УДК 62-9

A.Yu. Prokopenko, S.A. Denisov, A.S. Morkovin, D.K. Nesterov

OPTIMIZATION OF SWEEP-TYPE SAMPLER OPERATING MODE BY COMPUTER SIMULATION

Abstract. Modern mining industry requires a sampling device to provide reliable information about the material quality. The standards regulating the sampling procedure recommend the models of samplers placed in the conveyor belt unloading point. However, typically it is not possible to install a sampling device in the plant's unloading point. In such cases it is necessary to use sweep-type samplers that pick the material directly from the conveyor belt. The sampling error of sweep-type samplers is higher than that of models set in the unloading point, and depends on many factors. This paper is intended to study the sweep-type sampler parameters using computer simulation, determine the range of operating modes, define the technical requirements for a sweep-type sampler to achieve maximum sampling accuracy. We have carried out the sampling error study of the sweep-type sampler based on the simulation using finite element technique. Based on the simulation findings, the factors influencing the sampling quality in a continuous flow of bulk material were evaluated. It was established that maintaining the optimum stable sampling rate is necessary for the sweep-type sampler quality operation. Factors influencing the optimum sampling rate were established. For a number of conveyor rates and material particle sizes, the optimum sampling rates and motor parameters were calculated to maintain this rate. We concluded that computer simulation is necessary for the sweep-type sampler operation at a specific installation point and with specific production parameters for the correct selection of the sampler specifications and minimizing the sampling error.

Key words: crushed ore, quality, sampling, sweep-type sampler, conveyor belt sampler, cross belt sampler, hammer sampler, representativeness, particle size distribution.

DOI: 10.25018/0236-1493-2018-9-0-202-210

To increase the performance indicators of the mining and metals sector enterprises, it is necessary to know the exact parameters of the current production. Modern computing landscape and mechanical means allow for prompt response to the parameter change to compensate for it, and modern laboratory methods enable precise determination of the parameter value.

In this context, it becomes critically important to quickly and competently prepare samples for the laboratory that plausibly reflect the state of the material being processed [1, 2].

During the laboratory sample preparation, the correspondence between the characteristics of the material being processed and the characteristics of the specimen sampled for the laboratory is inevitably violated (sample representativeness). There is a so-called sampling error.

A lot of literature references are devoted to stationary sampling, in which the material is static [3]. In this case, the flow sampling procedure with continuous random movement of the bulk product is studied [4]. In case of the moving material, there are difficulties associated with the need to sample the entire flow area. This

ISSN 0236-1493. Горный информационно-аналитический бюллетень. 2018. № 9. С. 202–210.

sampling methodology, the error magnitude and the degree of sampling representativeness are most widely discussed in the works of the French engineer Pierre Gy [5]. The results of these studies were included in modern standards, in particular, the international standard ISO 3082 Iron ores — Sampling and sample preparation procedures [6], compiled with the participation of Russian experts.

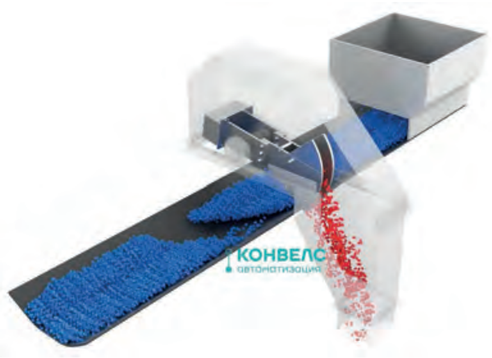
The basic requirements for samplers given in ISO 3082 include:

- absence of leakage or spillage of the material being sampled;
- absence of obstacles for the sampled material passage;
- sufficient sampler size to contain the entire sample volume;
- absence of sticking inside the sampler or risk of sampler clogging;
- absence of the sampled material mixing with any other substance unrelated to the sample;
- absence of change in the measured material characteristics due to sampling;
- the sampler bucket must cross the entire flow of material;
- the sampler bucket must cross the flow perpendicularly to the material flow direction;
- the bucket rate must not vary by more than ±5%;
- buckets with direct motion must have a direct opening, buckets with a circular motion must have a radial opening;
- the bucket opening plane must not be vertical or close to vertical.

