ГИАБ. Горный информационно-аналитический бюллетень /
MIAB. Mining Informational and Analytical Bulletin, 2020;(6):5-14
ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER

УДК 531+620.17 DOI: 10.25018/0236-1493-2020-6-0-5-14

ОПРЕДЕЛЕНИЕ ОБЩЕЙ АЭРОЗОЛЬНОЙ И ТОНКОДИСПЕРСНОЙ ПЫЛИ В УГЛЯХ

С.А. Эпштейн[1], Е.Л. Коссович[1], Е.П. Вишневская[1], К.В. Агарков[1], А.В. Колиух[1]
[1] НИТУ «МИСиС», Москва, Россия, e-mail: apshtein@yandex.ru

Аннотация: В настоящее время актуальными являются вопросы характеристики способности товарных углей выделять аэрозольную пыль при транспортировке и перевалке. В настоящей работе представлена новая методика определения содержания пыли в углях. Методика основана на имитации процессов перемещения и перевалки пробы угля крупностью менее 3 мм путем перемешивания углей с постоянной скоростью с одновременным пропусканием фиксированного объема воздуха через систему фильтров и определении суммарного содержания пыли и пыли классам крупности более и менее 10 мкм. При оценке содержания пыли в товарном угле в качестве пробы используют остаток ситового анализа представительной пробы угля после сита 3 мм. Приведены экспериментальные результаты исследования двух проб товарных углей Кузнецкого бассейна, различающихся по петрографическому составу и стадии метаморфизма. Показано, что в пределах установленной погрешности измерений, общее количество пыли, способной выделяться в условиях имитации перевалки, сопоставимо для исследованных углей. С другой стороны, содержание пыли с размерами частиц более и менее 10 мкм существенно различается в зависимости от петрографического состава и стадии метаморфизма углей. Так, высокое содержание в угле инертинита определяет, по всей видимости, увеличение содержания в пыли частиц менее 10 мкм.

Ключевые слова: уголь, пыль, метод оценки содержания пыли в углях, аэрозольная пыль, тонкодисперсная пыль, стадия метаморфизма, петрографический состав.

Благодарность: Работа выполнена при финансовой поддержке Российского научного фонда (грант № 18-77-10052).

Для цитирования: *Эпштейн С.А., Коссович Е.Л., Вишневская Е.П., Агарков К.В., Колиух А.В.* Определение общей аэрозольной и тонкодисперсной пыли в углях // Горный информационно-аналитический бюллетень. – 2020. – № 6. – С. 5–14. DOI: 10.25018/0236-1493-2020-6-0-5-14.

Determination of total and fine airborne dust in coals

S.A. Epshtein[1], E.L. Kossovich[1], E.P. Vishnevskaya[1], K.V. Agarkov[1], A.V. Koliukh[1]
[1] National University of Science and Technology «MISiS», Moscow, Russia, e-mail: apshtein@yandex.ru

Abstract: Issues on evaluation of coals ability to liberate airborne dust during transportation and transloading are nowadays relevantly current. In the current work, a new method was presented for evaluation of dust contents in coals. It is based on modeling of the processes of coals transloading and transportation. The essence is to stir coals sample of size <3mm at a constant rotation rate with a simultaneous passing a fixed volume of air through a filter system and determining the total airborne dust content and dust class sizes more or less than 10 microns.

During the tests, a sample of commodity coal is used as a residue of a sieve analysis of the representative coal sample after the sieve of 3 mm. Experiments were held at two hard coals of the Kuznetsk coal basin differing in their metamorphism degree and petrographic composition. It was established that within the measurement error, the total amount of airborne dust able to be released during transloading for both the considered samples is comparable. On the other hand, the size classes distribution for dust particles over or less than 10 microns varies significantly and depends on the coals rank and petrographic composition. High inertinite contents determines, presumably, the increase of fine dust particles (less than 10 microns) in the total airborne dust released.

Key words: coal, dust, method for dusting ability evaluation, airborne dust release, fine dust particles, metamorphism degree, petrographic composition

Acknowledgements: The work was supported by the Russian Science Foundation (grant No 18-77-10052).

For citation: Epshtein S.A., Kossovich E.L., Vishnevskaya E.P., Agarkov K.V., Koliukh A.V. Determination of total and fine airborne dust in coals. *MIAB. Mining Inf. Anal. Bull.* 2020;(6):5-14. [In Russ]. DOI: 10.25018/0236-1493-2020-6-0-5-14.

