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Original article

Assessment of the Spraying System Impact at the Preparation Stage of Iron Ore Concentrate Products

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Abstract
Introduction. Harmful components of ore dust, formed during the unloading of products in the preparation of iron ore concentrate (PPIOC) at the mixing stage, cause damage to both workers and equipment. To address this issue, liquid aerosol spraying using nozzles with large diameters (>20 µm) is used. However, this method proves ineffective in capturing fine-dust particles. Therefore, enhancing the efficiency of the dust deposition method through PPIOC dust spraying becomes a pressing challenge. The aim of this study is to investigate the impact of the Dry Fog technology, generating liquid droplets up to 20 µm in size, during the unloading stage of PPIOC at a mining and metallurgical enterprise in the precipitation of suspended fine-dust particles. The primary goal of this research was to assess the effectiveness and potential advantages of applying the Dry Fog technology for dust spraying with subsequent precipitation, as this technology has not been previously applied to PPIOC dust.
Materials and Methods. The experiment on the PPIOC dust deposition was conducted in a specially designed laboratory setup. Through physical modeling in the laboratory setup, parameters of the precipitation process were obtained. Subsequently, the results were analyzed to understand the dependence of dust precipitation over time, taking into account the influence of the Dry Fog technology. An experiment program was developed for physical modeling. According to the devised program, dust was uniformly loaded into the interior of the laboratory setup (from the top), distributed in the air stream throughout the volume of the setup by a fan, and an instrument located at the bottom recorded changes in concentration over time. Experiments on dust precipitation were then conducted using liquid spraying (filtered water as the liquid) introduced into the setup through nozzles generating droplets with sizes of 10 and 15 µm, concurrently with the loading of dust into the laboratory setup. The effectiveness of the Dry Fog technology in the deposition of PPIOC dust was determined visually and further analyzed based on a comparison of graphs. The dynamics of changes in the average dust concentrations depending on time was studied both during precipitation without spraying and using the Dry Fog technology. During the experiment, the characteristics of the microclimate inside the laboratory setup (humidity, temperature and air velocity) and the parameters of two nozzles — their operating pressure and the supplied liquid spraying time — were recorded.
Results. The comparison of the results showed a reduction in the dust precipitation time by 40% and 75% when using nozzles with sizes of 10 µm and 15 µm, respectively.
Discussion and Conclusion. The experiment results confirm the effectiveness of the Dry Fog technology for PPIOC dust precipitation during unloading at the mixing stage. Fundamental findings have been obtained, providing a basis for further assessment of the efficiency of dust precipitation with the additional application of pulsating ventilation. In such a combination, an additional 20–25% increase in precipitation efficiency is anticipated compared to the results presented in this article. The obtained results will support the justification of rational parameters and the implementation of the described method in production to enhance dust precipitation efficiency. Additionally, they will aid in developing a methodology to accelerate the PPIOC dust precipitation using the pulsating ventilation method.

Keywords: ore dust, dust from iron ore concentrate preparation products, iron ore concentrate, liquid spraying, mass transfer, dust deposition experiment, liquid aerosol, dust aerosol, pulsating ventilation method

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Научная статья

Оценка влияния системы орошения на этапе подготовки продуктов железорудного концентрата

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Аннотация

Введение. Вредные компоненты рудной пыли, образующейся при разгрузке продуктов подготовки железорудного концентрата (ППЖК) на стадии смешивания, наносят ущерб как работникам, так и оборудованию. Для решения этой проблемы применяется орошение жидкостным аэрозолем с использованием форсунок больших диаметров (>20 мкм). Однако данный метод неэффективен в улавливании мелкодисперсных частиц пыли, поэтому повышение эффективности метода осаждения орошением пыли ППЖК становится актуальной задачей. Целью данного исследования является изучение воздействия технологии «Сухой туман», генерирующей капли жидкости размером до 20 мкм, на этапе разгрузки ППЖК горно-металлургического предприятия при осаждении взвешенной мелкодисперсной пыли. Основной задачей данного исследования являлась оценка эффективности и возможных преимуществ применения технологии «Сухой туман» для орошения пыли с последующим осаждением, поскольку к пыли ППЖК описанная выше технология ранее не применялась.