Pierre Gy describes the samplers installed in the material unloading point as compliant with these requirements (Fig. 1).

Also, if it is necessary to pick samples directly from the conveyor belt, methods are suggested that require stopping the conveyor.

Unfortunately, in many situations, sampler installing in the unloading point or conveyor stopping for sampling is economically unsound. In this case the sweep-type samplers arewidely used internationally. Reference to these samplers is made in GOST R ISO 11648-2-2009 [7]. They are designed so that the sampler bucket, making a rotational motion, shifts the selected mass of material sideways from the conveyor belt (Fig. 2).



Cross belt sweep sampling simulation

This technique does not ensure compliance some of the requirements for samplers set forth in the standards. In particular:

- small material particles get into the gap between the edges of the bucket and the conveyor belt;

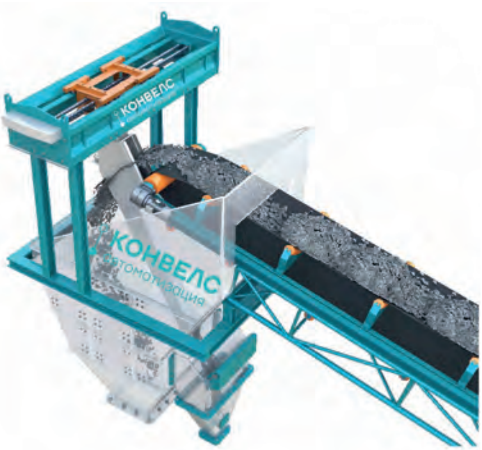


Fig. 1. Material sampling in the unloading point by a cross sampler — the sampled material portion is directed sideways from the main flow

Fig. 2. Sweep-type sampler

- the bucket opening plane is vertical or close to vertical.

In this regard, a thorough study is required for the representativeness of material sampled by the sweep-type sampler with different size of the sampled material and different rate of the conveyor belt.

Also, in the case of a sweep-type sampler, the requirement of constant bucket rate is much more difficult to follow than in the case of a sampler installed in the material unloading point. The motor must overcome the resistance of the material and remove it from the conveyor belt. In this regard, the sampler motor power is an important parameter.

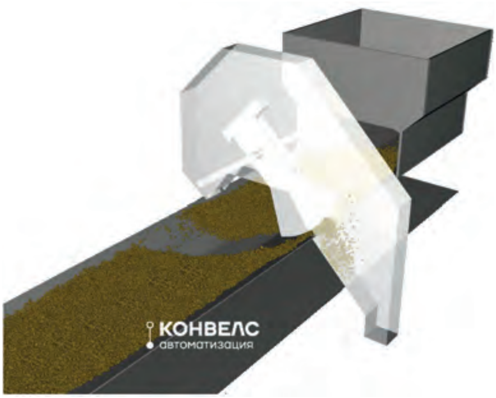


Fig. 3. Cross belt sweep sampling simulation. Flow rate = 530 t/h, bulk density of particles = = 1600 kg/m^3, conveyor rate = 1 m/s, slope of conveyor rollers — 35°/0°/35°, conveyor width — 1.2 m

This paper is intended to:

- study the sweep-type sampler parameters in different modes using the computer simulation;
- determine the range of operating modes, in which the maximum possible sampling representativeness is achieved;
- determine the technical requirements for a sweep-type sampler under these modes.

Simulation

To solve the task, mathematical simulation of the cross beltsweep sampling by the finite element technique in the ROCKY DEM Simulation software package was used.

The calculation was carried out for four different particle sizes (25 mm, 50 mm, 100 mm, 150 mm) and five different bucket rates (0.6 m/s, 0.8 m/s, 1 m/s, 1.2 m/s, 1.5 m/s). The bucket width was equal to the tripled maximum diameter of the material particles, according to GOST [8] and ISO [6]. The particles of different diameters were evenly distributed over the entire section of the conveyor. Sampling was carried out at a small distance from the conveyor loading point in order to avoid the effect of material segregation [9]. The total number of particles for each simulation was 62,000.

