UDC 622.2

R. A. APAKASHEV [1]*, Professor, Doctor of Chemical Sciences*
N. G. VALIEV [1]*, Professor, Head of Mining Department, Doctor of Engineering Sciences, niyaz.valiev@m.ursmu.ru*
M. L. KHAZIN [1]*, Professor, Doctor of Engineering Sciences*

[1]*Ural State Mining University, Yekaterinburg, Russia*

INFLUENCE OF ALKALINE TREATMENT ON PHYSICOCHEMICAL PROPERTIES OF SULPHIDE DUST

The study of the alkaline medium effect on the physicochemical parameters of copper–pyrite ore dust (granulometric, chemical and phase compositions) is aimed at assessment of opportunities for the efficiency enhancement in dust suppression during drilling and blasting by means of spraying mine roadways with alkaline solutions. The grain size analysis of the test dust samples shows that alkaline treatment has no noticeable influence on the degree of dust dispersion. The alkaline medium effect on the chemical composition of the test dust shows up as the increase in the contents of silicon, iron and oxygen present in the dust in the greatest amounts. The change in the chemical composition of the dust treated with the alkaline solution correlates with the change in the phase composition of the dust. The mass fraction of quartz decreases, which leads to the re-distribution of the mass fractions of other components, including the increased content of pyrite. Thus, spraying of mine roadways can increase the concentration of pyrite in the accumulated dust, which implies an increase in the dust explosion risk. In this regard, alkaline solutions are not a special preventive means capable to ensure enhanced efficiency of explosible dust suppression as compared with water spraying.

Keywords: *copper–pyrite ore, sulphide dust, explosibility, dust suppression, mine roadway spraying, grain size composition, chemical composition, phase composition, alkaline solution*
DOI: *10.17580/em.2025.01.21*

Introduction

The most dangerous accidents in blasting operations are unauthorized explosions of explosives and explosive materials. In underground mines, special dangers are brought by explosions of sulphide dust, mostly during blasting operations. Secondary explosion of sulphide dust amplifies harmful effects of the primary explosion, and increase, their action radius.

Accidents connected with sulphide ore dust explosions are hazardous to life, and lead to damage of electric and mechanical equipment, and to great material losses [1, 2]. Aside from that, sulphide ore dust has harmful effect on health [3, 4]. Therefore, it is important to investigate characteristics of sulphide ore dust and undertake measures to suppress dust formation [5, 6] and, accordingly, to reduce risk connected with explosions of sulphide dust.

Mining safety in face areas hazardous in terms of explosion of sulphide dust is ensured via implementation of special measures which are to be selected using a solid scientific approach on the basis of relevant research [7–9].

An effective method of sulphide dust explosion control during blasting is spraying and wetting of face surface with water before commencement of work. Also, before charging of boreholes, their open space is injected with air and water mixtures. In order to enhance efficiency of spraying, it is possible to use aqueous solutions of surface-active substances or other special chemical agents [10].

For many technological operations during mining, it is impossible to avoid dust formation. The risk and consequences of sulphide dust explosions necessitate development of purposeful preventive measures. To this effect, it is beneficial to involve the practical experience gained in abating coal dust explosions [11, 12]. For instance, coal dust suppression uses alkaline solutions for spraying. Effect of alkaline in this case is conditioned by the increase in coal wettability owing to the considerable increase in roughness and porosity of coal surface being in contact with alkaline solutions [13]. The wetting efficiency also depends on a coal rank.

Spraying with alkaline solutions can be also aimed at reducing high concentrations of sulfur dioxide in mine air. Sulfur dioxide is extremely toxic and explosive. A great quantity of sulfur dioxide is generated in burning of sulphide dust. In this case, quick reduction of sulfur dioxide concentration is possible with spraying of mine air with alkaline solution [14].

An important area of dust suppression research is optimization of a dust wetter composition. Different surfactants, and their foaming and wetting properties were studied with a view to settling coal dust [15, 16]. The multi-criterial analysis of scientific literature on water-based dust suppression solutions and their efficiency evaluation procedures at different-type dusting sources was performed [10]. However, the scientific literature lacks studies on influence exerted by alkaline medium on physical and chemical properties of sulphide dust at copper–pyrite deposits. In the meanwhile, such studies are necessary to assess efficiency of dust suppression in drilling and blasting by spraying of mine roadways with alkaline solution.

