SAFETY IN MINING AND PROCESSING INDUSTRY AND ENVIRONMENTAL PROTECTION

Research paper

https://doi.org/10.17073/2500-0632-2023-02-79
УДК 622:331.45

Chemical additive based on sodium oleate and linseed oil for preparation coal dust suppression composition

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Abstract
The mining, transportation, and processing of coal involve the formation and emission of significant amounts of particulate matter, which includes coal dust. The most commonly employed method for controlling coal dust in an air is water spray dust suppression (hydrodedusting). This method is founded on water's capacity to moisten dust particles and bond them to both each other and the surfaces where the dust settles. One notable limitation of this method is the coal's hydrophobic nature, which hinders water from wetting coal dust particles. In order to overcome this, surfactants are introduced into the water to increase the wettability of the hydrophobic coal particle surface. In this paper, we proposed a dust suppressant composition consisting of oleic acid, sodium hydroxide, and linseed oil in water. We examine its properties and evaluated its ability to enhance the wettability of coal dust. We have identified the most effective concentration, resulting in a working solution that improves the wettability of coal dust by 87 % compared to water, surpassing the wettability of most known reagents. The proposed composition contains 140 mg/L oleic acid, 100 mg/L sodium hydroxide, and 70 mg/L linseed oil in water. The simplicity of this composition, its minimal impact on the environment and human health, and its negligible influence on the further use of coal raw materials make this wetting agent composition highly promising for application in coal industry technologies of water spray dust suppression.

Keywords
coal dust, dust suppression, hydrodedusting, wettability, surfactants, sodium oleate, linseed oil

Acknowledgments
The research was carried out at the expense of a grant of the Ministry of Education and Science of the Republic of Khakassia (Agreement No. 93 of 13.12.2022).

For citation
Golubkov V.A., Gorenkova G.A., Vorozhtsov E.P., Bespalova M.A., Bortnikov S.V. Chemical additive based on sodium oleate and linseed oil for preparation coal dust suppression composition. *Mining Science and Technology* (*Russia*). 2023;8(4):341–349. https://doi.org/10.17073/2500-0632-2023-02-79

ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Добавка на основе олеата натрия и льняного масла для углепылеподавляющих растворов

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Аннотация
Добыча угля, его транспортировка и переработка сопровождаются образованием и поступлением в воздушную среду значительных объемов твердых частиц, в том числе угольной пыли. Наиболее распространенной технологией борьбы с угольной пылью в воздухе является гидрообеспыливание. Эта технология основана на способности воды смачивать пылевые частицы и связывать их между собой и с поверхностями, на которые осаждается пыль. Существенное ограничение данной технологии заключается в гидрофобности поверхности угля, которая препятствует смачиванию водой частиц угольной

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пыли. Для увеличения смачиваемости гидрофобной поверхности угольных частиц в воду добавляют поверхностно-активные вещества. В настоящей работе нами предложен состав для пылеподавления на основе олеиновой кислоты, гидроксида натрия и льняного масла в воде, изучены его свойства и оценена способность улучшать смачиваемость угольной пыли. Найдена наиболее эффективная концентрация, которая позволяет рабочему раствору улучшить смачиваемость угольной пыли на 187 % относительно воды, что превышает смачивающую способность большинства известных реагентов. Предлагаемый состав содержит 140 мг/л олеиновой кислоты, 100 мг/л гидроксида натрия, 70 мг/л льняного масла в воде. Простота состава, отсутствие вредности для окружающей среды и человека, незначительное влияние на дальнейшую эксплуатацию угольного сырья делают предлагаемый состав смачивателя перспективным для применения в технологиях гидрообеспыливания в угольной промышленности.

Ключевые слова

угольная пыль, пылеподавление, гидрообеспыливание, смачиваемость, поверхностно-активные вещества, олеат натрия, льняное масло

Благодарности

Исследование выполнено за счет гранта Министерства образования и науки Республики Хакасия (Соглашение № 93 от 13.12.2022).

Для цитирования

Golubkov V.A., Gorenkova G.A., Vorozhtsov E.P., Bespalova M.A., Bortnikov S.V. Chemical additive based on sodium oleate and linseed oil for preparation coal dust suppression composition. *Mining Science and Technology* (*Russia*). 2023;8(4):341–349. https://doi.org/10.17073/2500-0632-2023-02-79

Introduction

The development of coal deposits, coal transportation, and processing results in the release of significant amounts of particulate matter, including coal dust into the air.