The material particle size distribution was used as a parameter to determine the sample representativeness.

This was due to the particle size distribution being affected by a number of additional factors associated with the sampling itself — for example, fragmentation of particles [10], and most modern studies discuss the effect of sampling only on the element content in the final sample [2, 11].

In this case, Pierre Gy formula for calculating the sampling error is as follows:

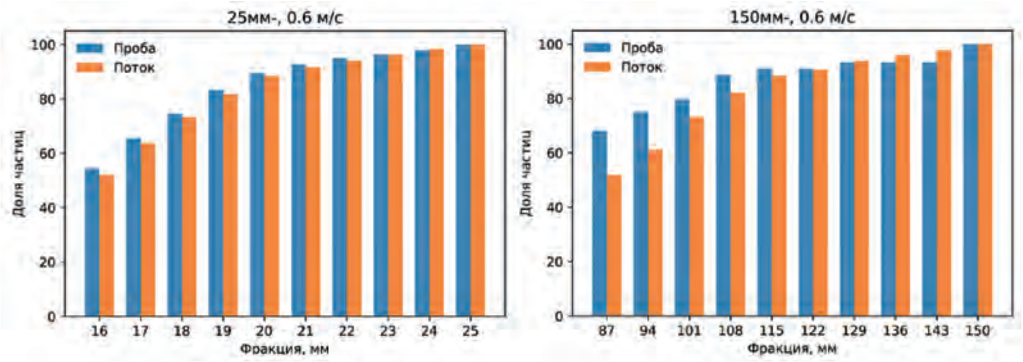


Fig. 4. Comparison of the sampling results for various particle sizes 25- and 150- with the bucket motion at a rate of 0.6 m/s

$$SE = \frac{\sum_{i=1}^{n} \left| f(a_i) - g(a_i) \right|}{n},$$

where a_1, a_2, ... a_n — an division of the $0.5x, x$ interval into n equal segments; $f(a_i)$ — relative number of particles with diameter less than a_i in the flow; $g(a_i)$ — relative number of particles with diameter less than a_i in the sample; SE — sampling error.

The sampling error calculation results for a series of experiments for different maximum particle sizes and different bucket rates are shown in Table 1.

Also, in addition, for the 300 mm bucket, several identical experiments were carried out at a rate of 1 m/s in order to determine the accuracy variation. The result of the simulation series is shown in Table 2.

As you can see, the sampling error significantly varies even when the experiment is repeated under the constant conditions. However, for all other equal flow parameters, the sampling of large particles gives a stable large error. This allows us to draw the following conclusions:

- to ensure the representative sampling, the sweep-type sampler should pick more point samples per lot than the samplers installed in the unloading point;
- as the particle size increases, it is also necessary to increase the number of point samples per lot.

In addition, it can be concluded that the bucket rate has a strong influence on the sampling error.

For quality sampling, it is necessary that the material from the flow section be completely introduced into the resulting sample [12]. To test this effect, the flow

Table 1

Sampling error

	25 mm (bucket width 75 mm)	50 mm (bucket width 150 mm)	100 mm (bucket width 300 mm)	150 mm (bucket width 450 mm)
0.6 m/s	0.892 %	2.127 %	1.763 %	4.157 %
0.8 m/s	0.431 %	0.656 %	1.637 %	1.808 %
1 m/s	0.323 %	1.027 %	4.035 %	5.187 %
1.2 m/s	0.321 %	0.534 %	1.106 %	1.030 %
1.5 m/s	0.763 %	1.219 %	1.190 %	2.009 %

Table 2

Sampling error simulation series for the same process parameters.
Bucket width — 300 mm, bucket rate — 1 m/s

1	2	3	4	5	6
4.524 %	4.071 %	1.295 %	2.201 %	1.835 %	1.318 %

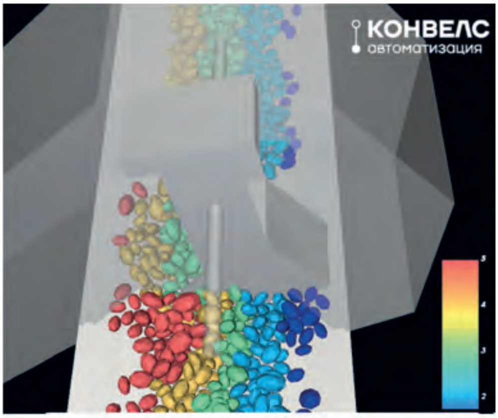


Fig. 5. Sampling uniformity simulation

was conditionally divided into 5 vertical sectors (Fig. 5). After that, the fraction of particles from each sector in the resulting sample was measured. The results are shown in Fig. 6.