The goal of this research is to analyze the influence of alkaline medium on physicochemical parameters of copper–pyrite ore dust (grain size composition, chemistry, phase composition) with a view to assessing potentiality of enhancement of dust suppression efficiency during blasting by means of spraying of mine roadways with alkaline solutions.

Experimentation

Aimed at efficiency enhancement in wet suppression of sulphide dust, the research was performed to assess applicability of alkaline solutions for spraying mine roadways during drilling and blasting.

The test subjects were the explosive samples of dust from crushing units arranged at the depths of 1095 and 1230 m in an underground mine at the Gai copper–pyrite ore deposit (hereinafter, these are dusts D1 and D2, respectively). The choice of the test subjects was governed by the analysis of the statistics on sulphide dust explosions in pyrite mines, and by the determined increasing trend of sulfur content of ore with the growing depth of the ore occurrence [17, 18].

Alongside with the mentioned influence of the occurrence depth on the sulfur content of ore and, accordingly, on the explosion risk, it is required to take into account another fact of no less importance. As per the research [17], sulfur content is higher in fine fractions (–40, –71+40, –100+71 μm) formed during primary disintegration of ore under manmade impact applied to rock mass. Explosion of sulphide dust is participated by particles smaller than 0.3 mm, and the higher explosion risk is a feature of particles less than 0.1 mm in size [17].

Based on the aforesaid, the test dust samples were subjected to the grain size analysis. The grain size composition was determined using dry screening and sedimentation with torsion balance [19]. For the grain size analysis by screening, 100.00 g of a dry material was weighed. The test screens had the mesh sizes of 0.160, 0.100, 0.071 and 0.063 mm. After screening, material from each screen was collected and weighed accurate within ± 0.01 g.

The chemical composition and distribution of elements were investigated using the X-ray spectroscopic analysis on a relevant supplement to Tescan Vega scanning electron microscope.

The phase composition of the dust samples was identified using Shimadzu XRD 7000 X-ray diffraction analyzer. Interpretation of X-ray patterns used the databases ICDD (International Centre for Diffraction Date 2012) and ASTM (American Society for Testing and Materials). The employed scientific equipment belongs to the Research Laboratory Center of the Ural State Mining University.

Results and discussion

The data of the grain size analysis (screening) of the test dusts from crushing units are given in **Table 1**.

Table 1. Grain size compositions of dusts D1 and D2

Fraction, µm	>160	160–100	100–71	71–63	< 63
Mass fraction, %*	6.08/9.78	0.24/0.37	0.54/0.30	0.31/0.21	92.83/89.34
*Numerator—value for D1, denominator—value for D2.					

The fraction composition studies used additionally the grain size analysis in water medium with torsion balance. This method offers information on amount of fractions by weight for particles smaller than 100 µm. The resultant differential curves obtained for the amount of fractions by weight are presented in **Fig. 1** and **Fig. 2**.

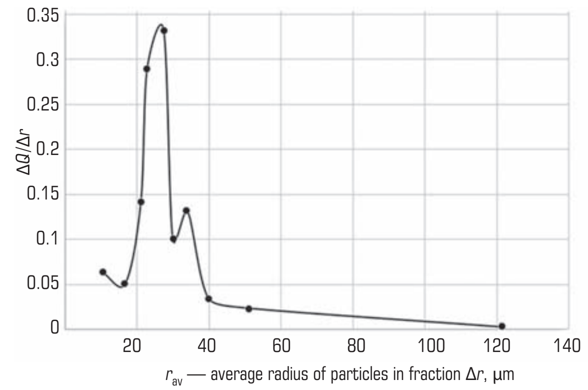

Fig. 1. Differential distribution curve for amount by weight for fractions of dust D1

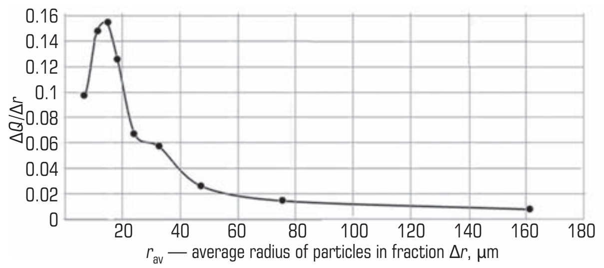

Fig. 2. Differential distribution curve for amount by weight for fractions of dust D2

The differential distribution curve shows the change in the amount ΔQ of particles by weight when their radius Δr changes. The area bounded by the differential curve and the abscissa axis gives the total amount by weight for particles of all sizes (100%), and the area bounded by two values of the radii r_n and r_m gives the percentage of particles in the range of the radii r_n and r_m in suspension.

