SCIENTIFIC MINING JOURNAL

The Publication of the Chamber of Mining Engineers of Türkiye

Original Research

www.mining.org.tr

Dust pollution characteristics and control measures of open cut coal mines

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*Received: 28 July 2022 * Accepted: 16 October 2023*

ABSTRACT

This paper provides a study on dust pollution in open cut coal mines and related characteristics and emission prevention measures. Dust laden soil samples were collected from open cut coal mines and subjected to alkaline digestion testing to determine the content of heavy metal pollutants and total pollutants. Then, the physical and chemical properties of the soil samples were measured and analysed. The effects of different phosphorus treatments on the pH value and water-soluble phosphorus of dust laden soil samples, as well as the content of water-soluble lead, zinc, and exchangeable lead and zinc in the soil samples were investigated. On this basis, multi-directional dust pollution control measures with public participation in construction dust supervision and control as the core are put forward. The test findings demonstrate that after the treatment, the amount of dust is decreased, the contaminated open cut coal mines soil may be repaired, and a satisfactory soil remediation impact is achieved. This study helps with the green and sustainable development in the area of intelligent coal mines and is a useful resource for addressing the issue of dust pollution in open cut coal mines.

Keywords: *Open cut coal mines; Dust pollution characteristics; Management measures; Water soluble; pH value; Containing substance*

Introduction

Although coal is still the largest source of primary energy consumption in all countries, the influence of environmental protection factors such as haze has led many countries to introduce coal restriction policies (Meha *et al.*, 2020). Coal industry is one of the important sources of global energy production and consumption, but it is also one of the main pollution sources of environmental pollution and resource waste (Jiskani *et al.*, 2021). This is mainly because coal mining will produce dust, waste gas, waste water, solid waste and other pollutants which could have a serious impact on the mining environment and public health. Therefore, the coal industry needs to take measures to reduce the emissions of these pollutants to protect the environment and public health. At the same time, the coal industry also needs to improve energy efficiency, increase operational efficiency, and address environmental and energy challenges such as climate change. In the future, the coal industry must develop towards green mining and clean utilisation to achieve sustainable development (Jiskani *et al.*, 2022). In the coal industry, coal production capacity is controlled by means of annual working hours and output targets, and coal mines with low safety levels and high production costs are closed, mainly open cut coal mines. The reasons are multifaceted: open cut coal mines have a high level of safety and fewer serious casualties; Low production cost of open pit coal mines, adapting to the current industry downturn situation; The production of open cut coal mines is easy to control and can respond to changes in market supply and demand relationships (Coglianese *et al.*, 2020). It is expected that the output of open cut coal mines will further increase in the proportion of the total domestic coal output (Trechera *et al.*, 2021). The new open cut coal mines pay more attention to water shortage areas, where there are many rocks, dry soil, less rain, and some areas may also encounter sandstorms. In open areas, coal mines are more likely to produce a large amount of dust during mining. Therefore, the calls

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https://doi.org/1030797/madencilik.1149989

for environmental protection from the entire society is increasing, mostly for controlling coal production and consumption, especially for the coal mines that cause environmental pollution. This requires that dust emissions must be controlled externally during the production and use of coal (Jing *et al.*, 2021). Studying the mechanism and laws of the occurrence, accumulation, migration, and diffusion of dust in open-out mines is a necessary link for the development of green mining in this area. This has certain guiding significance for dust control and dust reduction in open-pit mines.

In recent studies on dust emissions, Luo *et al.* (2021) studied the problem of PM concentration in hawusu open cut coal mine, and analysed the characteristics of PM changes and its relationship with meteorological factors. The average PM concentrations in the study area were lower than the average daily limit of China's national ambient air quality standard (GB 3095-2012). However, the average PM10 concentration in December exceeded the national limit value.The order of PM concentration was December > January > February. Among them, PM concentration was positively correlated with humidity and negatively correlated with wind speed. In December, temperature was positively correlated with PM concentration, while in January, temperature was negatively correlated with PM concentration. Therefore, under the combined effect of several meteorological factors, the order of influence on winter PM concentration at the bottom of the open pit is: humidity > temperature > wind speed > temperature difference. The findings of this study are helpful for green mining. Wang et al. (2022) investigated the dust pollution of open cut coal mines in cold areas and explored the main causes and influencing factors. The study determined the characteristics of dust pollution through statistical analysis and calculated the main factors affecting dust concentration using the comprehensive gray correlation. The results show that meteorological factors with significant effects on dust concentration vary by season, including dew point temperature in spring, solar radiation in summer and autumn, and boundary layer height in winter. Winter, followed by autumn and spring, is the most polluting season for mining activities. Based on the study findings, optimal mine design strategies can be developed to reduce dust pollution in mining and adjacent areas. Ding et al. (2019) proposed the effect of viscosity of polymer stabilizer on the structural strength and dust pollution resistance of red sand. The higher the solution viscosity is, the better the crust strength and dust corrosion resistance of red sand surface are. Therefore, the viscosity of polymer solution can effectively predict the structural strength of crust and the ultimate erosion resistance of sand after treatment. Heidari *et al.* (2021) proposed a quantitative source allocation and ecological health risk assessment of heavy metal pollution in urban and heavily polluted suburban road dust. They also analyzed the sources of heavy metals (as, CD, Co, Cr, Cu, Mn, Ni, Pb, and Zn) in road dust from Abbas City and its western suburbs in Iran, and evaluated their ecological and health risks. Although this study did not analyze the comprehensive factors, it emphasized the attention to traffic emission, which proved that traffic emission was the main source of heavy metals in road dust in the suburbs of Banda Abbas. Therefore, the characteristics and prevention measures of dust pollution in open cut coal mines were put forward, and effective conclusions were drawn. Through the summary of the above research, it can be found that the problem of dust pollution in open cut coal mines is relatively serious, and its harm level is far higher than other pollution sources in industrial production. Therefore, it is necessary to conduct further research on the dust pollution problem in open cut coal mines. After analyzing the characteristics of dust pollution in open cut coal mines, the study proposed some effective prevention and control measures, aiming to provide reference for relevant research.

