# Study of the characteristics of organic mining materials affecting their explosive properties

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**Abstract.** The article analyzes the explosive and fire-hazardous properties of coal dust of various dispersions using the example of coal mine dust. The authors proposed sample preparation methods for obtaining and studying dust fractions with a dispersity of less than 800 microns. The results of a study of the shapes of dust particles are presented. To study the characteristic particle sizes the authors suggested using the optical microscopy method implemented using a LEICA DM 4000 microscope and the "Image Scope Color" information processing application. To assess the reactivity of dust particles, the authors used a simultaneous thermal analysis method implemented using an STA 449 F1 Jupiter with NETZSCH Proteus Software. The results of a thermogravimetric study of narrow fractions of organic coal dust are presented. The influence of dispersion on the explosive properties of dusts has been established. The results obtained showed the need and expediency of further study of precisely fine fractions of explosive dusts of this kind.

## 1 Introduction

Considering the fire and explosion hazard characteristics of coal dust, most studies have confirmed the importance of studying the dust factor - dust explosion hazard [1-3]. The process of dust deposition and distribution of dust particles depending on the fractions is a rather complex process associated with the technology of mining and transportation of minerals [4-6]. It is generally accepted that dust exists in two states [5-8]:

- aerosol - dust floating in the mine atmosphere;
- airgel - deposited on various surfaces, but over time it can again become an aerosol.

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The ongoing studies of the dispersion composition of the coal dust are carried out to find zones of flammability and explosion, to determine the effect of dust on the physiological state of service personnel [9-11].

Analysis of the technological process associated with the operation of mining equipment showed the possibility of the formation and spread of aerosol particles. To determine their composition, concentration, and dynamics of existence, it is necessary to conduct a comprehensive study on new technological equipment with the aim of [12-14]:

- formation of criteria for the appearance, location of an object in space, deposition of aerosol particles and their control (dust sensors);
- development of new assessment analytical procedures for calculating hazardous concentrations;
- development of modern methods for monitoring their occurrence;
- preparation of optimal ventilation modes, dust suppression methods, from the point of view of organizational measures and technical implementation of devices.

Divisions of laboratories that are part of the detachments of paramilitary mine rescue units, coal mines, mainly carry out control sampling of their physicochemical properties [1, 3, 8].

Comprehensive laboratory studies involving modern applied scientific equipment and instruments that allow assessing the various properties of dust-air mixtures from the point of view of explosion and fire hazard are not carried out at almost all mining enterprises and in the detachments of paramilitary mine rescue unit teams [13, 15, 16].

Therefore, the preparation of modern methods for conducting coal dust studies using existing examination methods is advisable as a reinforcement and addition to proven methods for determining the fire and explosion hazard properties of coal dust. In this article, experiments are carried out on laboratory equipment to determine the dispersion composition using thermogravimetric analysis (TGA), an optical microscopic method for studying coal dust particles [16, 18, 19].

## 2 Problem statement

Based on the analysis of data contained in open sources of scientific and technical information, the authors of the article formulated the purpose of their research. For decades, with a frequency of once every 5-7 years, explosions have occurred at sites, primarily underground mining, namely in the workings of coal mines. The energy of explosions is inextricably linked with the amount of circulating coal dust [8, 20, 21]. Therefore, based on the available data, the authors of the article suggested that the goal of the work should be to study not the general composition of coal dust, but its dispersed composition, considering the characteristic particle sizes using modern microscopy methods, as well as studying the behavior of this kind of fractions when heated in an oxidative atmosphere using synchronous thermal analysis methods. environment. The authors of the article believe that only the use of an integrated approach to a comprehensive study of the fractional composition and physicochemical properties of particles during their controlled pyrolysis will make it possible to put forward a number of assumptions to increase the security of mining facilities and reduce damage from the influence of hazardous explosion factors in dust-air and methane-dust-air environments formed during the explosion [3, 6].

