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Comprehensive research method for explosive coal dust

Alexandr Sergienko[1*], *Maxim* Tumanov[2], *Nikolay* Chumakov[3], *Sergey* Zhikharev[4], *Tatyana* Kaverzneva[3], and *Sergey* Kriklivyy[5]

[1] Saint - Petersburg University of the State Fire Service of the Ministry of Emergency Situations of Russia, 196105 Saint Petersburg, Russia
[2] Saint - Petersburg Mining University, 199106 Saint Petersburg, Russia
[3] Higher School of Technosphere Safety of Peter the Great St. Petersburg Polytechnic University, 195251 Saint Petersburg, Russia
[4] Mining Institute of the Ural Branch of the Russian Academy of Science, 614007 Perm, Russia
[5]Saint-Petersburg State Institute of Technology, 190013 St. Petersburg, Russia

Abstract. The article briefly analyses the explosion and fire hazard properties of coal dust of different dispersions. It is emphasised that many experts working in the field of explosion protection and industrial safety pay insufficient attention to changes in the properties of the dust when reducing its dispersity. It is suggested to develop a new, complex methodology based on the dispersed composition of coal dust. The authors suggest to put methods of special sample preparation and dispersing of samples in two stages as a basis of the complex methodology. To do research with the help of thermal synchronous analysis of the smaller fractions, the authors propose to regrind the coal fraction obtained after the cone crusher in an analytical mill. To exclude adhesion of particles due to the process of static charges accumulation it is suggested to use impactless sieving machine of Retsch company which allows to take out the accumulated charges of static electricity. The coal dust fractions obtained after sieving were sent for granulometric analysis by a dynamic image processing method in CAMSIRE and by an optical microscopic method using a LEICA DM 4000 with image scope colour processing. A simultaneous thermal analysis was performed selectively for fractions smaller than 1000 μm. This was carried out with an STA 449 F3 and NETZSCH Proteus termal analysis application software. The authors consider that the obtained results allow to conclude that it is further expedient to carry out research work in this direction and will make it possible to develop recommendations aimed at prevention of coal dust aerosol explosions.

1 Introduction

Considering the explosion and fire hazard characteristics of coal dust it should be noted that most studies have confirmed the importance of studying the dust factor as the main factor of dust explosion hazards [1-6]. It is generally accepted that dust is in two states: aerosol - dust

* Corresponding author: sergienko-alex@yandex.ru

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hovering in the mine atmosphere and aerogel - dust settled / deposited on the soil, walls and roofs of mine workings and on machinery and equipment [5, 7, 8].

Aerogels in the form of deposited dust are generally regarded as a potential aerosol type, since aerogels can be easily converted to a suspended state. Therefore, all studies of the dispersion, mineral, and concentration composition of aerosols are also applicable to aerogels [5,6,9].

All dispersion studies are done for two purposes: to determine the physiological effects of dust on workers' health and to study the physical and technical parameters to determine the boundary zones of flammability and explosion [10-12].

Recently, experts working in the field of explosion and fire safety of coal mines and related industries, have come to the conclusion that it is necessary to carry out a comprehensive study of the dynamics of dust aerosols at a new technological and technical level [6,13,14]. But, again, this solution is seen by these specialists as the implementation of previously unresolved problems, namely the development of devices and dust sensors, determining the dynamics of dust formation, calculation of dangerous concentrations, selection of ventilation mode, monitoring of dust deposition, etc. Therefore, the dynamic characteristics of aerosols are considered in terms of their formation during the operation of mining, especially mining equipment and the transfer of dust particles in the transport process. Therefore, many investigations determine the criteria for aerosol particle circulation, optimise ventilation modes, select necessary systems for controlling the aerological, gas and dust components of the mine atmosphere, develop dust suppression methods, etc., that is, it deals with prevention or, rather, minimisation of factors of dangerous dust concentrations [15, 16, 17]. The control and measurement laboratories in paramilitary mine rescue units (PMRUs) and coal mines are mainly engaged in sampling and research on specific tasks for certain physicochemical properties [14, 18].

Comprehensive laboratory researches using modern applied scientific equipment and instruments to assess the various properties of dust-air mixtures in terms of explosion hazards in almost all mining operations and units PMRU are not carried out [1, 5, 10, 11].