Материалы и методы. Эксперимент по осаждению пыли ППЖК проводился в специально созданном лабораторном стенде. Посредством физического моделирования были получены параметры процесса осаждения. Далее полученные результаты подвергались анализу с точки зрения получения зависимости осаждения пыли с течением времени с учетом влияния технологии «Сухой туман». Для физического моделирования была разработана программа эксперимента. Согласно данной программе, пыль равномерно загружалась внутрь лабораторного стенда (сверху), распределялась в воздушном потоке по всему объему стенда крыльчаткой, а прибор, расположенный в нижней части, фиксировал изменение концентрации во времени. Далее были проведены эксперименты по осаждению пыли с применением жидкостного орошения. Совместно с загрузкой пыли в объем лабораторного стенда посредством форсунок, генерирующих капли размером 10 и 15 мкм, подавалась жидкость — отфильтрованная вода. Эффективность технологии «Сухой туман» при осаждении пыли ППЖК определялась визуально, и далее — на основании сопоставления графиков. Изучалась динамика изменения усредненных концентраций пыли от времени как при осаждении без орошения, так и с применением технологии «Сухой туман». В процессе эксперимента фиксировались характеристики микроклимата внутри лабораторного стенда (влажность, температура и скорость движения воздуха) и параметры двух форсунок — их рабочее давление и время распыления подаваемой жидкости.

Результаты исследования. Сравнение результатов эксперимента показало уменьшение времени осаждения на 40 % и 75 % при использовании форсунок на 10 мкм и 15 мкм соответственно.

Обсуждение и заключение. По результатам эксперимента подтверждена эффективность технологии «Сухой туман» для осаждения пыли ППЖК при разгрузке на стадии смешивания. Полученные базисные результаты позволят в дальнейшем оценить эффективность осаждения пыли с применением дополнительно режима пульсирующей вентиляции. В таком сочетании ожидается повышение эффективности осаждения еще на 20–25 % относительно результатов, представленных в данной статье. Полученные результаты дают возможность обосновать рациональные параметры и применить на производстве вышеописанный способ для повышения эффективности осаждения пыли. Помимо этого, они создают основу для разработки методики ускорения осаждения пыли ППЖК с применением метода пульсирующей вентиляции.

Ключевые слова: рудничная пыль, пыль продуктов подготовки железорудного концентрата, железорудный концентрат, жидкостное орошение, массоперенос, эксперимент по осаждению, жидкостный аэрозоль, пылеводяной аэрозоль, метод пульсирующей вентиляции

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Introduction. In order to reduce the level of atmospheric dust in production sites, the mining and metallurgical complex has successfully employed a range of innovative methods and advanced dust control technologies. Filtration systems, cyclones and ventilation systems are used, that are designed to effectively capture and remove the smallest dust particles [1–3]. In addition, engineers use methods of liquid spraying, aerial flotation and other advanced technologies that together provide an integrated approach to solving the problem of dust. The effectiveness of dust control measures is closely related to the unique features of the production processes, the characteristics of the equipment used, the design features of the premises and other important factors. Systematic maintenance of technical condition of the equipment is not just part of the technological process, but acts as an important element of the strategy to reduce the impact of production activities on the environment, contributes to the optimization of production efficiency. Comprehensive implementation of the above measures, combining various methods and technologies, allows you to achieve maximum efficiency in reducing the level of dust load within the working area.

At the stage of unloading and preparation of iron ore concentrate, where a significant amount of the smallest dispersed dust is formed, a liquid spraying system is used for a long time [4–6]. To create the smallest liquid aerosol, various types of nozzles are used, forming droplets with a diameter from 30 to 150 microns. In addition, nozzles with a larger diameter are also used. Deposition time t of the smallest dispersed dust (d = 1–10 microns) when using such nozzles can be quite long and reach 25,400 s (about 7 hours) [6]. At other stages of production, advanced Dry Fog technology is used for effective dust deposition. This technology uses nozzles of a smaller diameter that spray liquid with a droplet dispersion in the range from 1 to 20 microns [7]. In this technology, each drop of liquid serves as an effective tool for capturing and ensuring the settling of the smallest particles, creating a unique combination of technology and engineering in the fight against the problem of atmospheric dust.

Studies related to the use of the above-described technology for the deposition of fine dust in the preparation of iron ore concentrate products have not been conducted before. Therefore, the aim of this work was to analyze the effects of the Dry Fog technology, which generates liquid droplets up to 20 microns in size, at the stage of unloading the PPIOC of a mining and metallurgical enterprise during the deposition of suspended fine dust. The task was to evaluate the effectiveness and possible advantages of using the Dry Fog technology for dust spraying with subsequent precipitation.

Materials and Methods. To evaluate the effectiveness of the innovative Dry Fog technology, a series of experiments were conducted to measure dust deposition of the smallest particles of iron ore concentrate products using nozzles with diameters of 10 and 15 microns. To perform the experiment, a laboratory setup was developed (Fig. 1). This setup was used to analyze the deposition of coal dust in [8]. It was a cubic container with a volume of 1 m^3, made of organic glass in an aluminum frame.