1.1.Comprehensive influence characteristics of dust pollution on atmospheric environment in open cut coal mine

Dust Pollution Structure in Open Cut Coal Mines

In the field of modern environmental research, open cut coal mines dust mainly refers to all solid particles that can be suspended in the air for a long time in the area. The particle size range is generally 1-100 μm. According to the size expansion space of 10μm, the dust of open cut coal mines can be further divided into falling dust or fugitive dust (Markovi et al., 2021). Polluting dust generated during the construction of open cut coal mines is mainly the pollution dust of medium-sized particles with a particle size of about 65 μm, which is the most important source of environmental dust pollution in open cut coal mines (Benitez-Polo and Velasco, 2020). Dust sources can be divided into topsoil stripping dust and dust generated during production processes, such as mining equipment operations, transportation operations, dumping sites, and coal processing and storage in mining areas. The detailed proportion is shown in Figure 1.

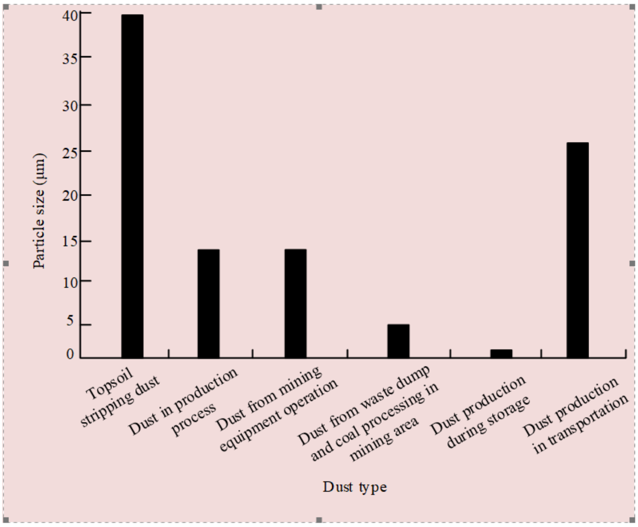

Figure 1. *Particle size distribution of atmospheric dust from various sources in open cut coal mines*

The high-precision definition of dust range in open cut coal mines plays an obvious role in the control of modern urban environmental dust pollution (Ma *et al.*, 2020). The traditional field of surface coal mine dust research has confused industrial dust with domestic dust. This has tended to lead to the definition of the hazards of dust pollution in industry, especially in surface coal mining projects. As a result, the hazards of dust pollution to the atmospheric environment and human health have been grossly underestimated and control methods have lacked real effectiveness. According to the specific characteristics of different dust and signs, such as physical properties, composition, particle size, etc., dust in open cut coal mines can be reasonably classified (Finke *et al.*, 2020; Tong *et al.*, 2019).

1.2.Characteristics of Influence of Dust Pollution on Air Environment in Open Cut Coal Mines

The mining sequence of open cut coal mines determines that some coal seams are in an exposed or semi exposed state. The coal seam undergoes a slow oxidation reaction after being exposed to oxygen, and the heat generated accumulates in the coal temperature under conditions where effective diffusion cannot be achieved. When the temperature rises to the point of coal seam combustion, coal will undergo spontaneous combustion (Guo et al., 2021; Kazi et al., 2019). The combustion process is often inadequate and produces a large amount of smoke and dust, as shown in Figure 2.

Figure 2. *Smoke dust produced by spontaneous combustion of coal seam*

The statistical value and experience of dust emission from dust sources in various links such as drilling, blasting, loading, hauling and drainage of open cut coal mines are shown as follows:

(1) Drilling

At present, the rotary drilling is mostly used in open cut mines, and the wet dust removal is used. The dust emission of the rotary drill is 1.05 kg/(unit·h) on average according to the field measurement. Some equipment with good dust removal effect can reach 0.22 kg/(set·h).