As you can see, for larger particles the best sampling uniformity is achieved at high rates, and for small ones — vice versa. In addition to the particle size and bucket rate, the rate and geometry of the conveyor, the geometry of the bucket itself and many other parameters should also be taken into account, therefore it is recommended to use mathematical simulation for determining optimal parameters for each specific application of cross belt-sweep sampling.

The bucket rate during the motion was kept constant, however the material resistance was unstable. In particular, this follows from fluctuations in the sampling error itself. To improve accuracy, sampling should be carried out as often as possible, which increases the equipment load.

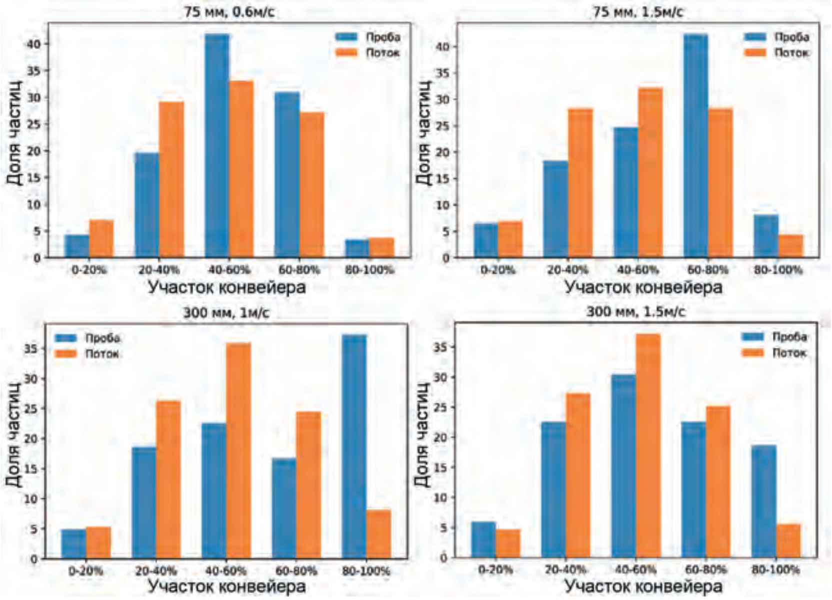


Fig. 6. Dependence of the material sampling uniformity on the particle size and sampler rate

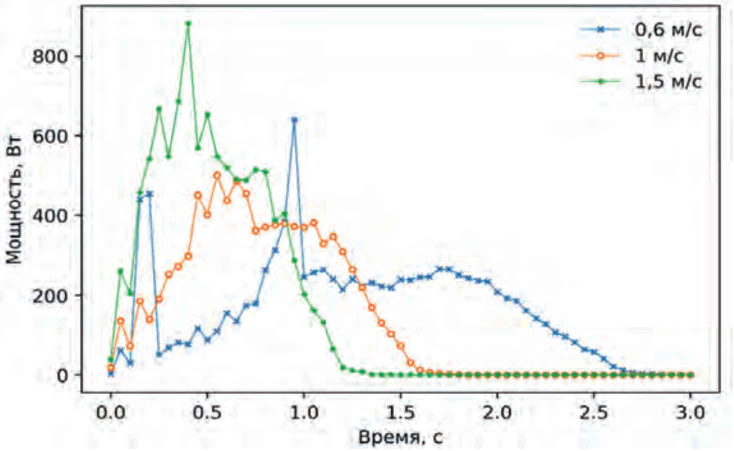


Fig. 7. Required power to maintain the set rate. Bucket width — 75 mm

Thus, we conclude that an important parameter of the sweep-type sampler is the motor power, which can ensure the maintenance of uniform rate throughout the sampling interval, taking into account the flow unevenness. Fig. 7 and 8 show the instantaneous power that is required to maintain a given rate when crossing the material flow.