Introduction

Coal dust is being evacuated from coal at any stage of its lifecycle, i.e. from mining to transportation and storage up until utilization. At the stage of mining, coal dust is assumed to be generated under the external effects such as cutting and crushing [1], whereas the dust elaboration during transportation and transloading could have been reasoned by many effects such as weak mechanical properties of coals [2], oxidation or storage of coal dust inside the trade products. Recent work on the study of the occurrence of nano- and micro-sized coal dust is mainly focused on the prevention of negative consequences for the coal mine workers and environmental protection. For instance, authors of [3–8] and many others conducted studies of dependence of the amount of emerging fine dust on the method of mining of the coal seam. In these and similar studies, it was proved experimentally and with the use of modern numerical-analytical mathematical modeling, that the method of mining has a significant effect on the amount of fine dust formed.

It is easy to notice that all the existing work on the investigation of the mechanisms of the emergence of coal dust of nano- and microsizes is based on the postulate that coal dust is formed under the influence of mechanical effects during mining, storage and transportation [9]. In the early to mid-20th century, attention was drawn to the experimentally observed relationships between the amount of coal dust (measured using the so-called drum tests — Hardgrove grindability) and the rank of coal [10]. This further was studied with help of the mathematical apparatus based on the theory of fracture mechanics (see, e.g., [11–13]). Experimental investigations were all mainly based on the Hardgrove grindability index evaluation with analysis of the distribution of crushed particles by the size classes [14, 15]. Such studies have made it possible to establish a correlation between the rank of coal and the amount of fine dust formed and further with the microcomponent composition [1, 2, 14]. Some recent works have been concentrated on development of new more accurate approaches for characterization of the relationship between coals brittleness at microscales and their dusting ability [16]. The latter experimental method was based on macroscale indentation technique allowing revealing coals brittleness. It is also worth mentioning that the method proposed in articles [16, 17] was not described fully and does not contain the information on its precision characteristics. Some other approaches were based on application of nanoindentation for characterization of coals crushing at nanoscale (e.g. see [18, 19]).

As it could be seen from the abovementioned works, there exists no unified technique allowing for evaluation and characterization of coals ability to elaborate the airborne dust, especially, of different size classes from micro to nanoscales. The aim of the current work is to develop a new method that may solve the mentioned problem, especially considering the commodity coals that are being shipped, transported and transloaded during their lifecycle from the mining site to the end consumer. The method proposed in the current paper is laboratory one but was developed to model the conditions of coals shipping and transloading and allows to evaluate the dust released during such processes, including the fine dust that has not been previously studied.

Materials and Methods

The proposed approach is based on modeling (imitation) of the processes of coals transloading. The essence is to stir coals sample of size <3 mm at a constant rotation velocity with a simultaneous passing a fixed volume of air through a filter system and determining the total airborne dust content and dust class sizes more or less than 10 microns.

The scheme of the experimental setup is demonstrated in Fig. 1 — 3.

For the tests, a coal sample is used with a particle size of less than 3 mm. When assessing the dust content in commodity coals, the remainder of a sieve analysis of a representative coal sample after a 3 mm sieve is used as a sample. Before the test, at least 500 g of a representative sample

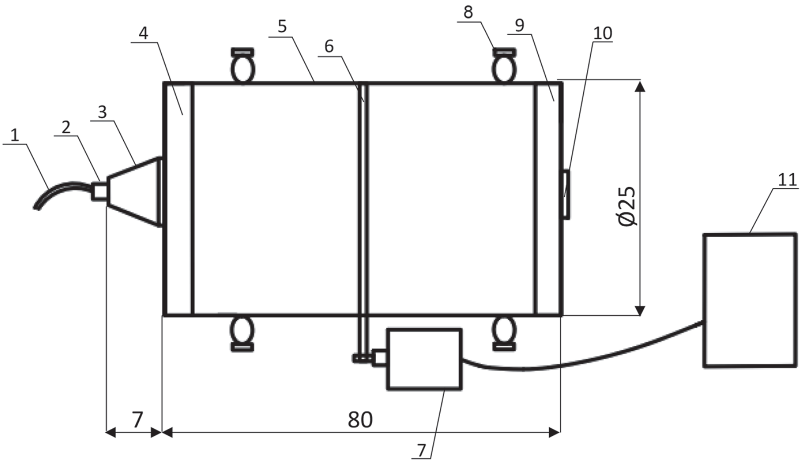

Fig. 1. The experimental setup (front view): 1 — silicone tube leading to the aspirator; 2 — fluoroplastic cartridge; 3 — holder filters in the form of a conical cartridge; 4 — front drum lid; 5 — cylinder drum; 6 — wheel drive belt; 7 — engine driving the drum; 8 — rollers for rotating the drum; 9 — rear drum lid; 10 — rear opening of the drum; 11 — control panel