Prolonged exposure to coal dust can lead to preventable but incurable lung diseases, such as pneumoconiosis, chronic obstructive pulmonary disease, tuberculosis, chronic bronchitis, emphysema, and more, some of which can be fatal [1–4]. Workers and engineers in coal mines, open pits, coal transfer stations, coal preparation shops, and those involved in coal transportation are most susceptible to these diseases. Additionally, high concentrations of coal dust mixed with oxygen in the air pose a fire and explosion hazard [5]. These pressing issues highlight the necessity for effective technologies for removing coal dust from the air while minimizing of aerological risks [6].

In order to prevent dust formation during the crushing, processing, and transportation of dusty materials and suppress generated dust at mining and processing facilities, measures such as dampening rock masses and capturing flying dust are implemented. These methods, which focus on reducing the dust load by wetting of particles with water, are collectively referred to as water spray dust suppression or hydrodedusting [7]. Hydrodedusting relies on water's ability to wet dust particles, bind them together, and settle them. A significant challenge of this method is the hydrophobicity of coal surfaces, which prevents water from wetting coal dust particles. To overcome this, it is necessary to modify the particle surfaces to make it hydrophilic.

Extensive research has been conducted in the development of coal dust control technologies. One of the most effective approaches is dust suppression through spraying water with the addition of surfactants [8]. This technology's development began in the early 20th century and gained particular importance after the 1970s due to the mechanization and intensification of coal mining [9, 10].

Surfactants, due to their diphilic nature, efficiently adsorb to the water-coal interface, rendering the surface of coal particles hydrophilic. This adsorption process reduces the free surface energy of coal dust and expedites the wetting process [11, 12].

Common wetting agents for coal dust suppression generally contain various surfactants as the main component to improve dust particles wetting. For example, in [13], authors propose using a combination of the sodium salt of alkylbenzosulfonic acid and oxyethylated alkylphenol (neonol), and in [14], the sodium salt of carboxymethylcellulose. Apart from surfactants, these wetting agents contain other components, comprising 0.2–2.0 wt.% of the total composition, such as urea, inorganic salts, alcohols and polyols. While many dust suppression formulations are known, the search for new, more effective, and environmentally friendly alternatives remains an urgent task.

The objective of this study was to improve the coal dust suppression process through hydrodedusting by developing a novel formulation of wetting agent. The criteria for selecting reagents in this work included:

– the reagent's performance in dust suppression, supported by at least indirect methods;

– the simplicity and cost-effectiveness of the proposed technology;

– the environmental friendliness of the reagent.

eISSN 2500-0632
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In this context, it was deemed appropriate to explore the use of a naturally derived substance with surface activity, namely, the sodium salt of oleic acid.

Oleic acid is an anionic surfactant that reduces the adhesion of non-polar substances in a “solid non-polar surface: polar liquid” surface system. Additionally, sodium oleate significantly reduces the explosion potential of coal dust [15].

Sodium hydroxide is a reagent that, when combined with oleic acid, forms water-soluble sodium oleate.

Linseed oil is a reagent capable of inducing particle adhesion through the affinity of the oil and coal particle polarity. Furthermore, fatty unsaturated acids with long alkyl chains can polymerize to create a monolayer on a surface [16].

We have proposed a composition [17] for use in hydrodedusting processes and have determined the optimum concentrations to enhance dust suppression efficiency through the application of various physicochemical methods.

Research Materials and Techniques

Reagent preparation

The reagents were prepared as follows: a combination of 30 mL of water and 6 g (~150 mmol) of sodium hydroxide were merged with 8 g (~28 mmol) of oleic acid. The resulting mixture was heated to 89–95°C. Subsequent to cooling, water was added to achieve a final volume of 1 L. To the resulting solution. We then added weighed portions of linseed oil while stirring to attain concentrations of 1, 4, 8, and 20 g/L.

