METHODOLOGICAL APPROACH TO ISSUE OF RESEARCHING DUST-EXPLOSION PROTECTION OF MINE WORKINGS OF COAL MINES

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ABSTRACT

This paper, basing on analytical review of the disasters and incidents related to explosions of dust/methane/air mixtures in mine working space, assumes that it is possible to improve the current explosion protection system of coal mines. The activities of the dust control mode, aimed at preventing formation of coal aerosols and their mixtures with methane, have been analyzed. The advantages and disadvantages of the current explosion protection systems have been considered from a critical point of view, and particular attention has been paid to application of inert (shale) dust for the purposes of explosion suppression. The experimental part of the paper contains the results of studying the effects of different concentrations of inert dust on the hazardous explosion factors of dust/methane/air mixtures. Above all, these factors are excessive explosion pressure and pressure rise rate at explosion. These parameters were determined via the methodology developed by the author, in a 20-litre sphere (explosion chamber). As a sample of coal dust, coal of D grade (long-flame) dispersed up to 63-94 micrometer fraction, was used. On the basis of the obtained results, an assumption was made that it is expedient and feasible to reduce the concentration of inert dust via adding to the inert dust composition of the inhibitors of the coal dust detonation combustion processes.

Key words: inert dust, rock dusting, dust-explosion protection, explosion, maximal explosion pressure, coal dust, pressure rise rate at explosion, aerosol, deflagration combustion, detonation.
1. INTRODUCTION

Increase of coal production volumes, induced by application of up-to-date high technology equipment, exacerbates the problem of the industrial safety of mining operations. Increase of cargo flows in the underground conditions, alongside with the increase of the work depth, is accompanied by increased gas emission and dust formation, which significantly reduces the effectiveness of the applied means of providing dust-methane-explosion safety [1, 2].

The analysis of the disasters occurred for the 10 recent years at the coal-mining enterprises of the Russian Federation, demonstrate that more than 25% from the total number of disasters related to ignitions and explosions of coal methane and coal dust. The death toll from these particular disasters was 84% of the mine workers from the total death toll of those killed in disasters for the specified period of time [1, 2, 3].

In addition, increase of the load on the mining face intensifies dust formation, increases air dustiness in mine workings, which causes increase in growth of occupational diseases of upper air passages of mine workers (pneumoconiosis, dust bronchitis), disabilities and premature deaths of workers.

It is possible to increase the safety level of dust-methane-explosion safety of the currently operating coal mines under the condition of implementing an integrated approach of improving safety and risk management, means and methods of explosion protection of mine workings, management of technological processes of underground coal mining.

2. METHODOLOGICAL FRAMEWORK

Activities of dust control mode of a coal-mining enterprise, aimed at preventing formation of explosive dust cloud and emergence of sources of inflammation, encompass:

- a set of activities aimed at elimination (reduction) of sources of dust formation;
- a set of activities aimed at neutralizing the explosive properties of settled coal dust in mine workings (road whitewashing, coal dust inertization, washing workings with water or wetting agent solution, binding coal dust via application of various pastes);
- a set of activities on localizing occurred dust explosions (application of rock-dust and water barriers, automatic systems of explosion suppression and localizing);
- a set of activities ensuring prevention of emergence of coal dust and gas inflammation sources [2, 3].

Analysis of the dust-explosion protection methods currently applied at the operating coal-mining enterprises (using mine named after A.D. Ruban of SUEK-Kuzbass Joint-Stock Company) demonstrated that, depending on specific geological and mining conditions, the methods which are most frequently applied are inertization of coal dust explosive properties via mine workings rock dusting and hydrodust explosive protection.

Thus, it can be concluded that the following activities are implemented most frequently:

- rock-dusting of mine workings, road whitening or mine washing;
- installing water and rock-dust explosion localizing barriers.
Methodological Approach to Issue of Researching Dust-Explosion Protection of Mine Workings of Coal Mines

The expediency of the application of each of the above mentioned activities is determined for a particular mine working, depending on its lifetime, dimensions, water cut, presence of transport communications and so on. [1, 3, 10].