Рис. 1. Схема экспериментальной установки (вид спереди): 1 — силиконовая трубка, ведущая к аспиратору; 2 — фторопластовый патрон; 3 — держатель фильтров в виде конического патрона; 4 — передняя крышка барабана; 5 — барабан цилиндрической формы; 6 — приводной ремень; 7 — мотор, приводящий в движение барабан; 8 — ролики для вращения барабана; 9 — задняя крышка барабана; 10 — заднее отверстие барабана; 11 — пульт управления

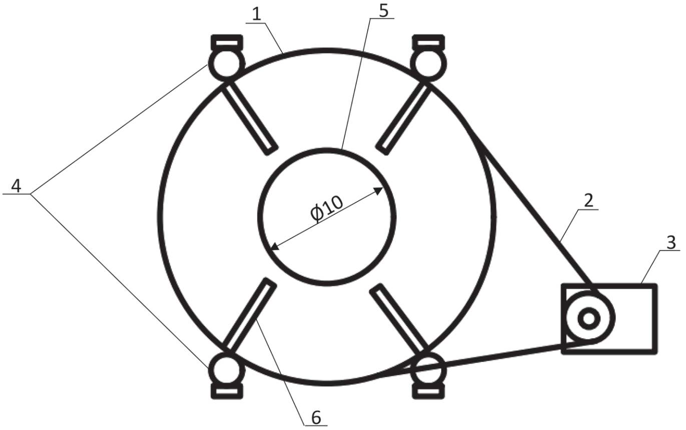

Fig. 2. The experimental setup (cross section): 1 — cylinder drum; 2 wheel drive belt; 3 — engine driving the drum; 4 — rollers for rotating the drum; 5 — openings in the drum lids; 6 — aluminum grates

Рис. 2. Схема экспериментальной установки (поперечный разрез): 1 — барабан цилиндрической формы; 2 — приводной ремень; 3 — мотор, приводящий в движение барабан; 4 — ролики для вращения барабана; 5 — отверстия в крышках барабана; 6 — дюралевые пластины (колосники)

is taken, laid out in a thin layer on a metal tray until it reaches an air-dry state. After that, a sample is taken to determine the content of total moisture in the coal and at least 3 three samples weighing 10 ± 0.01 g for the main testing.

The sample is placed in a previously thoroughly cleaned drum *5* (Fig. 1), the front lid *4* is closed and the filters *4* and *6* (Fig. 3) are installed in the holder *3*, which is a conical cartridge attached to the tube of the aspirator *1*. Next, the holder *3* is attached to drum lid *4* (Fig. 1) and is fixed it with screws *5*. The initial parameters on the aspirator are to be set as follows: air flow rate of 40 l/min, duration of flow analysis — 3 minutes. For testing, a PU-3E aspirator was used, designed to provide air sampling to determine the dust and aerosol content by pumping a given sample volu-

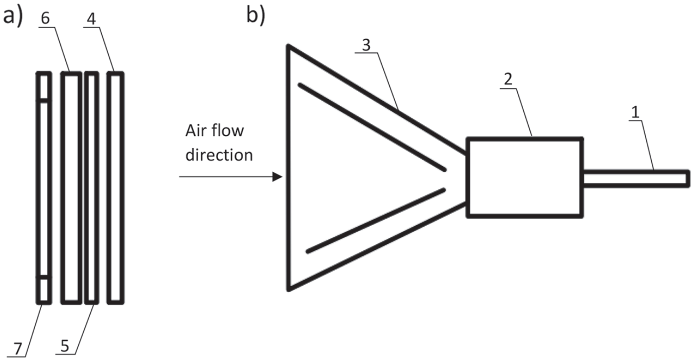

Fig. 3. Filter holder device: a) filters holding system; b) filter holder: 1 — silicone tube leading to the aspirator; 2 — fluoroplastic cartridge; 3 — filter holder in the form of a conical cartridge; 4 — thin filter AF-VP-20-10; 5 — ring gasket; 6 — filter FT-100-G2; 7 — locking ring pad