The wettability study of coal dust was carried out using samples collected from the Chernogorsky deposit within the Minusinsk coal basin. In accordance with the genetic classification by S.I. Arbuzov [18], it was determined that the coal from the Chernogorskoye deposit falls into the category of humus coal of D grade, commonly referred to as “candle coal”. The macrocomponent composition of the coal includes vitrinite (67–74%), semivitrinite (1–4%), fusinite (17–27%), and liptinite (2–8%), with varying percentages for each individual seam. The coal from this deposit is mid-ash coal, with ash content ranging from 2.8% to 30%. The average volatile-matter yield is within the range of 36–43%, and the lower calorific value is 4830 kcal/kg. Coal dust was obtained by grinding coal from the Chernogorsky coal deposit in a porcelain jar; averaging was carried out by the envelope method, and the powder was sieved through a 0.5 mm sieve. According to particle size analysis performed on a laser particle size analyzer Laska TD (Russia), the share of particles with sizes 0.5–5 μm is less than 0.05%; 5–20 μm, 56.0%; 20–50 μm, 43.5%; 50–100 μm, 0.5%.

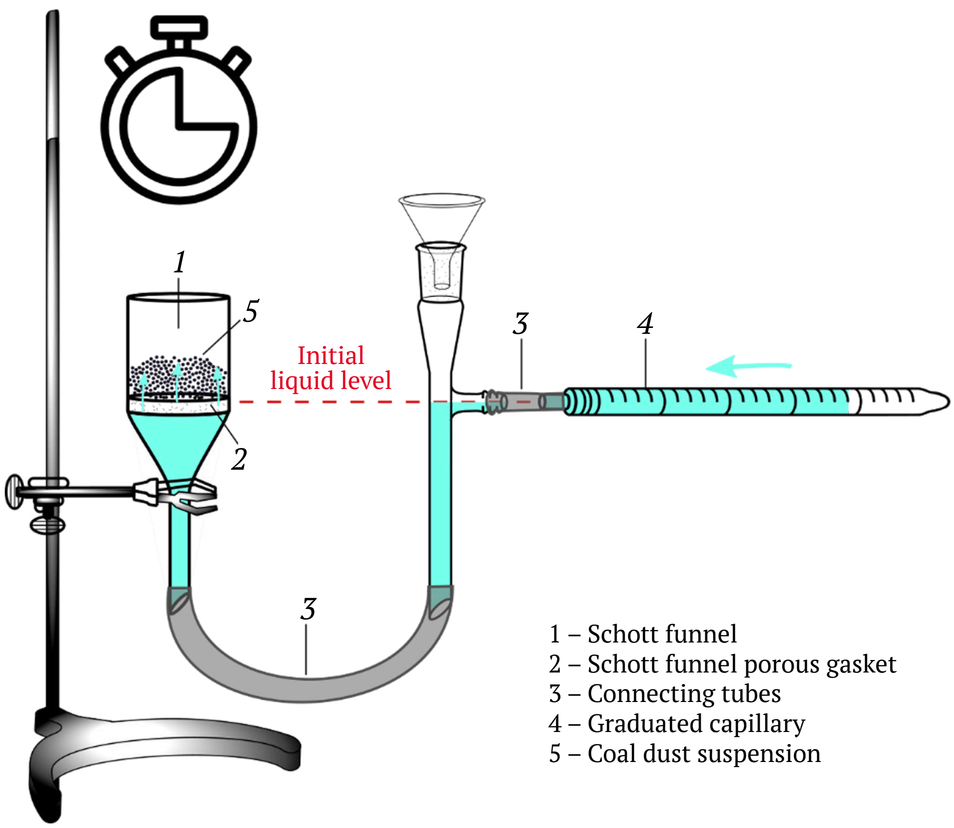

Fig. 1. Experimental set-up for wettability determination

Capillary soaking method

The wetting assessment of coal particle surfaces with aqueous solutions of various compositions was conducted using the established capillary soaking (absorption) method [19], as depicted in Fig. 1. A 1 g weighted portion of coal dust was placed in a Schott funnel (POR 100 class) with a porosity ranging from 0.04 to 0.1 mm. The room temperature was 21°C, and the maximum exposure time was 180 s. Wettability, which represents the maximum absorption of the solution, was determined as the ratio of the volume of absorbed liquid to the mass of coal, expressed as a percentage.

Film flotation method

The determination of the mass of coal particles applied to the surface of a liquid and their settling over time was carried out using VT-500 torsion scales. Specifically, 1 g of coal was applied to the surface of either water or reagent solution, and the weight of the settled particles after 1 and 3 min was measured.

Method of continuous weighing of settling particles

Sedimentation curves, which depict the weight of settling coal particles as a function of settling time, were obtained for coal particles in both water and reagent solutions using VT-500 torsion scales. This involved dispersing 1 g of coal was in 300 mL of a solution, and the weight of settling particles over time was recorded.