## 3 Materials and methods

The complex method for studying coal dust considered in this article consisted of special sample preparation and analysis of the resulting dispersed samples. In this case, methods of

granulometric, optical microscopic and synchronous thermal analysis (STA) were used. Optical microscopic analysis was performed using a LEICA DM 4000 microscope and the "Image Scope Color" information processing application. Synchronous thermal analysis and processing of the obtained data was carried out on STA 449 F3 Jupiter equipment with NETZSCH Proteus Termal Analysis software.

To achieve the set goals, pieces of coal with an average weight of 10 kg were taken. Then they were crushed and then sampling was carried out using the quartering method. Coarse grinding was carried out manually and using a cone vibration mill-crusher (up to fractions of 1 mm), and then further crushed in an analytical mill type IKA A11 basic.

As a result, the output was a coal dust fraction with a particle size not exceeding 500 μm. These procedures were carried out according to standard methods, however, it was not the coal itself that was subject to study, but its crushed samples with a dispersion of no more than 200 microns, but which made it possible to determine the fire and explosion hazard properties of coal according to current regulatory documents [10, 19, 21]. Therefore, some works provide results showing an increase in fire and explosion hazard properties with a decrease in coal dust fractions.

The dispersed composition of dust is an important characteristic of dust deposition and dust explosion safety. Despite the huge amount of work in this area, there is still no clear opinion about the sizes of particles that take the greatest part in the explosion. This fact suggests that the conditions for the occurrence of a coal dust explosion are influenced by many their characteristics and external disturbing factors. The results of past studies suggested that coal dust particles with a size not exceeding 74 microns could not lead to an explosion due to the necessary air exchange, carrying these fractions away from their accumulation sites. But studies conducted by the authors of the article showed different results, in terms of their fire and explosion hazard.

## 4 Results and discussion

As an experiment, pieces of coal weighing 10 kg were used. The dispersed coal samples were subsequently subjected to sieve granulometric analysis using the dry method. Sieve analysis was performed on an analytical complex (there is a shock-free sifting mode) device type RETSCH AS 200.

The choice of this type of equipment is explained by its capabilities to remove electrostatic charges generated during sample sieving and operate in shock-free mode.

In this case, the fractions are prepared according to the most optimal structures of dispersion parameters.

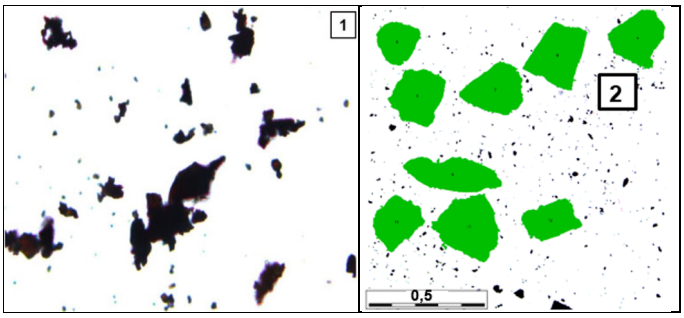


**Fig. 1.** Image of the shape of coal dust particles: 1. coming out after the sieve (mesh size 45 microns), with a resolution of 640 times; 2. when processing in the Image Scope program.

Research has shown that the dispersion composition is not the same. In addition, which is important in the study of particle size distribution, the authors found that more than 55% are coal “dust particles” with a dispersion of less than 94 microns.

Using a LEICA DM 4000 microscope and the “Image Scope Color” information processing application, the area of the irregular figure of the visible projection of dust particles was calculated, which made it possible to estimate the particle ratio using granulometric functions. Figure 2 shows one of the stages of studying the shapes of the studied coal dust samples.

In accordance with the recommendations of some researchers, the number of processed particles was more than 2000 pieces. To prove the heterogeneity of the shape and size of particles affecting their properties, using the equipment described above, we measured the characteristic dimensions of particles, namely length and width, area and the equivalent spherical diameter. Visualized graphical results of mathematical calculation of geometric characteristics are presented in Figure 3.