A high-precision aerosol particle mass concentration meter, AEROCON-P, was used as a means to monitor the concentration of particles in the atmosphere. This measuring device has been developed taking into account the requirements for determining the mass concentration of dust with a diverse origin and chemical composition. The mass concentration meter has a unique ability to register the dispersion of the studied particles, including those with a diameter of up to 10 microns.

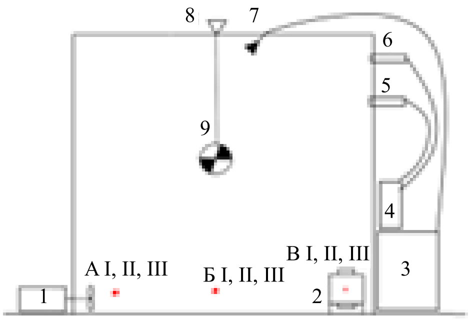

Fig. 1. Laboratory setup for dust deposition with a layout of equipment and measurement points:
1 — air flow generator; 2 — high-precision mass concentration meter for aerosol particles — AEROKON-P; 3 — fog generator; 4 — meteometer; 5 — humidity sensor; 6 — temperature sensor; 7 — nozzle; 8 — filling funnel; 9 — air pulsator

The order of measurements is indicated in Figure 1 by letters A, Б, В (location of the Aerocon-P sensor) (2). Values I, II and III (located next to the letters) correspond to the measurement points. According to the above scheme, the experiment was carried out over the entire area of the bottom of the laboratory box, namely at its 9 points (measurement points I, II, III should be understood as located in perspective, i.e. one after the other).

The experiments on dust deposition were carried out while monitoring the microclimate parameters. At the time of the deposition experiment, these parameters were controlled using a TESTO 435 (4) meteometer. During the experiments on dust deposition, the meteometer was used to control the parameters of the dust-air environment in the laboratory box — air temperature and humidity. This made it possible to establish the initial conditions of the experiment and conduct it under controlled conditions. The measuring device described above was used to monitor and maintain air humidity inside the setup in the range of 25–30% and temperature in the range from 22°C to 25°C. The assessment of the velocity of the air flow coming from the generator was carried out using a digital vane anemometer, which ensured a stable air velocity at the level of 4 m/s. To simulate the spraying system in the laboratory setup, an E218 installation was used, designed for misting by spraying liquid from various nozzles (Fig. 1). The operating pressure of this unit was 5.4 MPa, and the maximum was 12.41 MPa. For the experiment, nozzles with a diameter of 15 microns and 10 microns were used in this installation (Fig. 1).

The size of dust particles used in the deposition experiment, according to granulometric analysis, ranged from 1 micron to 40 microns (Fig. 2). Since the device for recording the concentration of particles in the air measured particles up to 10 microns in diameter, it was necessary to determine the percentage of these particles in the dust sample. According to this analysis, the required dust particle size used for the deposition experiment was approximately 10% of 1 gram of the sample used in dust analysis [9]. To correctly determine the concentration change by the device, the sample of the dust under study was increased to 5 grams in order to increase the concentration of fine dust with a diameter from 1 micron to 10 microns.

Dust deposition experiment was carried out in the laboratory setup described above, in compliance with all microclimate parameters regulated by appropriate measuring devices. A predetermined amount of dust weighing $m = 5$ g was placed into the laboratory box for 3–5 seconds using a filling funnel (Fig. 1). During this process, the air flow generator was activated, providing air supply at a speed of $V = 4$ m/s. The AEROCON-P measuring device, used as a mass concentration meter for aerosol particles, periodically recorded dust concentration data with an interval of 5 seconds, automatically transmitting the obtained values to a computer monitor [10]. The stage of the dust deposition experiment was completed when the dust concentration value recorded by the device was equal to $n = 0.00$ mg/m^3. The achievement of this value was considered as an indicator of completion of the experiment, in which all dust in the laboratory box was considered settled.