Measurement of electrokinetic potential

The measurements of particle distribution by hydrodynamic diameter using dynamic light scattering (DLS) and particle distribution by electrokinetic potential using electrophoretic mobility were carried out using a Zetasizer Nano ZS instrument (Malvern Instruments, UK). The instrument specifications include a 633 nm laser, backscattering mode at an angle of 173°, a polycarbonate cell with Pd electrodes, and a measurement temperature of 25°C. All measurements of coal colloids were performed at pH 11±0.1 and autogenous ionic strength. Micelles of the initial reagent were measured at autogenous pH and ionic strength.

A coal colloid for electrokinetic potential measurements was obtained by subjecting 1 g of coal to ultrasonic treatment in 50 ml of deionized water for 15 min (100 kJ) using a SONOPULSmini20 ultrasonic homogenizer (Bandelin, Germany). This suspension was allowed to stand for 24 h at room temperature, and then a top layer was sampled. The particles in this top layer were used as a model for coal dust particles.

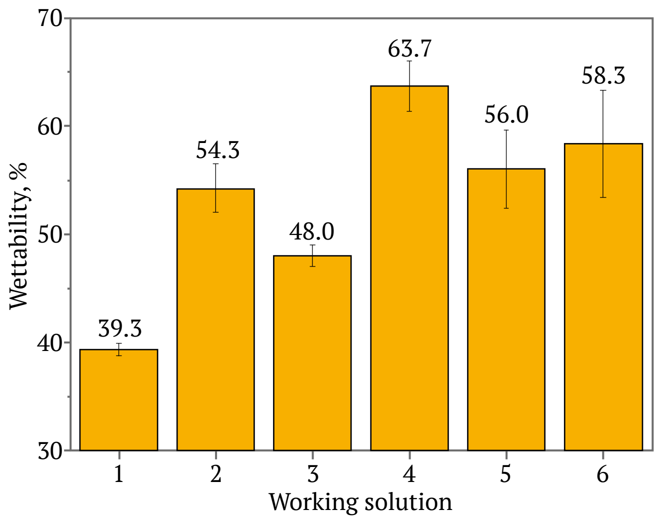

Fig. 2. Wettability of coal dust with working solutions: 1) distilled water; 2) sodium oleate (SO); 3) SO with linseed oil 1 g/L; 4) SO with linseed oil 4 g/L; 5) SO with linseed oil 8 g/L; 6) SO with linseed oil 20 g/L

The Findings and Discussion

Wettability measurement and formulation optimization

The wettability of coal dust was found to vary depending on the wetting agent used. When the dust was treated with distilled water, the wettability index was 39%. In order to enhance the wettability of dust particles, sodium oleate, a sodium salt of oleic acid, was introduced This resulted in an increased wettability of 54%. Notably, a more significant increase in wettability (up to 64%) was observed when using a sodium oleate solution with the addition of linseed oil. Linseed oil was added to the working solution in amounts of 1, 4, 8, 20 g/L. The optimum concentration of linseed oil in the solution was found to ne 4 g/L (Fig. 2).

Synthesis of optimal dust suppression reagent composition and its characteristics

Based on experimental data, the most effective reagent composition was selected, consisting of 8 g/L oleic acid, 6 g/L sodium hydroxide, and 4 g/L linseed oil. The resulting reagent is a transparent liquid with a light yellow color, a pH of 12.85, and a conductivity of 22 mS/cm.

The reagent forms a dispersed system due to the surfactant concentration exceeding the critical micelle concentration. The size distribution of the dispersed phase exhibits two modes: Mode1, likely comprising micelles with an average size of 7.5 nm, and Mode 2, with an average size of 150 nm (Fig. 3). The larger particles are believed to be aggregates of the surfactant micelles, and with sufficient dilution, both modes will dissolve. Therefore, this formulation aligns well with the requirements for wetting agents for dust suppression for coal and mining industries [20].

Selecting the optimal reagent dilution level

Using a reagent with a high concentration in hydrodedusting is economically inefficient, comes with technical and engineering challenges, and can even have a negative impact on the environment. Therefore, it is crucial to determine the optimum degree of dilution. The influence of reagent concentration on the wettability of coal dust was investigated using capillary soaking method. Pure water exhibited low wetting efficiency, at 39%, whereas the initial reagent demonstrated significantly higher efficiency at 64%. Dilution of the reagent led to an improvement in coal wettability: a 10% solution showed a wettability of 68%, a 3.3% solution reached 69%, and a 1.7% solution achieved 73% (Fig. 4).