Рис. 3. Устройство держателя фильтров: система удержания фильтров (а); держатель фильтра (б): 1 — силиконовая трубка, ведущая к аспиратору; 2 — фторопластовый патрон; 3 — держатель фильтров в виде конического патрона; 4- тонкий фильтр АФ-ВП-20-10; 5 — кольцевая прокладка; 6 — фильтр ФТ-100-G2; 7 — фиксирующая кольцевая накладка me through filters such as AFA VP 20, AFA VP 10 (or others). To collect dust, we used 2 sequentially installed filters:

- filter 6 (Fig. 3, *a*) FT-100-G2, cleaning class: G2 according to GOST EN 14799-2013, polyester material, diameter 40 mm, minimum particle size 10 microns;
- a fine particles filter 4 (Fig. 3, *a*) AF-VP-20-1 in accordance with TU 95 1892-89, perchlorvinyl material, working surface area — 20 cm^2, diameter 40 mm, the minimum size of trapped particles is 0.5 microns.

Before the testing procedure, the filters are weighed on an analytical balance with a division value of 0.1 mg. To do this, the filters are placed in pre-weighed containers with a tightly rubbed lid.

On the control panel *11* of engine *7* (Fig. 1), the drum roll speed is set at 30 rpm and at the same time the drum rotation and the aspirator are turned on. After stopping the drum, the aspirator is turned off, the filter holder is disconnected, and the filters are carefully removed and placed in pre-weighed containers with a tightly lidded cover. The mass of the collected dust is determined as the difference between the weight of the filter before and after the tests.

The results of measuring the mass of captured dust are used to calculate its content (% wt.) In coal (for the air-dry state) taken for testing: P_t — the total content of dust in filters *4* and *6*; P_1 is the dust content with a particle size of less than 10 microns; P_2 — dust content with a particle size of more than 10 microns.

To determine the dust content in commodity coal, the results of its sieve analysis are used, namely, the content in it the particles with size class of less than 3 mm.

Results

For testing, 2 samples of commodity coals from the Kuznetsk basin were used. Characteristics of coal are given in tables 1 and 2. Coal T is characterized by the highest ash content (14.7%) and a lower yield of volatiles in comparison with SS coal. Coal SS is characterized by a high content of inertinite in its composi-

Table 1

Proximate analysis of coals
Результаты технического анализа углей

Coal	Indices of proximate analysis						
	W^t, %	W^a, %	A^d, %	V^{daf}, %	Q_s^{daf}, kcal/kg	Q_i^r, kcal/kg	S_t^d, %
T	2,9	1,3	14,7	13,6	8353	6658	0,25
SS	5,0	1,4	6,8	20,3	8364	7129	0,20

W^t — total moisture; W^a — analytical moisture; A^d — ash on dry basis; V^{daf} — volatiles yield on dry, ash-free basis; Q_s^{daf} — gross calorific value on dry, ash-free basis; Q_i^r — net calorific value; S_t^d — Sulfur contents on dry basis

Table 2

Petrographic composition of coals
Петрографический состав углей

Coal	Vt ,%	Sv, %	I, %	L, %	MM, %	$R_{o,r}$, %
T	47,2	17,0	32,4	0	3,4	1,647
SS	29,8	17,6	51,6	0,6	0,4	1,132

Vt — vitrinite contents; Sv — semi-vitrinite contents; I — inertinite contents; L — liptinite contents; MM — mineral matter, $R_{o,r}$ — mean random vitrinite reflectance index.

Table 3

Results on determination of dust contents in coal SS
Результаты определения содержания пыли в угле СС

Round	P_1,%	P_2,%	P_t,%	mean P_1, %	standard deviation P_1	mean P_2, %	standard deviation P_2	mean P_t, %	standard deviation P_t
1	2,42	1,88	4,29	2,47	0,03	1,88	0,13	4,35	0,12
2	2,45	2,08	4,53						
3	2,48	1,80	4,29						
4	2,50	1,91	4,41						
5	2,49	1,72	4,22						

Table 4

Results on determination of dust contents in coal T
Результаты определения содержания пыли в угле Т

Round	P_1,%	P_2,%	P_t,%	mean P_1, %	standard deviation P_1	mean P_2, %	standard deviation P_2	mean P_t, %	standard deviation P_t
1	0,14	4,01	4,15	0,16	0,02	4,27	0,19	4,42	0,21
2	0,18	4,55	4,72						
3	0,15	4,26	4,41						
4	0,19	4,31	4,50						
5	0,13	4,21	4,35						

tion in comparison with coal T. Samples of coals were collected after sieving in accordance with GOST 2093-82 «Solid fuel. Size analysis». They represent the residue after a 3 mm sieve. For each sample of T and SS coals, 5 parallel tests were carried out.