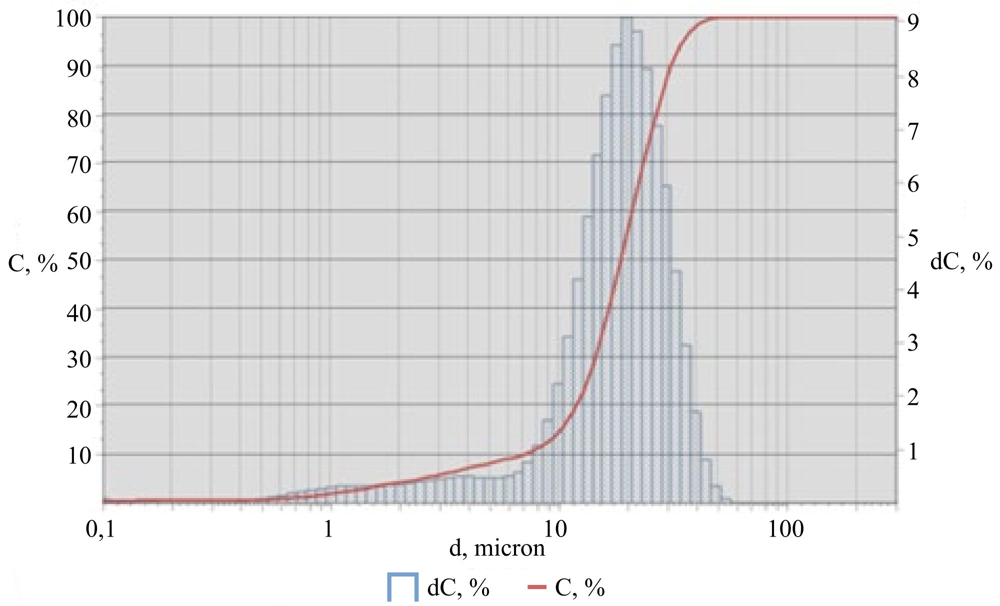

Fig. 2. Granulometric analysis of dust of sinter production of the mining and metallurgical complex:
C — percentage distribution of the number of particles in the sample by size, %;
dC — integral distribution of the percentage of particles in the sample by size, %;
d — particle size in the sample

Using similar parameters of temperature, humidity and air velocity during the dust deposition experiment, studies of the deposition of a dust-water aerosol were carried out with the alternate use of two nozzles (d = 10 and d = 15 microns) and control of the supplied pressure (p = 5.4 MPa) of the liquid. In addition, spraying time t = 2 minutes was monitored (after two minutes, the air humidity in the laboratory setup became maximum and amounted to 98.5%).

Results. Under the described conditions, a series of 10 dust deposition experiments was performed to ensure the reliability of the experimental data. The results of these experiments were processed, summarized in graphs and analyzed. Figure 3 provides graphs of the change in dust concentration values over time during 10 experiments from the deposition time.

According to the graph shown in Figure 3, the average dust deposition time without spraying and the use of pulsating ventilation was on average 1,828 seconds (30.5 minutes). During this time, dust in the production environment was in the air of the work area and caused harm not only to the equipment, but also to the personnel of the enterprise.

The results of 10 experiments on the deposition of a dust-water aerosol using two nozzles were also presented in the form of graphs of the dynamics of changes in the average concentration values from the time of aerosol deposition (Fig. 4, 5).