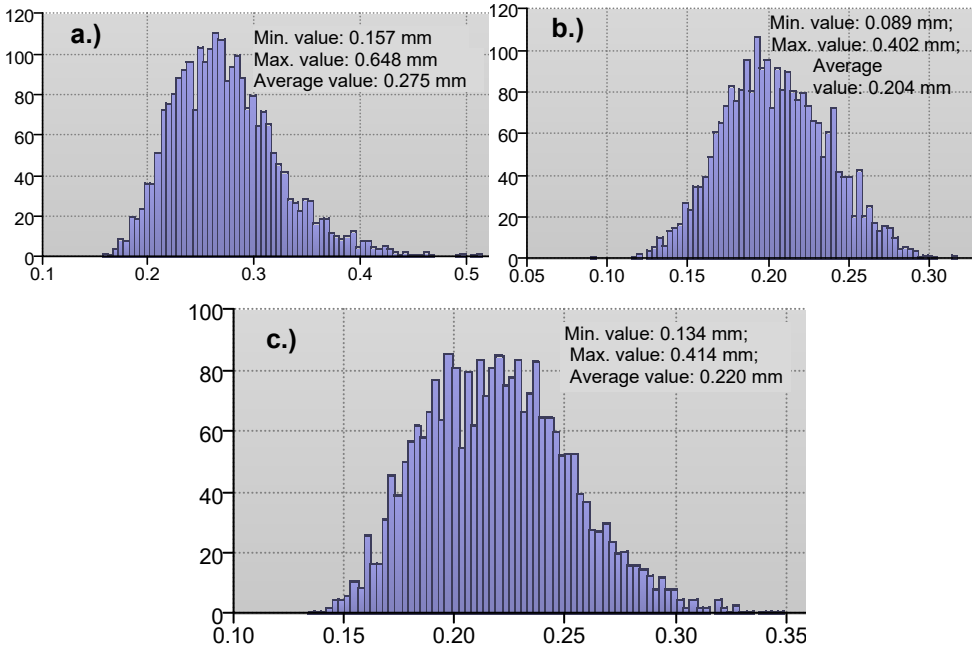


**Fig. 2.** A graphical result of measuring the geometric shapes of particles: a) length, b) width and c) the equivalent spherical diameter.

The graphical result presented in Figure 3 was obtained from microscopic analysis of 2504 particles of coal dust with a fractional composition of 200-250 microns.

The assumption that particles have a more ordered shape at sizes less than 300 μm was not confirmed. A more detailed description of the results is beyond the scope of this article, but nevertheless, we found that the uniformity of shapes begins to be observed in particles less than 100 microns. Since it is small particles less than 100 microns in size that pose various types of danger (bronchopulmonary, fire and explosion hazards, etc.), further attention will be paid to such particles.

In addition, experimental results on the study of narrower dust fractions showed that in the studied samples of 0-56 μm, the average value of dust particles ranged from 13.55 to 22.55 μm. This is precisely the fractional composition characteristic of floating dust, in

which, depending on the turbulence of the air flow, the formation of explosive concentrations is possible.

To assess the reactivity of coal dust, simultaneously with the study of its granulometric composition of various fractions (see above), thermogravimetric studies were carried out. Some results of heating samples in an oxidizing environment are shown in Figure 3. Air with an oxygen content of 20% was used as an oxidizing environment.