In order to estimate the added wetting performance when surfactants are used, the following formula is employed:

$$E_r = \frac{E_w P_r}{P_w},$$

where E_r represents wetting agent performance, %, E_w is water performance (100%), P_r is wetting agent performance in an experiment, %, (i.e. wettability), in this case, and P_w is water performance in an experiment.

In studies involving different additives, the relative efficiency ranged from 100% (equal to the effect of pure water) to 193% (exceeding the efficiency of water by nearly 2 times) [8]. The proposed composition demonstrates maximum efficiency in wetting coal dust at a dilution of up to 1.7% (140 mg/L oleic acid, 100 mg/L sodium hydroxide, 70 mg/L linseed oil in water). Its efficiency relative to pure water was 187%. Considering the availability and affordability of the components and their low potential environmental impact, this version of the reagent is recommended for further research.

It is important to note that not only wettability but also the wetting rate depends on the composition used. Water exhibited a lower initial wetting rate, whereas hydrodedusting reagent solutions demonstrated significantly higher rates. However, the initial settling rate remained independent of surfactant concentration in the system (Fig. 5).

Particle immersion tests in surfactant solutions, including methods like the film flotation method and sedimentation analysis, are conventional approaches for assessing the wetting efficiency of coal dust using working solutions [8, 21]. The rate at which particles immerse from the solution's surface is a key determinant of wetting efficiency. With an increase in concentration up to 3.3%, there is an observable increase in the mass of settled particles. This suggests

