dust pollution level was measured 3 times every 20 seconds. When processing the data, the dust pollution level was determined at these intervals and on average for the whole period of hoisting.

The forecast data on dust pollution in real conditions were obtained considering the relation between the БПСМ-4 bucket surface area (2.0 m^2) and the model bucket area (0.01131 m^2), that made

2/0.01131≈177. With the test section diameter of the wind tunnel of 0.25 m and air rate in it of 10 m/s, the amount of air going through it makes 0.49 m^3/s. As mentioned above, through the shaft *Glavnyi* 160.4 m^3/s of air is delivered to ventilate mining operations in Novokonstantinovskaya underground mine. So, the amount of air in real conditions is 160.4/0.49 ≈ 327 times larger. Thus, dust pollution in real conditions will be 327/177≈1.85 times less than in the model.

Table 2 gives the results of laboratory investigations into dust pollution when bucket hoisting rock mass in *Glavnyi*. Column 4 presents dust pollution resulted from measurements in the model, column 6 presents results of the recalculated level considering adjusting the obtained data to real conditions, Column 7 presents relation of dust pollution to maximum allowed concentration of dust for these conditions which makes 0.6 mg/m^3.

Each of the 5 series consisted of 5 experiments of 3 samplings to determine the dust pollution level. The numbered filters were weighed before and after the experiments on the electronic scales ВЛР-200 with weighing accuracy of 0.05 mg (Fig. 4).

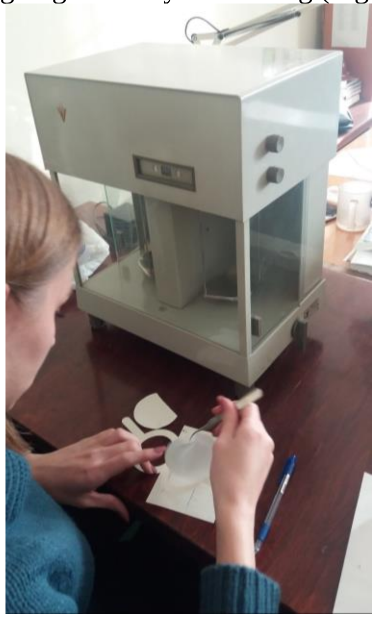

Fig. 4. Weighing the filter on the scales

The average data of each experiment are given in Table 2.

Table 2

Results of the laboratory investigations into dust pollution at bucket hoisting

Bucket loading means	Rock mass properties	Period of sampling and average per hoisting cycle	Dust pollution level, $mg/m^3 \cdot s$		Excess of permissible dust pollution, times, times
			modeled	calculated for real conditions	
Belt or plate feeder	Natural moisture	0-20 s	23	12.4	20.7
		21-40 s	9	4.9	8.1
		41-60 s	4	2.2	3.6
		0-60 s	12	6.5	10.8
	Watered bucket surface	0-20 s	0.8	0.44	0.73
		21-40 s	3.3	1.8	3.0
		41-60 s	6.7	3.6	6.0
		0-60 s	3.6	2.0	3.3
	Bischofite-treated surface	0-20 s	0	0	-
		21-40 s	0.85	0.46	0.77
		41-60 s	0.85	0.46	0.77
		0-60 s	0.57	0.31	0.52
Vibrating feeder	Natural moisture	0-20 s	6	3.2	5.4
		21-40 s	2.5	1.4	2.3
		41-60 s	1	0.54	0.9
		0-60 s	3.2	1.73	2.9
	Watered bucket surface	0-20 s	0	0	-
		21-40 s	0.5	0.27	0.45
		41-60 s	2	1.1	1.8
		0-60 s	0.8	0.44	0.73

The obtained results show that belt and plate feeders produce the average value of dust pollution at hoisting which is 11 times larger than its maximum allowable value. As it was assumed, during the first time period (0-20 s) the excess was maximal (20.7 times), gradually decreasing to 8.1 times during the second period (21-40 s) and was minimal at the end of hoisting (41-60 s) – 3.6 times. However, in any case, the observed considerable excess of pollution rates results in additional measures for decreasing it to the allowable level.

Watering the surface of the bucket loaded with rock mass decreases the average dust pollution by over 3 times (from 6.5 to 2 mg/m^3) but it still is 3.3 times larger than the maximum allowable concentration of dust. Dust pollution during separate time periods is completely different: minimum dust pollution which is even 1.36 times less than the allowable level occurs at the start of hoisting.

During the second time period, dust pollution is 3 times larger than its maximum allowable value, at the end of hoisting it is 6 times larger. These results can be explained by the fact that at the start of hoisting capillary forces of adhesion of the watered ore mass are sufficient for binding dust-like particles, but in the course of time high rates of the counter air flow result in the increased surface "drying". So, even watering of the surface of the ore mass loaded into the bucket does not ensure observance of the dust pollution norms.

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Continuation of table. 2

Vibrating feeder	Natural moisture	0-20 s	6	3.2	5.4
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		0-60 s	3.2	1.73	2.9
	Watered bucket surface	0-20 s	0	0	-
		21-40 s	0.5	0.27	0.45
		41-60 s	2	1.1	1.8
		0-60 s	0.8	0.44	0.73

That is why at the next stage of modeling the rock mass surface was treated with the bischofite-water solution according to [5]: the solution density is about 1.2 g/cm^3, its specific consumption is about 0.7-0.8 kg per 1 m^2 of the treated area. As the treated surface keeps moisture for a longer period, the adhesion between fine particles and with larger ones increases considerably and results in sharp decrease of dust pollution: no pollution at the beginning, steadily low pollution (0.75-0.8 of the maximum allowable dust concentration) during the second and the third periods. The whole hoisting cycle is characterized by the dust pollution level which is 2 times lower that allowable values.

A vibrating feeder applied to loading the bucket and low natural moisture of rock mass make dust pollution 3.5…4 times lower than use of belt or plate feeders. However, the average dust pollution value at bucket hoisting is still almost 3 times greater than its maximum allowable figures.

Watered surface of the rock mass loaded into the bucket decreases dust pollution considerably: there is practically no pollution at the start of hoisting, its growth is seen up to 0.4-0.5 and 1.5-2 respectively of the maximum allowable values during the second and the third periods. During the whole hoisting cycle the average dust pollution is 1.3-1.4 times lower as compared with its maximum allowable values, i.e. it satisfies the current safety regulations [1].

Conclusions. The conducted investigations into the dust formation process confirm the possibility of use of bucket hoisting of uranium ores on the daylight surface in *Glavnyi* shaft at Novokonstantinovskaya underground mine of the SE “VostGOK”. To ensure observance of the current dust pollution norms for the downcast air, the design of the underground loading facilities should provide for a vibrating feeder to load the bucket.

In this case, thorough watering of the surface of the rock mass loaded into the bucket or even its high natural moisture (not less than 4%) provides observance of current dust pollution norms (the pollution level is 0.7-0.75 of maximum allowable values for such conditions). However, it should be noted that increase of mining depth and, consequently, the height of the mined rock mass hoisting onto the daylight surface will result in the increased hoisting time. High natural moisture of ore or additional watering of its surface will not be able to provide sufficient decrease of the dust pollution level.

To observe dust pollution norms, use of a belt or a plate feeder requires treatment of the surface of the rock mass loaded into the bucket with SAMs (e.g. bischofite-water solutions).

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