As a consequence, the development of new methods of laboratory research of coal dust aerosols using the methods of engineering expertise is necessary as an addition to the existing methods of determining their fire and explosive properties. This paper considers the part of complex laboratory research of dust-air mixtures conducted by the authors of the article, namely: dispersion analysis, thermogravimetric analysis and optical-microscopic method of investigation of particles [5, 7, 19].

2 Materials and methods

The complex method of coal dust investigation considered in this article consisted in special sample preparation and examination of the obtained dispersed samples. At that, methods of particle size distribution, optical and microscopic and synchronous thermal analysis were used.

In order to achieve the set objectives, samples were taken from pieces of coal with an average weight of 10 kg after grinding using the quarting method for further milling to fractions not exceeding 1 mm in size. The milling was carried out in several stages. In the first stage a vibrating cone mill grinder was used, and in the second stage, to obtain fractions smaller than 500 µm dispersion was carried out in an analytical mill IKA A11 basic.

This kind of sample preparation is explained by the fact that in order to assess the quality of the extracted hard coal before shipment to the consumers, technical analysis is carried out based on the known standard methods. However, according to the methods of analysis of technical properties of coal raw material, not the coal itself is examined, but only the samples selected from the mined or shipped batch of coal, crushed to a dispersion of less than 200 (212) microns [6, 14, 20].

Current regulations recommend determining technical characteristics and explosion and fire hazard properties of hard coal precisely for fractions less than 200 microns. Therefore, many researchers have had the opportunity to study the effect of dispersion composition of coal on its explosion and fire properties of such heterogeneous in dispersion composition of coal dust. As a result, in most works of a number of researchers it is confirmed the increase of explosion- fire hazard with decreasing fractions [21, 22]. However, only with application of modern devices and apparatuses, namely the increasing availability of highly scientific analytical devices (equipment/scientific complexes) which allow to use synchronous thermogravimetric analysis (STA) combining thermogravimetric analysis (TG) and differential thermal analysis (DTA) and/or differential-scanning calorimetry (DSC), the possibility to determine new quantitative and qualitative relations of influence of dispersion composition of coal dust on low or high temperature process has appeared. In this case our experimental results allowed us to propose the assumption that localisation of the dispersion composition of coal dust changes its flammable properties [6, 14, 22].

Figure 1 shows the appearance of the main research equipment designed to solve the set tasks for the comprehensive study of the fractional composition of coal dust.

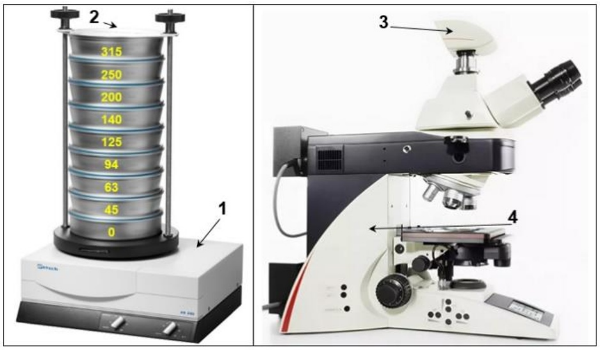

Fig. 1. Exterior view of the main equipment for the study of the dispersed composition of coal dust: 1- Retsch AS 200 analytical sieving machine with a set of standard sieves 0-315 microns and point 2 shows the place of connection of the earthing switch to relieve static voltage; 3 - LEICA DFC video camera mounted on 4 - LEICA DM 4000 microscope.