The results of parallel measurements of the dust content in coals T and SS are presented in Tables 3 and 4.

It is obvious that the standard deviation for the P_1 fraction for coal SS (dust with particle sizes less than 10 microns) does not exceed 1% of its mean value. For the fraction P_2 (larger than 10 microns) and the total airborne dust contents P_t, their standard deviation across the rounds does not exceed 10%. As for the coal T, the statistical characteristics (namely, the standard deviations of the indicated in Table 4 values) are comparable to those obtained for the different coal.

It is interesting to note that the total dust content in both considered coals is almost the same — 4.45 and 4.32% for SS and T coals, respectively. However, these coals differ significantly in the dust content of different sizes. For example, the dust content with particle sizes of less than 10 microns for coal T is 0.16%, and in the SS coal — 2.47%, which is 4 and 57% of the total airborne dust captured during testing (Fig. 4).

Such differences are most likely related to the peculiarities of the petrographic composition of the coals. Namely, SS coal has a significantly higher content of inertinite in its composition. In some previous works, authors have demonstrated that the presence of inertinite macerals allows for the formation of more fine dust in comparison with coals mainly consisting of vitrinite [14].

The latter could be tentatively explained by the fact that inertinite macerals have revealed their higher brittleness at nano- and microindentation [20–22].

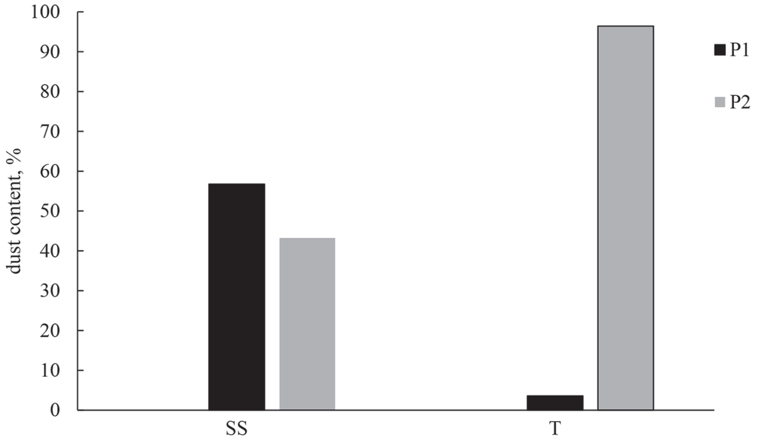

Fig. 4. Ratio of dust of different sizes (P_1 is the dust content with particles size of less than 10 microns, P_2 is the dust content with particles size of more than 10 microns) in SS and T coals

Рис. 4. Соотношение пыли различных размеров (P_1 — содержание пыли с размером частиц менее 10 мкм, P_2 — содержание пыли с размером частиц более 10 мкм) в углях SS и T

Conclusions

1. A new method was presented for evaluation and characterization of commodity coals ability to evacuate airborne dust at the processes of transportation and transloading. The method is released on a novel installation designed to serve as its base. The principal scheme of such installation has been given, and the mode of the experiments was discussed.

2. The proposed method allows not only to evaluate the amount of airborne dust released during the transloading (as modelled in the laboratory conditions), but also to distinguish the size classes of such dust, namely, coarse particles (more than 10 microns in the diameter) and fine ones (less than 10 microns).

3. Experiments were held at two hard coals differing in their metamorphism degree and petrographic composition. It was established that within the measurement error, the total amount of airborne dust able to be released during transloading for both the considered samples is comparable. On the other hand, the size classes distribution varies significantly and depends, presumably, on the coals structural properties including petrographic composition.

СПИСОК ЛИТЕРАТУРЫ

1. *Organiscak J.A.*, *Page S.J.* Airborne Dust Liberation During Coal Crushing // Coal Preparation. 2000. Vol. 21. No 5—6. Pp. 423—453. DOI: 10.1080/07349340108945630.

2. *Organiscak J.A.*, *Page S.J.* Laboratory investigation of coal grindability and airborne respirable dust // Journal of the Mine Ventilation Society of South Africa. 1993. Vol. 46. No 7. Pp. 98—105.

3. *Jiang H., Du C., Dong J.* Investigation of rock cutting dust formation and suppression using water jets during mining // Powder Technology. 2017. Vol. 307. Pp. 99—108. DOI: 10.1016/j.powtec.2016.11.029.