It follows from Figs. 1 and 2 that in dusts D1 and D2, the particles smaller than 0.1 mm in size are dominated by the particle size of 20–40 and 7–40 µm, respectively. The areas bounded by the radii 20–40 µm in Fig. 1 and by the radii 7–40 µm in Fig. 2 are very similar in value. This implies that dust D2 is finer (highly dispersive) and, consequently, more explosion risky.

The influence of alkaline medium on grain size composition was studied using dust D2. An alkaline solution (pH = 9) was prepared by means of dissolving of sodium hydroxide at a concentrate adopted in coal dust suppression. The prepared solution was mixed with the test dust at a ratio of 3:1. In 48 h after dust settling, the solution was elutriated, and the settlings were held at 40 °C until drying, with the subsequent sedimentation analysis using dry screening. The results are compiled in **Table 2** together with the check test data (without alkaline pretreatment of dust).

Table 2. Influence of alkaline medium on grain size composition of dust D2

Fraction, µm	>160	160–100	100–71	71–63	< 63
Mass fraction, %*	9.78/9.98	0.37/0.35	0.30/0.32	0.21/0.18	89.34/89.17
**Numerator — dust without pretreatment with alkaline solution; denominator — dust after pretreatment with alkaline solution.*					

According to the grain size analysis of the test dust in Table 2, treatment with alkaline solution has no noticeable influence on the dust dispersion. It should be taken into account that the grain size analysis using dry screening involves intense shaking of screens. Such mechanical impact induces deaggregation of particles which aggregated via agglutination during alkaline treatment. For the detailed analysis of such situation, the dust samples treated only with water and only with alkaline solution were additionally examined using an electron microscope prior to screening.

Figure 3 offers an electron image of dry dust D2 after alkaline treatment. The visible large aggregates of particles suggest their formation via coupling.

A similar situation, without particle aggregates, takes place in case of dry dust wetted with water before drying. Nonetheless, wetting of ore dust particles in a liquid medium, and a certain aggregation of particles is observed at both pH = 7 (neutral medium) and pH = 9 (alkaline medium). By way of example, **Fig. 4** shows an amplified image of dust particles in a drop of water, obtained from Altami digital optical microscope. It is seen that the particles are wetted well, and the smallest particles get aggregated with the large particles.

The aggregates are weak and fail as liquid flow changes its direction. The chemical consolidation of the dust particles is absent irrespective of the value of the medium pH.

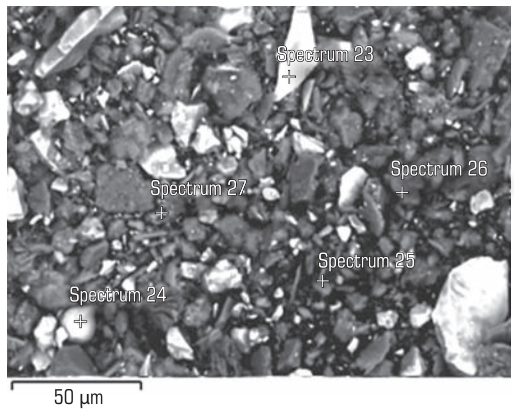

Fig. 3. Dust D2 pre-held in alkaline solution

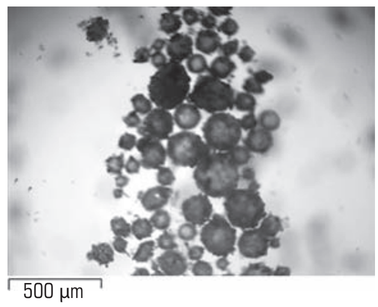

Fig. 4. Dust D2 in drop of water

Table 3. Mineral composition of dust D2 after pre-wetting in water and in alkaline solution