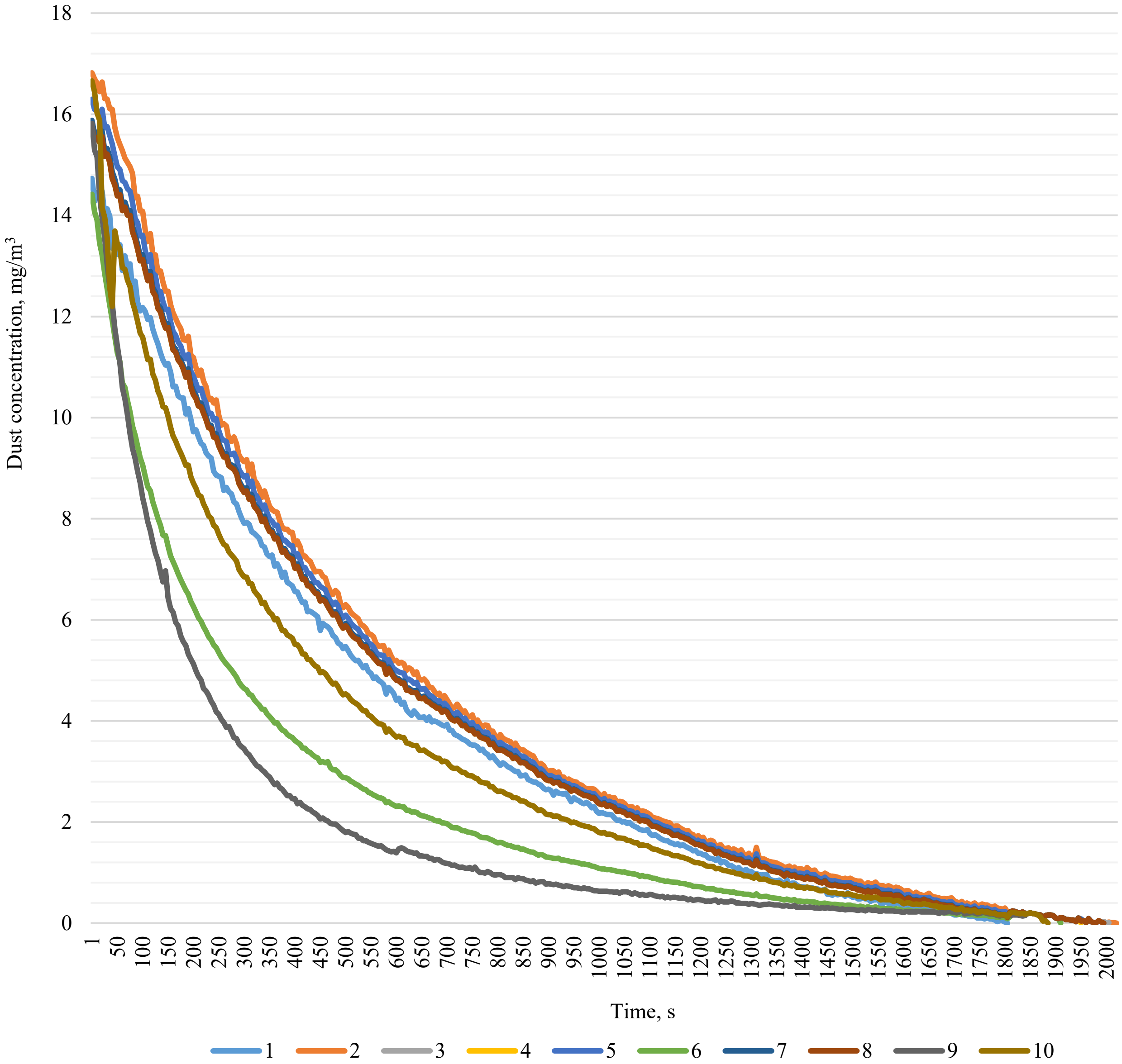

Fig. 3. Graphs of changes in dust concentration over time based on the results of 10 experiments

According to the graphs shown in Figure 4, the average deposition time of a dust-water aerosol when using nozzles with a diameter of 10 microns was 1115 s (18.5 min). The efficiency of this method, relative to the time of self-deposition of dust, was about 40%. However, according to Figure 5, when using a nozzle with a diameter of 15 microns, the average deposition time of a dust-water aerosol was 475 s (≈ 8 min.). The effectiveness of this method was 74%.