Taking into account that the researches to determine the explosion and fire hazardous properties aimed to study the behaviour of coal dust of separate fractions with particle size less than 200 (212) microns were not carried out, the thermal decomposition processes of separate fractions of dust samples in inert (argon and nitrogen) and oxidizing (air) media were carried out. Since the work on research of coal dust by methods of thermal synchronous analysis is going on, the results (STA) are not considered in this paper in details. However, we consider it necessary to share some results. STA analyses of hard coal samples were carried out with the STA 449 F3 Jupiter and the NETZSCH application software Proteus Thermal Analysis**.**

Using STA methods were selected some marks of hard coal samples: «LF» (long flame), «SR» (self - rotating), «O» (oily) etc., crushed and sieved into specific fractions taking into account the sieve set. A set of sieves made it possible to obtain coal dust of the following composition in terms of dispersion: 0÷45; 45÷63; 63÷94; 94÷125; 125÷140; 140÷200; 200÷250, 250÷315, 315÷500 и 500÷1000 µm. As a result of the STA study, it was found that fractions with a particle size of less than 94 µm are significantly more reactive, i.e. thermal degradation processes occur at earlier stages. So, for example, fractions with particle size less than 74 µm started to undergo pyrolysis at temperatures of 100 degrees less than fractions

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with particle size more than 500 μm. Obtained results allow to assume that namely coal dust particles up to 100 μm are initiators of many extremely hazardous processes leading to coal dust explosion in the space of mine workings. In future it is planned to study the rate of growth of explosion pressure and the maximum explosion pressure forming in such kind of coal dust combustion of the given dispersion.

The results of STA analysis of coal dust particles of different fractions have shown the need for a more detailed and thorough study of the dispersion composition of coal dust.

The dispersion composition of dust is one of the most important indicators of dust deposition and dust explosion safety. Despite the vast amount of work in this field there is still no unequivocal opinion on the particle size that is most involved in an explosion. This is due to many factors affecting the explosiveness of coal dust: the lower concentration limit, the range of dust particles becoming airborne, volatile matter yield, ash content, moisture, etc.

Particles smaller than 74 μm were previously considered not dangerous from the point of view of explosion as it was believed that their concentration for initiating an explosion was negligible and most of such fractions were carried away by the air stream during ventilation. However, studies of explosive properties have shown otherwise.

By now the subject of influence of dispersion composition of coal on its fire-engineering characteristics is deeply studied, which indicates their increase with decreasing fractions [7, 14, 22].

3 Results

As described above, pieces of hard coal weighing about 10 kg were selected for research. The dispersed hard coal samples were further subjected to dry sieve granulometric analysis. The sieve analyses were carried out with the help of an analytical complex (there is a shock-free sieving mode) sieve shaker series AS 200 from Retsch.

The choice of this type of sieve shaker is not accidental and is based on its ability to shake out electrostatic charges from the sieving process. In this way the relative integrity of the material particles and the absence of adhesion between them is ensured.

With hammerless screening, the cells are virtually unclogged and can be easily cleaned of residues. As there is no effect of "punching" of the particles in the impact sieving method, the fractions are obtained with more stringent shapes in terms of dispersion parameters.

Results of dispersed samples of coal grade mark «O» are summarised in table 1.

Table 1. Results of sieving a hard coal sample.

Fractional dispersion, μm	Fractional yield, %
<45	3.80
45÷63	18.56
63÷94	32.77
94÷125	14.58
125÷140	9.74
140÷200	20.55

Investigations of the fractional composition of passes under 200 microns have shown that the fractional composition is not homogeneous in terms of dispersion. So, for example, the fraction with dispersion of particles 63÷94 accounts for 32.77 %. In addition, which is important in studying of particle size distribution, authors have established that more than 55 % are coal dust particles with dispersion less than 94 microns. The obtained data confirm the necessity to study the explosion and fire hazard properties of narrower dust fractions.

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A LEICA DM 4000 microscope + an Image Scope Colour information processing software was used for the microscopic investigations. With its help, the area of the irregular figure of the visible projection of dust particles was calculated, which allowed the ratio of particles and density of their distribution to be estimated using integral and differential granulometric functions. In Figure 2 below, one of the results of microscopic observation of the coal dust particles is shown as an example. For better display of dust particles, the recommendations of microscope and its application software were used. In addition, the authors took into account the experience of other researchers in solving similar problems [12, 18, 22].