Mineral composition, mass %	Dust pre-wetted in water, %	Dust pre-wetted in alkaline solution, %
Quartz SiO_2	12.0	10.6
Pyrite FeS_2	67.2	72.5
Chalcopyrite $CuFeS_2$	3.7	3.4
Muskovite $K_2(Al,Fe)(Si_6,Al_2,O_{20})(OH)_4$	3.3	3.2
Gypsum $CaSO_4 \cdot 2\ H_2O$	4.9	1.9
Clinochlore $(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$	8.6	8.1
Sphalerite ZnS	0.3	0.3

It is important that in case of fat coal, poorly wettable with water, addition of alkali to water has an insignificant influence on dust suppression efficiency. In a general case, effect of alkali is conditioned by increased wettability of coal because of increased porosity and roughness of coal surface during its chemical interaction with alkaline solution [13]. In our study, the copper–pyrite ore dust gets wetted with water. On the other hand, the electron microscopic analysis shows that the dust particles are mostly smooth and have no roughness, both initially and after treatment with alkaline solution (see Fig. 3). The aforesaid means that dust suppression using alkaline solution has selective efficiency and in special cases.

The present research included the study of the effect exerted by alkaline medium (pH = 9) on the chemical and phase compositions of dust. Washing of the test dust in water and in alkaline solution lased for 48 h, and further drying under a weak heat took 8 h.

The implemented research proves that the alkaline effect on the dust chemistry is mainly the change of the amount of oxygen, iron and silicon. There is a little amount of these elements in dust, and contact with alkaline solution leads to a decrease in the content of silicon.

Silicon occurs in dust mostly in the composition of quartz. Customary, quartz resists alkaline impact. Under ambient temperature, quartz gets dissolved very slowly in alkali. The rate of dissolving of silicon dioxide in alkaline medium can be increased by raising temperature and enlarging specific surface [20]. Specific surface of a dispersed substance grows as the size of particles decreases. On the other hand, the rate of the heterogeneous reaction is directly proportional to the area of the contact surface between reagents. For this reason, the most probable cause of decrease in silicon content of dust is high dispersion of quartz particles, which promotes its dissolving when in contact with alkali.

The similar results, as in case of the chemical composition of dust, were also obtained in the study of alkaline influence on the phase composition (**Table 3**).

After alkaline treatment, the amounts of minerals in the dust change (see Table 3). For instance, the mass fraction of quartz decreases, which may be connected with dissolving of fine and dispersed particles of the mineral in alkali. In addition, the content of gypsum drops by two and a half times, which agrees with the known data on solubility of this mineral [21]. The most probable cause of the gypsum presence in the copper–pyrite ore dust is the process losses of cement that contains gypsum.

The decrease in the amounts of quartz and gypsum after treatment with alkaline solution influences the content of pyrite FeS_2 as its mass fraction in ore dust grows by more than 7%. The increase in the content of the sulphide component increases explosibility of dust.

Conclusions

The research findings are generalized below.

Treatment of sulphide dust with alkaline solution has influence neither on grain size composition of the dust nor on wetting of fine and dispersed particles. Alkaline treatment of copper–pyrite ore dust decreases significantly quartz content of the dust and leads to the re-distribution of the mass fractions of the dust components. The content of the explosive pyrite fraction grows in this case. For this reason, spraying of mine roadways with alkaline solutions may lead to the increased concentration of pyrite in dust, which elevates the risk of dust explosion. So, alkaline solution is not a special preventive agent capable to enhance efficiency of sulphide dust suppression as compared with water spraying. Considering this fact, transition to spraying of copper–pyrite mine roadways with alkaline solutions has no evident benefits in terms of improvement of underground mining safety.