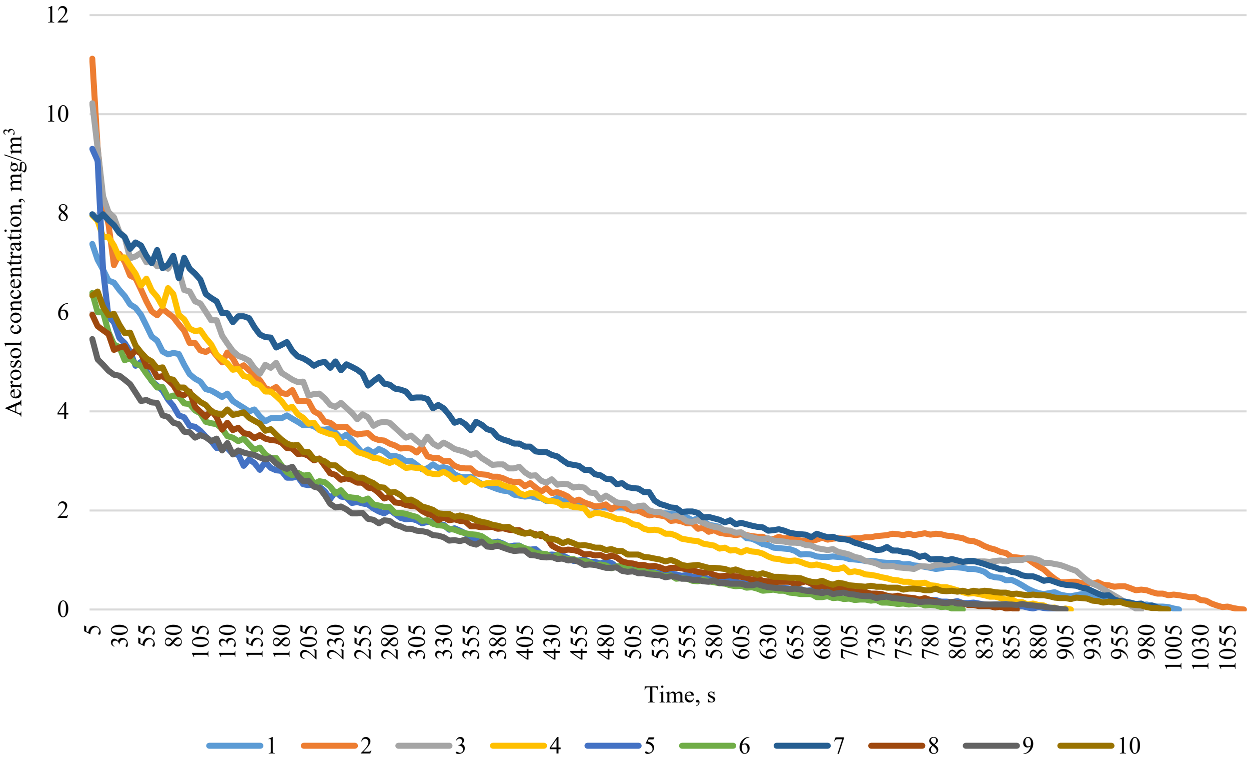

Fig. 4. Graphs of changes in the concentration of the dust-water aerosol over time (nozzle dimeter 10 microns)

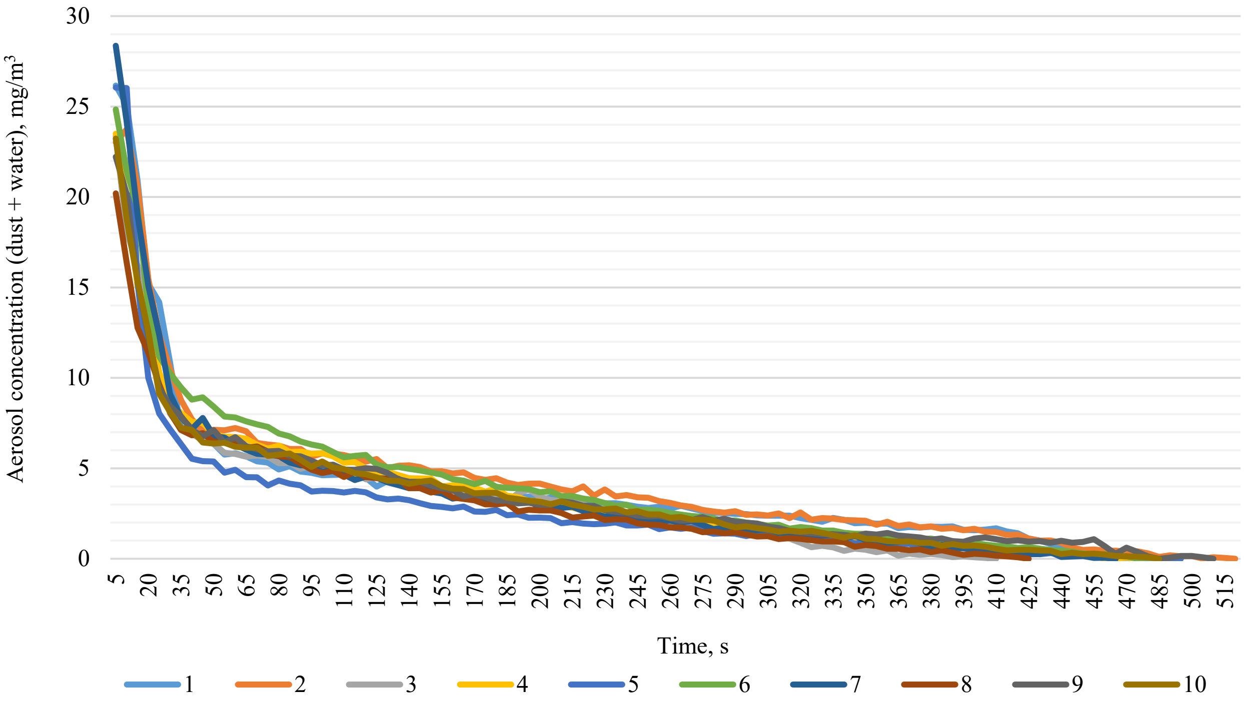

Fig. 5. Graphs of changes in the concentration of the dust-water aerosol over time (nozzle dimeter 15 microns)

Figure 6 shows the recalculated dependences of aerosol concentrations obtained as a result of spraying experiments using nozzles with a diameter of 10 microns and 15 microns. During the experiments, different dust concentrations were detected, which were recorded by the device. For ease of presentation, these concentrations were recalculated and expressed as a percentage depending on the deposition time.