4. *Korshunov A.N.*, *Dergunov D.M.*, *Logov A.B.*, *Gerike B.L.* Coal cutting with a disk // Soviet Mining Science. 1975. Vol. 11. No 5. Pp. 571—573. DOI: 10.1007/BF02499387.

5. *Chen S., Wang H., Li Y., Cui H., Zhao J., Zhang X.* Theoretical and numerical analysis of coal dust separated by centrifugal force for working and heading faces // International Journal of Coal Science & Technology. 2014. Vol. 1. No 3. Pp. 338—345. DOI: 10.1007/s40789-014-0039-9.

6. *Стародубов А. Н.*, *Кравцов В. П.*, *Зиновьев В. В.* Проблемы пылеобразования и мероприятия по обеспечению безопасности и экологичности разработки угольных месторождений // Вестник Кузбасского государственного технического университета. — 2018. — № 4. — С. 99—104. DOI: 10.26730/1999-4125-2018-4-99-104.

7. *Журавлева Н. В.* Методы оценки влияния процессов добычи и переработки углей Кузнецкого угольного бассейна на экологическое состояние природной среды // Вестник Научого центра по безопасности работ в угольной промышленности. — 2016. — № 4. — С. 102—112.

8. *Викторов С. Д.*, *Кочанов А. Н.* Экспериментальное изучение закономерностей образования субмикронных частиц при разрушении горных пород // Физико-технические проблемы разработки полезных ископаемых. — 2016. — № 5. — С. 76—83. DOI: 10.1134/S1062739116041370.

9. *Page S. J.*, *Organiscak J. A.* Suggestion of a cause-and-effect relationship among coal rank, airborne dust, and incidence of workers' pneumoconiosis // AIHAJ — American Industrial Hygiene Association. 2000. Vol. 61. No 6. Pp. 785—787.

10. *Beron A. I.*, *Pozin E. Z.*, *Melamed V. Z.* Distribution pattern of the grain-size composition of coal fractured by cutting // Soviet Mining Science. 1971. Vol. 7. No 5. Pp. 512—517. DOI: 10.1007/BF02501061.

11. *Panov G. E.* Dust formation kinetics as a function of the principal mechanical properties of coals // Soviet Mining Science. 1967. Vol. 3. No 5. Pp. 511—514. DOI: 10.1007/BF02497948.

12. *Phan Quang Van* The determination of coal dust emission and percentage of quartz in coal dust emission during the cutting anthracite coal by shearing and bottom blade of the plow // Procedia Earth and Planetary Science. 2009. Vol. 1. No 1. Pp. 250—256. DOI: 10.1016/j.proeps.2009.09.040.

13. *Phan Quang Van*, *Drebenstedt C.* The determination of quartz percentages in coal dust emission during the anthracite coal cutting by mechanical cutting tool / Mine Planning and Equipment Selection. Cham: Springer International Publishing, 2014. Pp. 665—676. DOI: 10.1007/978-3-319-02678-7_64.

14. *Baafi E. Y.*, *Ramani R. V.* Rank and maceral effects on coal dust generation // International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts. 1979. Vol. 16. No 2. Pp. 107—115. DOI: 10.1016/0148-9062(79)91447-5.

15. *Hower J. C.*, *Graese A. M.*, *Klapheke J. G.* Influence of microlithotype composition on hardgrove grindability for selected eastern Kentucky coals // International Journal of Coal Geology. 1987. Vol. 7. No 3. Pp. 227—244. DOI: 10.1016/0166-5162(87)90038-3.

16. *Zhou W., Wang H., Wang D., Du Y., Zhang K., Qiao Y.* An experimental investigation on the influence of coal brittleness on dust generation // Powder Technology. 2020. Vol. 364. Pp. 457—466. DOI: 10.1016/J.POWTEC.2020.01.074.

17. *Zhou W., Wang H., Wang D., Du Y., Zhang K., Kang W.* The effect of coal proximate compositions on the characteristics of dust generation using a conical pick cutting system // Powder Technology. 2019. Vol. 355. Pp. 573—581. DOI: 10.1016/j.powtec.2019.07.093.

18. *Коссович Е. Л.*, *Эпштейн С. А.*, *Бородич Ф. М.*, *Добрякова Н. Н.*, *Просина В. А.* Взаимосвязи между неоднородностью распределения механических свойств углей на микро и наноуровнях и их способностью к внезапным выбросам и разрушению // Горный информационно-аналитический бюллетень. — 2019. — № 5. — С. 156—172. DOI: 10.25018/0236-1493-019-05-0-156-172.