As you can see in Fig. 7, in general, an increased bucket rate requires a more powerful motor for sampling. However, with sampling too slow, the material begins to accumulate near the bucket walls, making it difficult to move (Fig. 8). We consider this effect in more detail on the example of a 75 mm bucket moving at a rate of 0.6 m/s. The greatest load on the sampler corresponds to the moment when the bucket is completely immersed in the material flow (Fig. 9). With further movement, the material accumulated near the walls will pass along the bucket, and the load on the sampler will decrease.

Thus, to select the optimum power of the sampler motor, not only the required bucket rate, but also the material flow rate and the conveyor geometry must be taken into account. Table 3 below shows the maximum power values necessary to

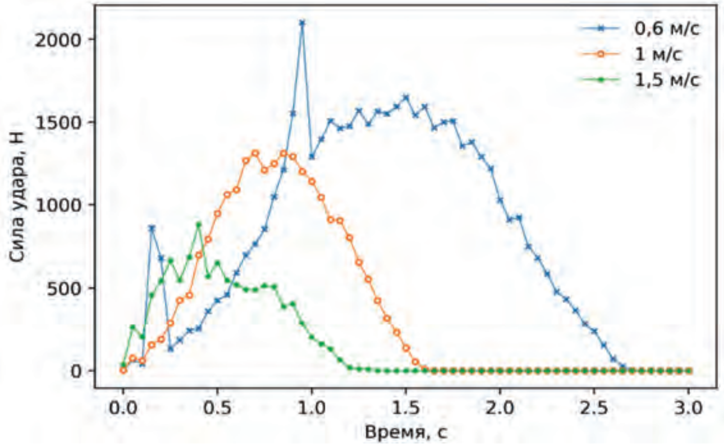


Fig. 8. Material load on the bucket. Bucket width — 75 mm

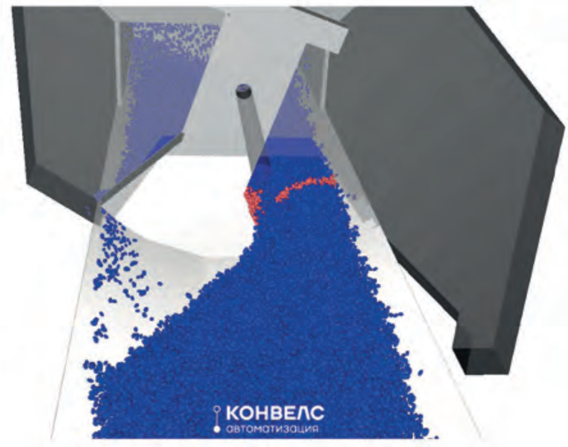


Fig. 9. Moment of maximum load on the bucket

maintain a uniform bucket motion under given conditions.

On the other hand, when sampling a large-diameter material, the maximum resistance often occurs at the initial moment (Fig. 10). This is due to the fact that the edge of the bucket falls exactly on the face of a particle and cannot push it away or inside the bucket because of the pressure of the rest of the material.

Conclusion

The sweep design of the sampling device is not listed among those recommended by the ISO standard with good reason. As you can see, this method sampling representativeness involves a number of issues. A separate in-depth sampling error analysis is required for each particular sweep-type sampler application.

According to the results of this analysis, for each installation point, calculations of the optimal bucket rate, the number of point samples per product lot, the minimum motor power are required. The increased number of point samples per lot suggests a necessity to use a system for further sample treatment designed for a larger amount of material. A larger sample reduction ratio is also required.