When comparing the previously determined values of the efficiency of dust deposition using nozzles of 10 and 15 microns, the latter gave a significant effect. With the use of a 15 micron nozzle, the dust deposition efficiency was about two times higher than with a 10 micron nozzle. When using a 15 micron nozzle, dust particles exhibited low tendency to stick together and formed large liquid droplets less effectively, which reduced the effect of "condensate" during spraying. Fine droplets filled the dusty air environment better and could be used in those places of technological production where large droplets could cause damage.

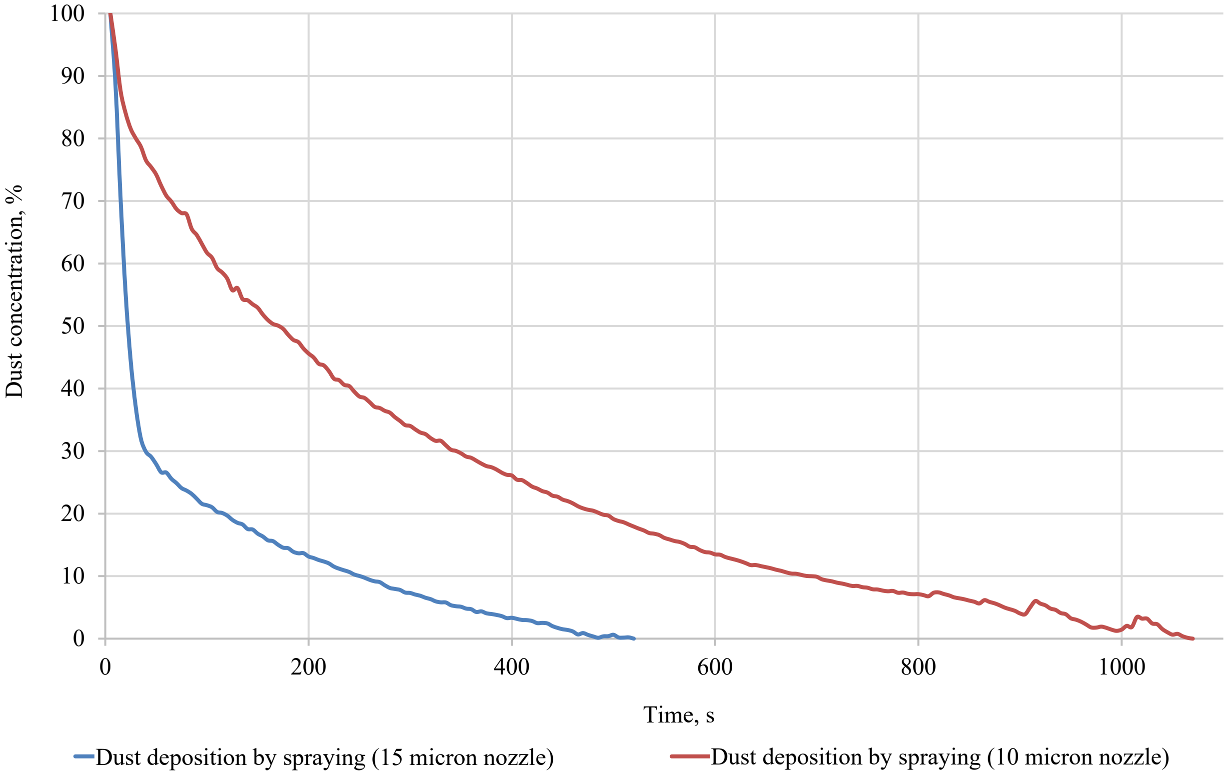

Fig. 6. Graph of changes in dust concentrations (%) over time under the conditions of dust deposition by spraying when using nozzles with dimeters of 15 microns and 10 microns

Discussion and Conclusion. As a result of the conducted experiments on dust deposition in the laboratory setup, the time of dust deposition was determined under two different scenarios: during the natural deposition of dust and during the deposition of a dust-water aerosol (by exposure to a liquid aerosol using nozzles with diameters of 10 and 15 microns).

In the future, to develop a technique for dust deposition, it is necessary to use the following parameters as rational:

– humidity of air inside the laboratory — φ = 25–30%;

– air temperature in the laboratory setup — T = 22–25°C;

– air velocity generated by the airflow generator should be at the level of V = 4 m/s.

The following technical parameters of the spraying system should also be used:

– it is recommended to use nozzles with diameters of 10 microns and 15 microns to disperse the liquid;

– working pressure in the liquid supply system — p = 5.4 MPa;

– spraying time of the liquid aerosol — 2 min.