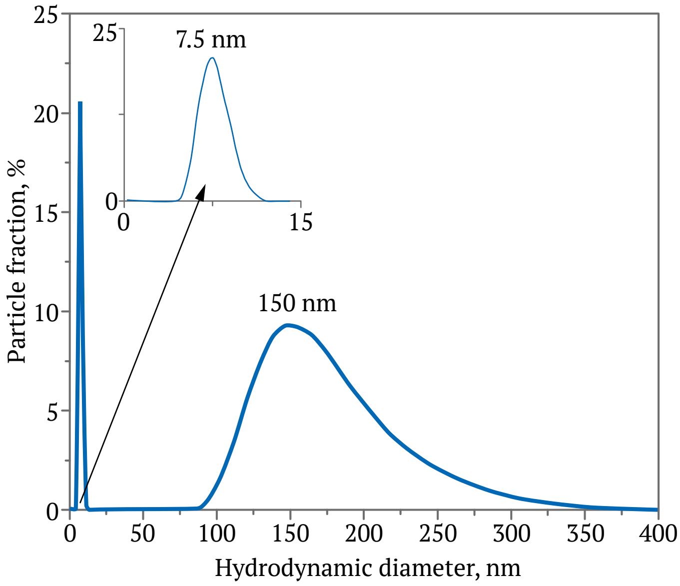

Fig. 3. Micelles and floccule size distribution in the initial reagent

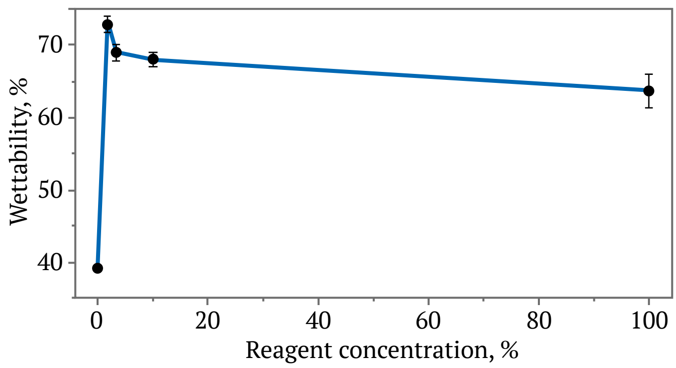

Fig. 4. Wettability of coal with reagent solutions of different concentrations

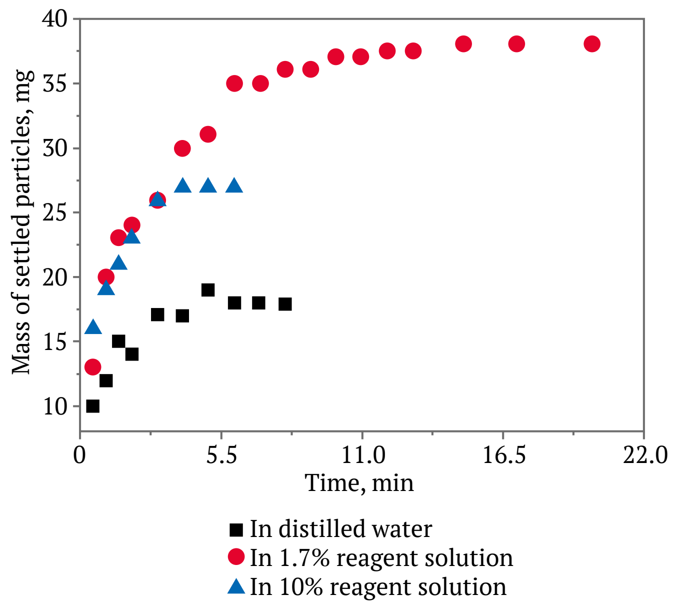

Fig. 5. Coal dust particle sedimentation rate in wetting reagent solutions

an improved wetting of the particles, making it easier for them to pass through the liquid surface. However, when the reagent concentration exceeds 5%, the mass of settling particles over time significantly decreases, sometimes even falling below that of pure water. In such cases, the settling process is limited not by the particle's penetration from the liquid surface into the solution volume, but by the aggregative stability of the particles. Naturally, the adsorption of an anionic surfactant leads in an increase in the surface charge of the particles, resulting in greater electrostatic repulsion between them.

In order to confirm the established patterns, the distributions of hydrodynamic radii and electrokinetic potentials of coal colloids were measured (Fig. 7).