References

1. Teterev N. A., Ermolayev A. I., Kuznetsov A. M. Effect of physicochemical properties on explosibility of sulphide dust. *MIAB*. 2018. No. 12. Special Issue 63. pp. 3–11.
2. Pinaev A. V., Pinaev P. A. On the explosiveness of suspensions of sulfide ore dust in air in shock waves. *Journal of Physics Conference Series*. 2019. Vol. 1382. ID 012095.
3. Rao Y., Tian Ch., Wei Xu et al. Explosion pressure and minimum explosible concentration properties of metal sulfide ore dust clouds. *Journal of Chemistry*. 2020. ID 7980403.
4. Khudhur D. A., Abdullah T. A. T., Ali M. W. Mechanisms, severity and ignitability factors, explosibility testing method, explosion severity characteristics, and damage control for dust explosion: A concise review. *Journal of Physics: Conference Series*. 2021. Vol. 1892. ID 012023.
5. Li Z., Hu P., Xu Y. Study on sulfide ore dust dispersion and dust reduction measures based on simulation. *Minerals*. 2024. Vol. 14, Iss. 5. ID 523.
6. Mitishova N. A. Development of technological recommendations for ensuring fire and explosion safety during underground development of pyrite ore deposits *Izvestija Tulskogo Gosudarstvennogo Universiteta. Nauki o Zemle*. 2021. No. 4. pp. 165–177.
7. Rylnikova M. V., Mitishova N. A. Research technique for explosion hazard of low-grade sulphide ore in underground mines. *MIAB*. 2019. No. 9. pp. 41–51.
8. Fan J. Q., Bai J. P., Zhao Y. S. et al. Experimental study of factors influencing explosion characteristics of sulfur dust. *China Safety Science Journal*. 2018. Vol. 28, No. 2. pp. 81–86.
9. Ufatova Z. G. The current state of the problem of predicting spontaneous combustion and explosiveness of sulfide ores and host rocks at a depth of more than 1500 m. *Mining Industry Journal*. 2021. No. 2. pp. 77–80.
10. Strokova V. V., Ishmukhametov A. M., Esina A. Yu. et al. Water-based dust suppressing compositions: Analysis of the state and prospects of development. *Vestnik technologicheskogo universiteta*. 2021. Vol. 24, No. 12. pp. 5–38.
11. Bałaga D., Siegmund M., Kalita M. et al. Selection of operational parameters for a smart spraying system to control airborne PM10 and PM2.5 dusts in underground coal mines. *Process Safety and Environmental Protection*. 2021. Vol. 148. pp. 482–494.
12. Zhang X., Han Z., Wang C., Yu Y., Wu B. Combustion-explosion suppression and environmental protection of typical sulfur-containing hazardous chemicals. *RSC Advances*. 2024. Vol. 14, Iss. 40. pp. 29072–29082.
13. Guo H., Gao Zh. X., Fu Ch. Y. et al. Experimental study on the feasibility of reducing coal dust by alkaline solution. *Bulgarian Chemical Communications*. 2018. Vol. 50, No. 1. pp. 171–175.
14. Drizhd N. A., Kamarov R. K., Isabek T. K., Portnov V. S. Physicochemical effects exerted on sulfur-bearing gases in underground mining. Karaganda : Izdatelstvo Karagandinskogo gosudarstvennogo technicheskogo universiteta, 2013. 262 p.
15. Wang M., Li R., Li Y. et al. Clinical statistics analysis on the characteristics of pneumoconiosis of Chinese miner population. *Journel of thoracic Disease*. 2016. Vol. 8, No. 8. pp. 2203–2211.
16. Wang W., Wang Y., Shi G. Optical estimation on pollution level of respirable dust based on infrared transmitting behavior in coalmine fully mechanized working face. *Journal of Spectroscopy*. 2016. Vol. 2016, No. 11. ID 2626414.
17. Mitishova N. A., Fedotenko V. S., Gorbatova E. A., Aybinder A. G. Geological and structural analysis of pyrrhic ores and rocks in assessing the explosive hazard of sulfide dust. *Izvestiya TulGU*. 2020. No. 4. pp. 350–363.
18. Ketrov A. A., Yudovskaya M. A., Shelukhina Yu. S., Velivetskaya T. A., Palamarchuk R. S. Sources and evolution of isotopic composition of sulfur in sulphides in the Kharaelakh and Pyasino-Vologochan intrusive rocks, Norilsk ore province. *Geologiya rudnih mestorozhdenij*. 2022. Vol. 64, No. 6. pp. 57–686.
19. Kouzov P. A. Analysis of Dispersion Composition of Industrial Dusts and Ground Materials: Essentials. Leningrad : Khimiya, 1974. 279 p.
20. Zanaveskin K. L., Maslennikov A. N., Zanaveskina S. M. et al. Leaching SiO_2 and Al_2O_3 impurities from leucoxene (Yaregskoe deposit) by sodium hydroxide solution. *Chemical Technology*. 2018. Vol. 19, No. 4. pp. 161–172.
21. Lebedev A. L., Kosorukov V. L. Gypsum solubility in water at 25°C. *Geochemistry International*. 2017. Vol. 55, No. 2. pp. 205–210.