19. *Argatov I. I.*, *Borodich F. M.*, *Epshtein S. A.*, *Kossovich E. L.* Contact stiffness depth-sensing indentation: Understanding of material properties of thin films attached to substrates // Mechanics of Materials. 2017. Vol. 114. Pp. 172—179. DOI: 10.1016/j.mechmat.2017.08.009.

20. *Kožušníková A.* Determination of microhardness and elastic modulus of coal components by using indentation method // GeoLines. 2009. Vol. 22. Pp. 40—43.

21. *Epshtein S.A., Borodich F.M., Bull S.J.* Evaluation of elastic modulus and hardness of highly inhomogeneous materials by nanoindentation // Applied Physics A. 2015. Vol. 119. No 1. Pp. 325—335. DOI: 10.1007/s00339-014-8971-5.

22. *Коссович Е.Л., Добрякова Н.Н., Эпштейн С.А., Белов Д.С.* Определение механических свойств микрокомпонентов углей методом непрерывного индентирования // Физико-технические проблемы разработки полезных ископаемых. — 2016. — № 5. — С. 84—91. DOI: 10.1134/S1062739116041382. ГИАБ

REFERENCES

1. Organiscak J.A., Page S.J. Airborne Dust Liberation During Coal Crushing. *Coal Preparation*. 2000. Vol. 21. No 5—6. Pp. 423—453. DOI: 10.1080/07349340108945630.

2. Organiscak J.A., Page S.J. Laboratory investigation of coal grindability and airborne respirable dust. *Journal of the Mine Ventilation Society of South Africa*. 1993. Vol. 46. No 7. Pp. 98—105.

3. Jiang H., Du C., Dong J. Investigation of rock cutting dust formation and suppression using water jets during mining. *Powder Technology*. 2017. Vol. 307. Pp. 99—108. DOI: 10.1016/j.powtec.2016.11.029.

4. Korshunov A.N., Dergunov D.M., Logov A.B., Gerike B.L. Coal cutting with a disk. *Soviet Mining Science*. 1975. Vol. 11. No 5. Pp. 571—573. DOI: 10.1007/BF02499387.

5. Chen S., Wang H., Li Y., Cui H., Zhao J., Zhang X. Theoretical and numerical analysis of coal dust separated by centrifugal force for working and heading faces. *International Journal of Coal Science & Technology*. 2014. Vol. 1. No 3. Pp. 338—345. DOI: 10.1007/s40789-014-0039-9.

6. Starodubov A.N., Kravtsov V.P., Zinoviev V.V. Dust formation problems and measures to ensure labor protection and ecological safety in development of coal deposits. *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta*. 2018, no 4, pp. 99—104. DOI: 10.26730/1999-4125-2018-4-99-104. [In Russ].

7. Zhuravleva N.V. Methods for assessing the impact of extraction and processing of coal of the Kuznetsk coal basin on the ecological state of the eivnronment. *Vestnik nauchnogo tsentra po bezopasnosti rabot v ugolnoy promyshlennosti*. 2016, no 4, pp. 102—112. [In Russ].

8. Viktorov S.D., Kochanov A.N. Experimental regularities in formation of submicron particles under rock failure. *Fiziko-tekhnicheskiye problemy razrabotki poleznykh iskopayemykh*. 2016, no 5, pp. 76—83. [In Russ]. DOI: 10.1134/S1062739116041370.

9. Page S.J., Organiscak J.A. Suggestion of a cause-and-effect relationship among coal rank, airborne dust, and incidence of workers' pneumoconiosis. *AIHAJ — American Industrial Hygiene Association*. 2000. Vol. 61. No 6. Pp. 785—787.

10. Beron A.I., Pozin E.Z., Melamed V.Z. Distribution pattern of the grain-size composition of coal fractured by cutting. *Soviet Mining Science*. 1971. Vol. 7. No 5. Pp. 512—517. DOI: 10.1007/BF02501061.

11. Panov G.E. Dust formation kinetics as a function of the principal mechanical properties of coals. *Soviet Mining Science*. 1967. Vol. 3. No 5. Pp. 511—514. DOI: 10.1007/BF02497948.

12. Phan Quang Van The determination of coal dust emission and percentage of quartz in coal dust emission during the cutting anthracite coal by shearing and bottom blade of the plow. *Procedia Earth and Planetary Science*. 2009. Vol. 1. No 1. Pp. 250—256. DOI: 10.1016/j.proeps.2009.09.040.