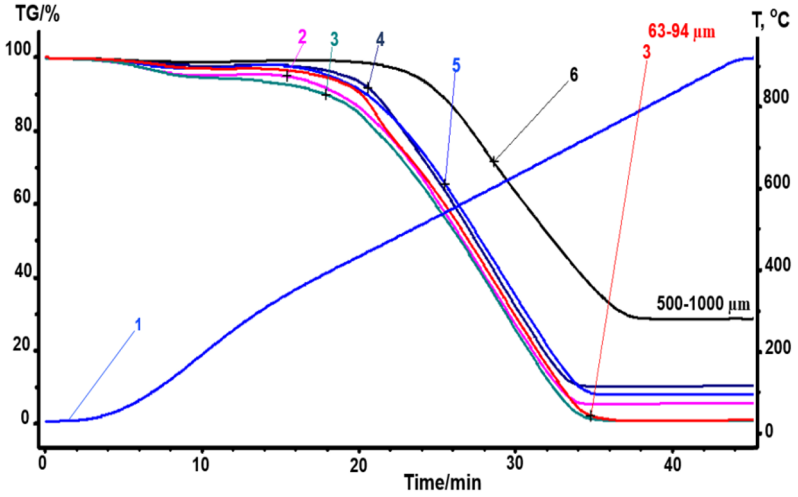


**Fig. 3.** Graph of mass loss during TG study of narrow dust fractions: 1 – heating rate 20 K/min; 2-0÷45; 3-45÷63; 3-63÷94; 4-74÷94; 5-94-125 and 6-500÷1000 microns.

As a result of the study using STA methods, it was found that fractions with a particle size of less than 94 microns are significantly more reactive, i.e. their thermal destruction processes occur at earlier stages. For example, fractions with a dispersity of less than 74 microns began to undergo pyrolysis at temperatures 100 °C lower than fractions with a dispersity of more than 500 microns. The results obtained suggested that it is the coal dust particles up to 100 µm that become the sources of processes that lead to the coal dust explosion. Thus, it has been established that the fire and explosion hazard properties of coal dust change with the localization of its dispersion composition, i.e. new quantitative values of the influence of the dispersion composition of coal dust on the process of temperature pyrolysis were obtained [8, 16, 22].

## 5 Conclusion

The authors found virtually no scientific work related to the study of fractions of coal dust particles with a size not exceeding 74 microns that affect the fire and explosion properties, so the results obtained are innovative in nature and do not contradict the general theory of fire and explosion hazard of small fractions of coal. [3, 10, 19]. However, in this area, the work carried out under the leadership of V.A. Rodionov is of interest. The results we obtained partially coincide and do not contradict those taught by S.Ya. Zhikharev, V.A. Rodionov and other researchers.

The studies performed have shown that for dust fractions with a dispersion of coal dust particles not exceeding 850 microns, there are about 60% of fractions with a dispersity not exceeding 100 microns for various types of coals. The use of optical microscopic analysis made it possible to establish the presence of particle conglomerates. We believe that the

formation of conglomerates can be explained both by forces of mutual attraction, including due to potential differences, and by a developed surface (adhesion of particles to each other). These facts suggest that particles smaller than 63 μm may account for significantly more than 25% of the total number of particles in a 0-100 μm sample.

The results of experiments using modern equipment based on software to assess reactivity using synchronous thermal analysis methods led to the conclusion that the most dangerous coal dust particles are fractions with a particle size not exceeding 100 μm, more specifically 74 μm. Thus, we can assume that it is particles of 0-100 microns that play the initial role at the stage of formation and development of an emergency, the end result of which is an explosion. to the explosion of the command center. The authors believe that further research needs to be continued with particles with a dispersion of less than 100 microns and, based on the results obtained, to develop recommendations aimed at preventive measures to prevent such accidents in coal mines.