For the purposes of optimizing the results of analyzing the effectiveness of dust protection activities of coal mines, the analysis was conducted with application of efficiency ratio \( S \geq 1 \).

Dust protection efficiency ratio:

\[
S = \frac{X_w}{X_s}, \text{where}
\]

\( X_w \) - weight efficiency of action of water, manifested by the amount of weight units of pure coal dust, protected against with one weight unit of water,

\( X_s \) - the same weight efficiency of action of solid nonflammable particles.

Thus, the distribution of the efficiency ratio of the activities is as follows: rock-dusting – 1, binding with solutions/pastes -1.8 - 3.6, fog-forming screens - \( \infty \), whitening – 1.

Currently, dust-explosion activities are the easiest and the most efficient, compared to others.

3. DISCUSSION

However, the practical experience of the application of each of the activities revealed a number of drawbacks:

- when binding pastes were applied to mine workings’ edges, the mine workings were covered with new layers of settled dust fairly rapidly. In this respect, one more drawback is incomplete compliance of the applied pastes with the sanitary and hygienic requirements, their high cost, low biodegradability, and insufficient awareness of the effects on human health;

- application of foggers is efficient if they are installed directly at the dust formation source (at the areas of pouring out from one conveyor on another, on the lower and upper longwall conjunctions), and when mines fully utilize conveyors in the operations, transported rock mass is the main source of dust formation (on average, the length of development workings exceeds 2,500 meters). The required excessive number of foggers affects the climate conditions in mine workings;

- dust suppression activities based solely on watering principles, are unable to manage the current intensity of dust formation, and excessive application of water negatively affects the sanitary and hygienic conditions in underground mine workings;

- inert dust has been used for diluting coal dust fairly long. Shale dust efficiently absorbs heat, thus preventing development of coal dust explosion. The effects of shale dust on human health are well known. Shale inert dust is of low cost and easily available. Hereinafter, inert dust and shale inert dust imply hydrophobic inert dust [2, 3, 4].

In order to demonstrate the need to look for new methods or to improve the existing methods of diluting explosive coal dust aerosols formed in coal mines, a number of experiments were conducted. The research component of the experiments focused on studying pressure change of coal aerosols in relation to concentration of shale coal dust in them. In addition, it was required to determine if it is possible to reduce the amount of used inert dust.
4. EXPERIMENT

Scientific and technological research of the coal aerosol detonation combustion processes was conducted at the plant made under Austrian license by China’s Institute of Industrial Explosion Protection. The plant was installed at St. Petersburg Mining University.

At the plant, an experiment was conducted on studying the processes of detonation inflammation of assigned concentration of coal and shale dust, for determining the most effective ratios.

Inflammation of the control sample of coal dust and the studied samples (coal dust + shale inert dust) was executed by means of chemical igniters having power of 10 kJ [5, 6, 7].

Test system of sphere explosion ETD-20L DG (figure 1) and the developed methodology of working with it enable to determine:

- $P_{ex}$ – maximal excessive explosion pressure emerging at deflagration combustion of gas-, steam- or dust-air mixture in a closed vessel, with initial mixture pressure 101.3 kPa;
- $P_{max}$ – the highest value of explosion pressure (maximal explosion pressure), determined experimentally within the explosion range of dust concentration, MPa. Maximal explosion pressure ($P_{max}$) is calculated via program methods by automatic recalculation from $P_{ex}$.
- $\frac{dP}{dt}$ – ratio of pressure rise which occurs at explosion in a closed vessel, to the time interval within which this rise occurred (velocity of pressure rise at explosion), MPa/s;
- $K_{st}$ – transformation coefficient (Bartnekh constant), which enables to classify dust by the parameters of aerosol explosiveness and calculate explosion characteristics for bigger volumes, MPa·m/s [8, 9, 10].

![Figure 1](image_url)  
*Figure 1.* Exterior of ETD-20 L DG plant (St. Petersburg Mining University) [10] and drawing of the main unit. On the left – the unit exterior. On the right – main unit: 1 – water outlet, 2 – pressure sensor, 3 - manometer, 4 – dust collector of 0.6 dm$^3$ in volume, 5 – air intake, source of inflammation, 7 – ricochet nozzle, 8 – quick-action valve, 9 – water intake, 10 – outlet of air and reaction products [9].