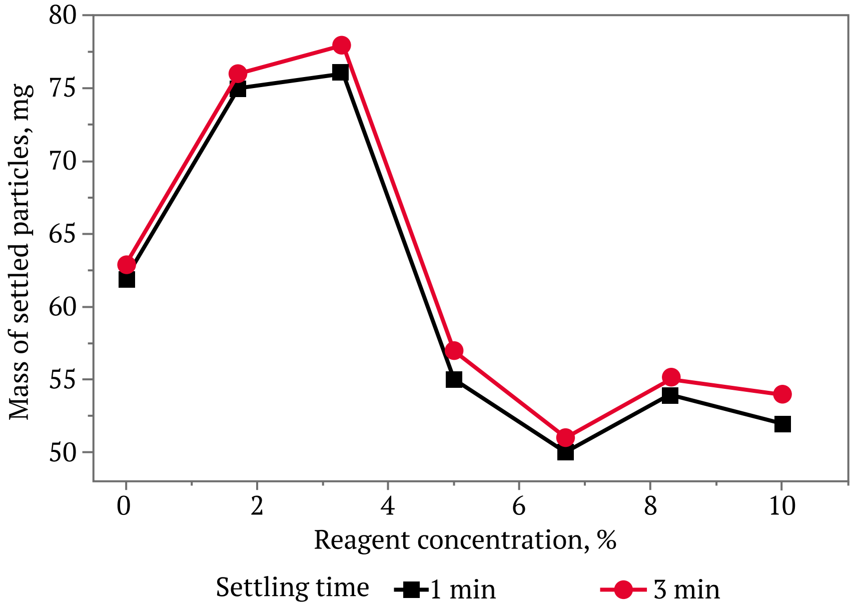

Fig. 6. Dependence of settled particle mass on reagent concentration

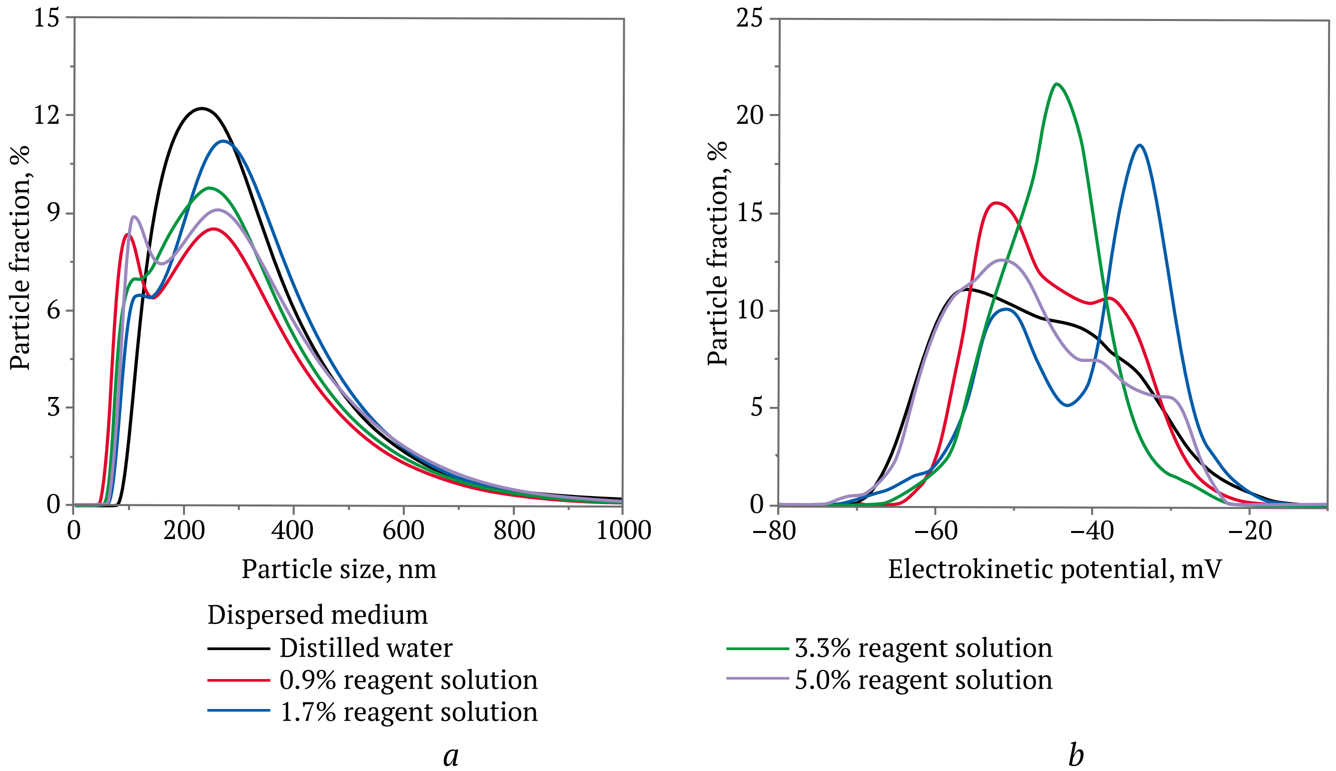

Fig. 7. Colloidal particle size (*a*) and electrokinetic potential (*b*) distribution with dust suppression reagent additives

In water, the particle distribution is monomodal, with an average size of 230 nm. However, upon the addition of a surfactant, we observe the emergence of two modes in the size distribution across all reagent concentrations. A significant portion of the particles experience size reduction, forming a mode with an average size of 100–110 nm. This phenomenon represents particle disaggregation or disagglomeration resulting from electrostatic repulsion, a well-known phenomenon [22]. It is worth noting that the use of sodium oleate for dispersing carbon black is also known to lead to particle size reduction [23].

At a pH of 11, a coal colloid exhibits a strongly negative charge, with an average ζ potential of −46 mV. The introduction of a surfactant and its adsorption on the particle surfaces result in alterations to the charge distribution of the particles (Fig. 7, *b*). This surfactant adsorption involves two concurrent processes: the suppression of surface acid group dissociation in coal and the emergence of new ionization centers through dissociated adsorbate molecules [24]. At lower surfactant concentrations (0.9% reagent solution), both factors exert a weak influence, and at the highest surfactant concentration (5% reagent solution), the particle charge distribution remains similar to that of coal in water, signifying a compensation of these factors. However, the most intriguing results are observed at reagent concentrations of 1.7 and 3.3%. In these cases, there is a narrowing of the particle distribution in ζ potential and a shift towards lower charges. These formulations also yield better results in wettability measurement and particle immersion experiments.

Upon contact between coal particles and atomized drops of surfactant solution, effective wetting of coal particles occurs, in contrast to pure water drops. Fig. 8 graphically illustrates the action of the anionic surfactant additives in the water spray dust suppression process. In the initial stages (processes I and II), dust particles and droplets collide, which are largely independent of solution properties. When a hydrophobic coal dust particle interacts with pure water, it exhibits a limiting wetting angle θ > 90°, preventing droplets from capturing coal dust and depositing it (process III). However, the adsorption of sodium oleate from drops of surfactant solution renders the surface of coal particles more hydrophilic. In this scenario, the interaction of solute, solid particle, and water allows water to spread over the initially hydrophobic surface, with a limiting wetting angle θ < 90° (process III). This altered liquid-solid interaction pattern leads to particle aggregation through particle absorption by droplets (process IV), which proliferates [12]. Nevertheless, excessive adsorption and correspondingly high surface charge on the particles can slow or even stop the particle immersion due to electrostatic repulsion. This explains the observed extreme dependence of wetting performance on surfactant concentration and justifies the selection of the reagent concentration required for high coal dust wetting performance.