## References

1. S.V. Balovtsev, A.M. Merkulova, MIAB. Mining Inf. Anal. Bull. **3,** 170-181 (2024). DOI: 10.25018/0236_1493_2024_3_0_170.
2. S.G. Gendler, M.S. Kryukova, MIAB. MiningInf.Anal.Bull. **9-1**, 248-269 (2023).
3. S.Ya. Zhikharev, V.D. Tsygankov, V.A. Rodionov, A.G. Isaevich, GORNYI ZHURNAL, **11**, 70–75 (2023). DOI: 10.17580/gzh.2023.11.11
4. Y.I. Vinogradov, S.V. Khokhlov, R.R. Zigangirov, A.A. Miftakhov, Y.I. Suvorov, Journal of Mining Institute, 1-15 (2024).
5. G. Sikorova, N. Chumakov, M. Tumanov, S. Zhikharev, S. Panov E3S Web of Conf., **402,** 11019 (2023)
6. V.A. Rodionov, G.N. Karpov, A.V. Leisle MIAB. Mining Inf. Anal. Bull., **6-1**, 198-213, (2022). DOI: 10.25018/0236_1493_2022_61_0_198.
7. Kongar-Syuryun Ch.B., Kovalski E.R. Geology and Geophysics of Russian South. 2023. **13(4)**, 177-187.
8. S.Ya. Zhikharev, V.A. Rodionov, D.S. Kormshchikov, V.A. Nikashin, Gornyi Zhurnal, **11**, 75–80 (2023). DOI: 10.17580/gzh.2023.11.11
9. I.E. Kolesnichenko, V.B. Artemyev, E.A. Kolesnichenko, et al., Ugol, 6, 30-35 (2016) DOI: http://dx.doi.org/10.18796/0041-5790-2016-6-30-35
10. I.V. Klimova, Yu.G. Smirnov, V.A. Rodionov, Occupational Safety in Industry, **1**, 46–50 (2022) https://doi.org/10.24000/0409-2961-2022-1-46-50
11. K.A. Kolvakh, Mining Inf. Anal. Bull. (MIAB) **3,** 124-132 (2023)
12. E.Yu. Kulikova, S.V. Balovtsev, O.V. Skopintseva, Sustainable Development of Mountain Territories, **15(1),** 7-16 (2023).
13. V.A. Rodionov, A.S. Seregin, D.A. Ikonnikov, GORNYI ZHURNAL, **9**, 35–40 (2023). DOI: 10.17580/gzh.2023.09.05
14. C.B. Kongar-Syuryun, A.V. Aleksakhin, E.N. Eliseeva, et al., Resources, **12(4)**, 50 (2023).
15. S.G. Gendler, T.A. Vasilenko, A.Yu. Stepantsova, MIAB. Mining Inf. Anal. Bull. **9-1**, 135-148 (2023)
16. V. Rodionov, I. Skripnik, Yu. Ksenofontov, et al. AIP Conference Proceedings **2467**, 080004 (2022); https://doi.org/10.1063/5.0093906

17. M.V. Tumanov, S.G. Gendler, E.I. Kabanov, V.A. Rodionov, E.A. Prokhorova, MIAB. Mining Inf. Anal. Bull. **6-1**, 230-247 (2022); https://doi.org/10.25018/0236_1493_2022_61_0_230.
18. I.I. Raguzin, E.N. Bykowa, O.U. Lepikhina, Lomonosov geography journal, **78(3),** 92-103 (2023). DOI: https://doi.org/10.55959/MSU0579-9414.5.78.3.8
19. Tatyana Kaverzneva, Vladimir Rodionov, Igor Skripnik, Sergey Zhikharev, and Maxim Polyukhovich, E3S Web of Conferences **458**, 08011 (2023). https://doi.org/10.1051/e3sconf/202345808011
20. S. Khokhlov, Z. Abiev, V. Makkoev, Appl. Sci. **12**, 1515 (2022). https://doi.org/10.3390/app12031515
21. V. Rodionov, I. Skripnik, T. Kaverzneva, S. Zhikharev, et al., E3S Web Conf., **417,** 05013, (2023) DOI: https://doi.org/10.1051/e3sconf/202341705013
22. M.R. Dmitrievich, R.V. Alekseevich and S.V. Borisovich, International Journal of Civil Engineering & Technology (IJCIET) **10(2),** 1154–1161, IJCIET_10_02_112 (2019)