13. Phan Quang Van, Drebenstedt C. The determination of quartz percentages in coal dust emission during the anthracite coal cutting by mechanical cutting tool. *Mine Planning and Equipment Selection.* Cham: Springer International Publishing, 2014. Pp. 665—676. DOI: 10.1007/978-3-319-02678-7_64.

14. Baafi E.Y., Ramani R.V. Rank and maceral effects on coal dust generation. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*. 1979. Vol. 16. No 2. Pp. 107—115. DOI: 10.1016/0148-9062(79)91447-5.

15. Hower J. C., Graese A. M., Klapheke J. G. Influence of microlithotype composition on hardgrove grindability for selected eastern Kentucky coals. I*nternational Journal of Coal Geology*. 1987. Vol. 7. No 3. Pp. 227—244. DOI: 10.1016/0166-5162(87)90038-3.

16. Zhou W., Wang H., Wang D., Du Y., Zhang K., Qiao Y. An experimental investigation on the influence of coal brittleness on dust generation. *Powder Technology*. 2020. Vol. 364. Pp. 457—466. DOI: 10.1016/J.POWTEC.2020.01.074.

17. Zhou W., Wang H., Wang D., Du Y., Zhang K., Kang W. The effect of coal proximate compositions on the characteristics of dust generation using a conical pick cutting system. *Powder Technology*. 2019. Vol. 355. Pp. 573—581. DOI: 10.1016/j.powtec.2019.07.093.

18. Kossovich E. L., Epshtein S. A., Borodich F. M., Dobryakova N. N., Prosina V. A. Connections between micro/nano scale heterogeneity of mechanical properties of coals and their propensity to outbursts and crushing. *MIAB. Mining Inf. Anal. Bull.* 2019;(5):156-172. [In Russ]. DOI: 10.25018/0236-1493-2019-05-0-156-172.

19. Argatov I. I., Borodich F. M., Epshtein S. A., Kossovich E. L. Contact stiffness depth-sensing indentation: Understanding of material properties of thin films attached to substrates. *Mechanics of Materials*. 2017. Vol. 114. Pp. 172—179. DOI: 10.1016/j.mechmat.2017.08.009.

20. Kožušníková A. Determination of microhardness and elastic modulus of coal components by using indentation method. *GeoLines*. 2009. Vol. 22. Pp. 40—43.

21. Epshtein S. A., Borodich F. M., Bull S. J. Evaluation of elastic modulus and hardness of highly inhomogeneous materials by nanoindentation. *Applied Physics A*. 2015. Vol. 119. No 1. Pp. 325—335. DOI: 10.1007/s00339-014-8971-5.

22. Kossovich E. L., Dobryakova N. N., Epshtein S. A., Belov D. S. Mechanical properties of coal microcomponents under continuous indentation. *Fiziko-tekhnicheskiye problemy razrabotki poleznykh iskopayemykh*. 2016, no 5, pp. 84—91. [In Russ]. DOI: 10.1134/S1062739116041382.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Эпштейн Светлана Абрамовна[1] — д-р техн. наук, старший научный сотрудник,
зав. лабораторией, e-mail: apshtein@yandex.ru,
Коссович Елена Леонидовна[1] — канд. физ.-мат. наук,
старший научный сотрудник, e-mail: e.kossovich@misis.ru,
Вишневская Елена Петровна[1] — аспирант,
Агарков Кирилл Владимирович[1] — аспирант,
Колиух Артем Валерьевич[1] — студент
[1] НИТУ «МИСиС», научно-учебная испытательная лаборатория «Физико-химии углей».
Для контактов: Эпштейн С.А., e-mail: apshtein@yandex.ru

INFORMATION ABOUT THE AUTHORS

S.A. Epshtein[1], Dr. Sci. (Eng.), Senior Researcher,
Head of Laboratory, e-mail: apshtein@yandex.ru,
E.L. Kossovich[1], Cand. Sci. (Phys. Mathem.),
Senior Researcher, e-mail: e.kossovich@misis.ru,
E.P. Vishnevskaya[1], Graduate Student,
K.V. Agarkov[1], Graduate Student,
A.V. Koliukh[1], Student,
[1] National University of Science and Technology «MISiS», 119049, Moscow, Russia,
Scientific and Training Laboratory of Physics and Chemistry of Coals.
Corresponding author: S.A. Epshtein, e-mail: apshtein@yandex.ru

Получена редакцией 06.02.2020; получена после рецензии 22.04.2020; принята к печати 20.05.2020.
Received by the editors 06.02.2020; received after the review 22.04.2020; accepted for printing 20.05.2020.