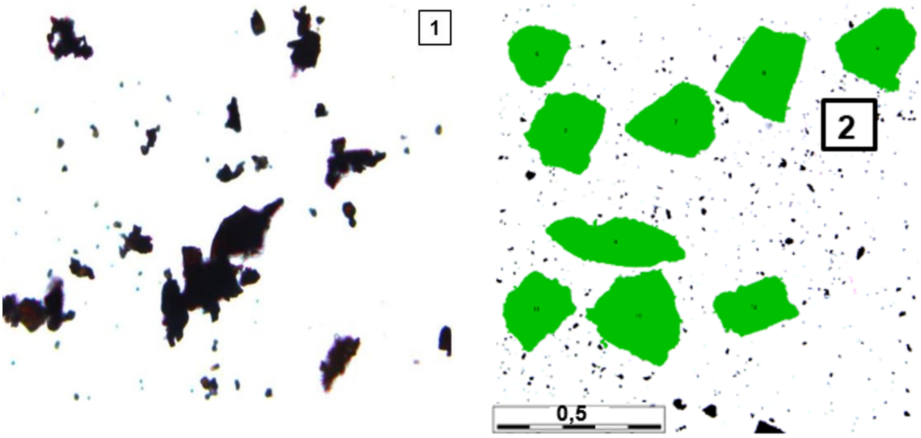

Fig. 2. Shape of coal dust particles: view of the particles that have passed through a 45 μm sieve at 630x magnification; 2. A fragment of the dispersion of coal dust particles after statistical processing in the Image Scope programme.

Figure 3 shows an example of the downstream processing of dust particles to calculate the density of the particle distribution.

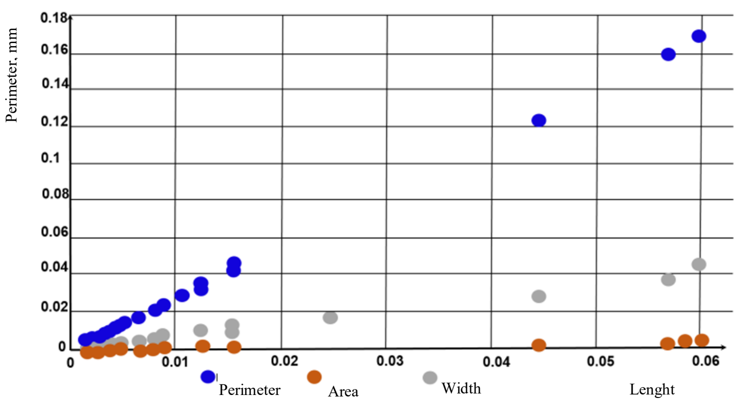

Fig. 3. Graphic fragment of dust particle processing software for calculating the density of particle distribution.

In figure 3 it can be seen that it is possible to estimate the ratio of irregularly shaped particles not only in length and width, but also in area and perimeter.

The results of the statistical determination of particle sizes by Image Scope for samples 1 and 2 are shown in Table 2.

Table 2. Results of coal dust particles treatment.

Coal brand « O»	Sample 1	Sample 2
Measurable attribute	diametric equivalent	
Number of measurements	2805	740
Min. value	0.00131 mm	0.00131 mm
Max. value	0.14 mm	0.32 mm
Average value	0.0103 mm	0.0204 mm
Dispersion	0.000117 sq.mm	0.00249 sq.mm
SD	0.0108	0.0499

The tests showed that in the tested samples the average dust particles were in the range of 10 to 20 μm. This is precisely the fractional composition characteristic of airborne dust, at which, depending on the turbulence of the air flow, explosive concentrations can be formed.

4 Conclusion

The results obtained do not contradict the results of other researchers, but at the same time they are ambiguous [2, 7, 14, 22]. Most likely it is explained by the lack of possibility for some researchers to study exactly the contribution of fines smaller than 74 μm to increase explosive properties of coal dust. In our case for hard coal of different grades, it was found that among dust fractions (dispersibility of particles less than 850 μm) the part of fractions with dispersibility less than 100 μm is about 60%. This fact, together with the results of synchronous thermal analysis, allowed us to propose the assumption that the particles with particle size less than 100 microns are the most dangerous at the initial stage of occurrence and development of emergency situation which results in dust-coal mixture explosion.

We believe that this work should be continued to further investigate the pyrolysis processes of coal dust, the maximum explosion pressure, and its rate of pressure build-up. Then proceed to develop reasoned recommendations aimed at controlling the formation of explosive and flammable coal aerosols.

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