The results obtained show different values of the efficiency of dust deposition using nozzles that generate different droplet diameters used in the spraying process. The nozzles described in the article demonstrate a significant improvement in the process of dust deposition by spraying when using nozzles of 10 and 15 microns, rather than when using nozzles generating droplets larger than 15 microns in the spraying process [7]. In addition, reducing the amount of moisture in the air of the production workshops will have less negative impact on the equipment.

The analysis of the data obtained confirmed the higher efficiency of dust deposition process when using the Dry Fog technology during the unloading of the PPIOC at the mixing stage. The results obtained provide a basis for further evaluation of the effectiveness of dust deposition process using the pulsating ventilation method. Based on the work of other authors who use this technology [7], an additional increase in deposition efficiency values by 20–25% is predicted, relative to the use of the Dry Fog technology. The results obtained in this work will be used in further development of a technique for dust deposition of iron ore concentrate products using the pulsating ventilation method.

The obtained values of the efficiency indicators of the Dry Fog technology give reason to recommend it for implementation in production for dust deposition in mining and metallurgical production sites with a high dust load.

References

1. Kalimulina EG, Temnikov VV. Utilization of aspiration dusts in steelmaking production at "EVRAZ NTMK" JSC. *Chernye metally.* 2018;(7):38–40. (In Russ.).

2. Kazyuta VI. Clearing ferroalloy furnaces' gases in bag filters. *Stal'.* 2022;(4):51–61. (In Russ.).

3. Petrov GV, Fokina SB. Increase of industrial and ecological safety of electrosteel-smelting production on the basis of processing of zinc-containing dump dusts. *Mining informational and analytical bulletin (scientific and technical journal)*. 2017;(S5–2):277–285. (In Russ.).

4. Kochetov OS, Otrubyannikov EV. Forsunochnyi skrubber dlya ochistki gazov ot pyli i khimicheskikh vrednykh veshchestv. In: *Trudy mezhdunarodnoi nauchno-prakticheskoi konferentsii Innovatsionnyi put' razvitiya kak otvet na vyzovy novogo vremeni Magnitogorsk, September 20, 2021.* Ufa: Aeterna; 2021. P. 48–49. (In Russ.).

5. Snitsereva VP, Kozlova LO. Sources of dust formation and integrated dusting at zhezkazgan concentrating factories. *Mining informational and analytical bulletin (scientific and technical journal).* 2021;(S1–1):38–46. https://doi.org/10.25018/0236_1493_2021_1_1_38 (In Russ.).

6. Cecala AB, O'Brien AD. *Dust Control Handbook for Industrial Minerals Mining and Processing.* CreateSpace Independent Publishing Platform; 2015. 312 p.

7. Chaulya SK, Chowdhury A, Sunil Kumar, Singh RS, Singh SK, Singh RK, et al. Fugitive dust emission control study for a developed smart dry fog system. *Journal of Environmental Management.* 2021;285:112116. https://doi.org/10.1016/j.jenvman.2021.112116

8. Filin AE, Kurnosov IYu, Kolesnikova LA, Ovchinnikova TI, Kolesnikov AS. Description of the methodology for conducting an experiment on dust deposition of mining and metallurgical production. *Ugol'.* 2022;9(1158):67–72. https://doi.org/10.18796/0041-5790-2022-9-67-72 (In Russ.).

9. Krasilova VA, Epshtein SA, Kossovich EL, Kozyrev MM, Ionin AA. Development of method for coal dust particle size distribution characterization by laser diffraction. *Mining informational and analytical bulletin (scientific and technical journal).* 2022;(2):5–16. https://doi.org/10.25018/0236_1493_2022_2_0_5 (In Russ.).

10. Sukhikh EA, Krylov AA, Smol'nikova AI, Antip'eva MV, Ulanova TS. Metody opredeleniya respirabel'nykh fraktsii melkodispersnykh chastits v vozdushnoi srede. In: *Trudy mezhdunarodnoi nauchno-prakticheskoi konferentsii "Zdorov'e i okruzhayushchaya sreda" Minsk, November 19–20, 2020.* Minsk: Belarusian State University; 2021. P. 454–457. (In Russ.).

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Claimed contributorship:

IYu Kurnosov: conducting the experiment, interpreting the logic of the data obtained, creating the basis for the article, analyzing the research results, translating into a foreign language.

AE Filin: setting the goals and objectives of the study, providing a theoretical basis and developing the methodology for the experiment, monitoring the results of the experiment and justifying the theory behind the research.

SV Tertychnaya: processing of literary sources, providing a scientific base, forming research conclusions, editing the text and graphs of the manuscript.

Conflict of interest statement: the authors do not have any conflict of interest.

All authors have read and approved the final manuscript.

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