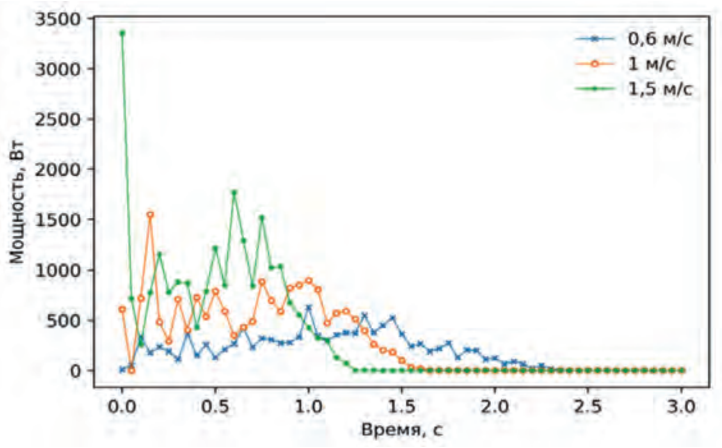


Fig. 10. Required power to maintain the set rate. Bucket width — 450 mm

Table 3

Maximum motor power required to maintain the set rate, W

	25 mm (bucket width 75 mm)	**50 mm** (bucket width 150 mm)	**100 mm** (bucket width 300 mm)	**150 mm** (bucket width 450 mm)
0.6 m/s	638	590	489	629
0.8 m/s	711	652	801	1061
1 m/s	500	1061	1133	1547
1.2 m/s	1013	777	1348	1908
1.5 m/s	881	1253	1508	3353

Nevertheless, conveyor belt sweep sampling remains the only technologically feasible method in many production processes. To increase its representativeness, the sampling process computer simulation can be carried out, with further calculation of all the required parameters. This requires modern software systems and high-performance computers.

LLC KONVELS Avtomatizatsiya, offering a sampling system to its customers, also includes a full range of mathematical simulations of the system. We separately calculate all the parameters of the proposed device, using all available data on the production characteristics at the installation point for simulation. This allows us to minimize the sampling error even when using such a device as a sweep-type sampler.

Conclusions

Based on the results of the conducted studies, the following conclusions can be drawn:

- When sampling bulk material from the conveyor belt using a sweep-type sampler, point samples will have a sampling error on the particle size distribution ranging from 1% for large grades to 5% for small grades. In this case, an increase in the number of point samples is required to obtain a representative material sample.
- An increase in the number of point samples leads to an increase in the sweep-type sampler performance, but the sampling rate cannot be proportionally increased, since it significantly affects the sampling representativeness of individual material flow portions. To determine the optimal operating mode of the sweep-type sampler with a view to achieve a minimum sampling error, simulation for a specific application is needed.
- To minimize the sampling error, a motor of appropriate capacity is required to maintain a constant sampling rate. Mathematical simulation helps calculate the required motor power with high accuracy.

REFERENCES

1. Turtygina N. A. The essence of the problem of ore quality control and management at mining enterprises. *Mining Informational and Analytical Bulletin*. 2012, vol. 6, pp. 372—373.

2. Karin Engström, Kim H. Esbensen. Evaluation of sampling systems in iron ore concentrating and pelletizing processes — Quantification of Total Sampling Error (TSE) vs. process variation. *Minerals Engineering*, 2018, vol. 116, pp. 203—208.

3. Morozov V. B., Morozova T. G. Methodological and technical support of the representative samples obtaining process. *Izvestia, Tula State University. Technical science*. 2015, vol. 7, part 2, pp. 14—21.

4. Gorelov A. S. Methodology of automated statistic control of large-scale production. *Izvestia, Tula State University. Technical science*. 2010, vol. 2, part 1, pp. 173—186.

5. Pierre M. Gy. *Sampling of particulate materials.Theory and practice*. Amsterdam: Elsevier Scientific Publishing Company. 1979. 431 p.

6. *ISO 3082:2017(E)* Iron ores. Sampling and sample preparation procedures. Geneva: International Organization for Standardization. 2017. 81 p.

7. *GOST R ISO 11648-2-2009* Statistical methods. Sampling from bulk materials. Part 2. Moscow, Standartinform, 2010. 139 p.

8. *GOST 14180-80* Ores and concentrates of non-ferrous metals. Moscow, Izdatelstvo standartov, 1990, 19 p.