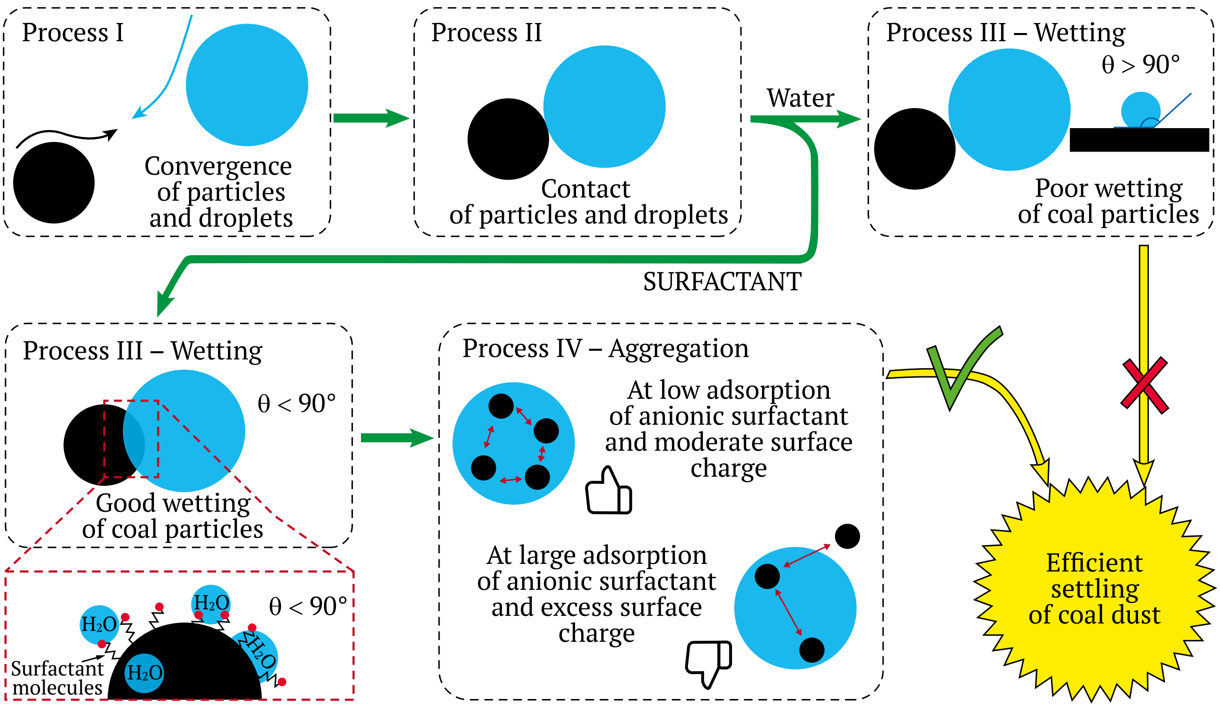

Fig. 8. Scheme of action of anionic surfactant additives in the process of water spray dust suppression

Conclusion

We have introduced a wetting agent composition for coal dust suppression [17], thoroughly studied its properties, and evaluated its ability to improve the wettability of hydrophobic surface. Through physicochemical methods, we determined the most effective concentration for water spray dust suppression. The optimal composition for hydrodedusting was found to be a 1.7% aqueous solution of the reagent, consisting of 140 mg/L oleic acid, 100 mg/l sodium hydroxide, and 70 mg/L linseed oil in water). This solution demonstrated remarkable efficiency in coal dust wetting experiments, achieving a performance level of 187% compared to pure water (set at 100%). This places it on par with the most effective dust suppression formulations reported in research publications in this field. The findings clearly illustrate that the components of the working solutions have a positive impact on coal wettability and wetting speed. One notable advantage of this composition is the safety of the surfactants used - oleic acid and linseed oil – both derived from renewable vegetable sources.

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Received 04.02.2023
Revised 28.06.2023
Accepted 30.06.2023