During the experiment, a number of tests were conducted, with different ratios of coal and inert dust (table 1).

Control sample of coal dust was coal of D grade (long-flame).
A number of intermediate steps were performed for obtaining the experimental material. In order to avoid morphological and physical-chemical alternations in the tested sample, all the experiment work was conducted as quickly as possible.

For obtaining a sample of required dispersion, granulometric sieving was performed. At the sample preparation stage, a hermetically sealed coal specimen hacked off the front of the mine face, was transported to the laboratory. It was crushed at the crusher, and granulometric sieving was performed. For further work, the fraction with required dispersion was chosen, all further tests were performed on it. The operations of sample preparation and criteria of working fraction selection are described in more detail in the following studies [10, 11, 12].

In our case, the coal sample dispersion was 63-94 micrometers. Throughout this interval, maximal characteristics of the process of coal dust combustion process are observed, which is confirmed in a number of studies [10, 12-16].

As inert additives, inert dust was used (of combined composition, including shale+dolomite+limestone) approved by Central Coal Chemistry Laboratory of town of Kiselevsk for using in the mine geological conditions, of hydrophobic inert dust, in line with GOST R 51569 standard.

This dust has high extent of hydrophobization, and it is designated for use in watered mine workings and areas of intense dust formation, it is recommended for application in coal mining coal processing industry for preventing and suppressing coal dust explosions.

Table 1

<table>
<thead>
<tr>
<th>Sequence No.</th>
<th>Weight of coal dust, g</th>
<th>Weight of inert dust, g</th>
<th>Maximal pressure, MPa</th>
<th>Pressure rise rate at explosion, MPa/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.458</td>
<td>17.80</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0.395</td>
<td>12.41</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>6</td>
<td>0.253</td>
<td>10.38</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>8</td>
<td>0.145</td>
<td>7.09</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>-</td>
<td>0.745</td>
<td>43.86</td>
</tr>
</tbody>
</table>

5. RESULTS

Visualization of the experimental data obtained by the authors of the paper, was performed in OriginPro software, as available software ExTest does not provide graphic data of relevant resolution and perform further mathematic processing of the data. Processing of the results is feasible in commonly used Microsoft Office package, with using Excel [12].

The graphic results, namely the dependency of the rate of explosion pressure change on the inert dust concentration in the control sample, and the explosion pressure of the control sample, are presented in figure 2.
Figure 2. Graph of pressure with constant concentration of coal dust (5) and changing concentration of shale dust (1-4).

During pure coal dust inflammation, the pressure inside the explosion chamber had the maximum value (0.745 MPa).

Diluting the control sample ($P_{ex}=0.745$ MPa) with inert dust up to 1:1 proportion, does not reduce the parameters of dust detonation combustion to $P_{ex}=0.458$ MPa.

Only when the control sample is diluted with inert dust up to 1:4 ratio (2 g:8 g), hazardous explosion factors reduce down to $P_{ex}=0.14$ MPa.

Pressure rise rate at explosion reduced compared to the control sample from 43.86 MPa/s down to 7.09 MPa/s, which demonstrate the expediency of shale dust application in certain concentrations for explosion suppression of the processes of detonation combustion wave propagation throughout mine workings. The results which we obtained, are in line with the results of the following studies [4, 10, 11, 12].

6. CONCLUSIONS

In summary, basing on the experiment, we can conclude that from among the currently applied activities on ensuring dust-explosion protection, prevents most efficiently dust inflammation and explosion.

At the same time, in our opinion, further work in this area is required, such as studying the issue of diluting inert dust with inhibitory additives enabling both to increase the efficiency of shale dust application and to decrease the shale dust amount. Such a decrease, in turn, will enable to compensate the costs on adding inhibitors to the composition of inert dust.

In our opinion, improving the methods of mine workings rock dusting will enable to increase the efficiency of this activity and provide higher extent of dust-explosion protection of coal mines and, as a result, will prevent or reduce the risk of accidents with fatalities caused by explosion of coal dust aerosols in mine workings’ space.
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