9. Lomonosov G. G., Turtygina N. A. The phenomenon of ore mass segregation and its influence on the development of mining product quality. *Mining Informational and Analytical Bulletin*. 2014, vol. 6, pp. 37—40.

10. Pawlus P., Zelasko W. The importance of sampling interval for rough contact mechanics. *Wear*, 2012, vol. 276—277, pp. 121—129.

11. Claude Bazin, Daniel Hodouin, Raphaël Mermillod Blondin. Estimation of the variance of the fundamental error associated to the sampling of low grade ores. *International Journal of Mineral Processing*. 2013, vol. 124, pp. 117—123.

12. Barry A. Wills, James Finch. *Wills' Mineral Processing Technology*. Amsterdam: Elsevier Scientific Publishing Company. 2016, 498 p.

AUTHORS

Prokopenko A.Yu.[1], General Director, e-mail: alexei.prokopenko@konvels.com,
Denisov S.A.[1], Deputy General Director for Development, e-mail: sergei.denisov@konvels.com,
Morkovin A.S.[1], Head of Mathematical Modeling Department,
e-mail: alexander.morkovin@konvels.com.
Nesterov D.K.[1], Head of Design Department, e-mail: dmitry.nesterov@konvels.com,
[1] KONVELS Automation Ltd., 117393, Moscow, Russia.

ОТДЕЛЬНЫЕ СТАТЬИ ГОРНОГО ИНФОРМАЦИОННО-АНАЛИТИЧЕСКОГО БЮЛЛЕТЕНЯ (СПЕЦИАЛЬНЫЙ ВЫПУСК)

ОПРЕДЕЛЕНИЕ РЕЖИМОВ РАБОТЫ ДЕГАЗАЦИОННЫХ УСТАНОВОК УГОЛЬНЫХ ШАХТ С УЧАСТКАМИ ПОДЗЕМНЫХ ГАЗОПРОВОДОВ ИЗ КОМПОЗИТНЫХ МАТЕРИАЛОВ

(2018, № 5, СВ 19, 12 с.)

Малашкина Валентина Александровна — доктор технических наук, профессор, МГИ НИТУ «МИСиС».

Расчет конструктивных параметров и технических характеристик дегазационных установок произведен с учетом гидродинамических особенностей движения влажной метановоздушной смеси по вакуумному подземному дегазационному трубопроводу, который может быть собран из стальных или из стеклопластиковых звеньев труб, а также иметь комбинированный набор материалов трубопровода. Выбор рациональных режимов движения влажной метановоздушной смеси по подземному вакуумному дегазационному трубопроводу становится возможным за счет обязательной корректировки расчетных величин диаметров участковых и магистральных трубопроводов по предварительно определенным интервалам критериев гидродинамического подобия, определяемых с учетом материала трубопровода, что обеспечивает повышение эффективности работы любой дегазационной установки.

Ключевые слова: дегазация, гидравлическое сопротивление, подземный вакуумный газопровод, метановоздушная смесь, условия труда шахтеров.

DEFINITION OF THE MODES OF DEGASSING PLANTS OF COAL MINES WITH SECTIONS OF UNDERGROUND PIPELINES MADE OF COMPOSITE MATERIALS

Malashkina V.A., Doctor of Technical Sciences, Professor, Mining Institute,
National University of Science and Technology «MISiS», 119049, Moscow, Russia, e-mail: ud@msmu.ru.

Calculation of design parameters and technical characteristics of degassing units should be made taking into account the hydrodynamic characteristics of the movement of wet methane-air mixture through a vacuum underground degassing pipeline, which can be assembled from steel pipe links, from fiberglass pipe links, as well as have a combined set of pipeline materials. The choice of rational modes of motion of a wet methane-air mixture through an underground vacuum degassing pipeline becomes possible due to the obligatory correction of calculated values of diameters of precinct and main pipelines at predetermined intervals of hydrodynamic similarity criteria determined taking into account the thermal of the pipeline, which ensures an increase in the efficiency of any degassing installation.

Key words: degassing, hydraulic co-resisting, underground vacuum gas pipeline, methane-air mixture, working conditions of miners.