(2) Blasting

The amount of dust generated during blasting operation is large, and is affected by different charging methods, blasting mesh methods, and initiation sequences. There are two feasible evaluation methods. One is to establish a monitoring system in the mine to observe the smoke and dust during and after blasting; The Salingermann series method is used to calculate the average concentration of smoke and dust, and the ray recovery method is used to obtain the volume of smoke and dust, thereby calculating the amount of dust. Second, the amount of dust produced by blasting is about 0.0011% of the amount of blasting. The error of the second method is large, so the result can only be used to estimate the order of magnitude.

(3) Loading

The dust generated during truck and shovel loading operations, and the amount of dust generated can be calculated by the following equation (Wirth et al., 2020):

$$Q_m = Y_n \times D_f \times S_c \times E_v \quad (1)$$

Where, Q_m is the dust emission intensity [kg/h], Y_n is the ambient wind speed [m/s], D_f is the unloading height of the shovel [m], S_c is the moisture content of the material [%]. E_v is the loading capacity per unit time [m^3/h].

(4) Transportation

The dust produced by railway transportation is small, while the belt conveyor transportation can be controlled by the construction of belt corridor, but the dust in truck haulage is not only large, but also difficult to control. At present, the mainstream of most open cut mines is truck transportation, which is responsible for approximately 60% of the total dust generation in open cut mines. The dust emission from a single truck can be calculated as follows:

$$Q_r = F_b \times H_e \times J_z \quad (2)$$

Where, Q_r is the dust emission of a single truck [kg/km]; F_b represents the truck running speed, the unit is km/h; H_e represents vehicle load with unit t; J_z represents the amount of road surface material, and the unit is km/m^2.

(5) Soil dumping link

The dust generated during dumping operations includes unorganized dust generated during truck dumping operations and when the dumping site is exposed to the air and blown by the wind. The former can be calculated according to equation (1), but the latter dominates in the total dust emission. However, the amount of dust raised is directly related to the implementation of greening and reclamation operations in the waste dump, and there is currently no unified formula.

2. Experimental analysis

2.1. Materials and methods

(1) Collection of soil samples from opencast coal mine dust pollution

In the process of setting up sampling points for dust contaminated soil in open cut coal mines, full consideration should be given to the land in front of the chromium slag pile in the research area. The pollutants were not treated for anti-seepage or coverage during the initial stage of accumulation. After several years, although the accumulated slag was treated accordingly, due to the relatively backward technology level, the soil and groundwater were severely polluted due to mining. It can reflect the overall environmental conditions of the study area. In addition, the layout of sampling points should strictly comply with the relevant requirements in the Technical Specification for Soil Monitoring (Shi *et al.*, 2021). When collecting soil samples at each layout point, attention should be paid to multiple samples (at least three), mixed evenly, and then around 100g of soil samples should be selected and placed in clean plastic bags, and brought back to the laboratory. The soil samples brought back should be air dried in a constant temperature drying oven not exceeding 40°C, and attention should be paid to dust pollution and the entry of alkaline gases during the air drying process of the samples. Use a 10 mesh nylon sieve to remove debris such as gravel and animal residues from the air dried soil sample; Using the quartet method, select 100g of selected soil and grind it with a wooden stick or mortar; Treat with a 100 mesh nylon sieve and place it in a self sealing bag for later use.

(2) Soil sample treatment and determination

GB 5085.3-207 was used to carry out alkali digestion of the above collected soil samples, and GB/T 15555.4-95 was used to determine the content of heavy metal pollutants in the soil samples after alkali digestion; General analysis TAS990 atomic absorption spectrophotometer was used to determine the content of total pollutants in the soil samples; And the physicochemical properties of soil samples were determined and analyzed by conventional agricultural chemical analysis method.

(3) Assessment of mining area pollution soil form method

The morphological method is a screening method to achieve the purpose of diagnosis and identification by identifying the macro morphology or microstructure of tissue samples or other samples. It is a common research and diagnostic method in the fields of medicine, biology and so on. In order to realize the accurate detection of soil morphological characteristics, the morphological method is mainly used to classify the pollutants in the soil pollution samples in the mining area.

(4) Data analysis

All experimental data were plotted using Microsoft Office Excel 2003, Microsoft Office Visio 2003 and SigmaPlot 9.0. At the same time, SPSS software was used to analyze the experimental data, and LSD and Duncan were used to process the significant correlation test between the data, so that the significance level is $P < 0.05$. The overall flow of the study method is shown in Figure 3.

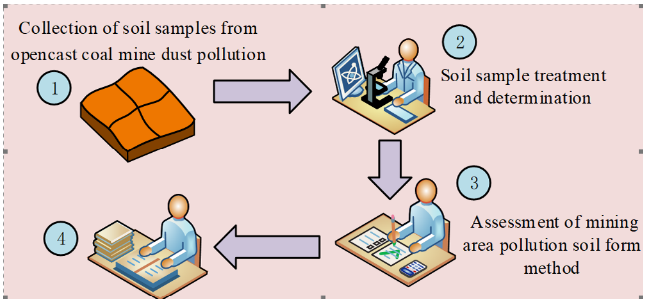

Figure 3. *Overall flow of the study methods*

2.2. Analysis and Discussion of Results

Based on the above evaluation results, taking Pb and Zn contaminated soil as an example, the remediation effect of soil with P/Pb molar ratios of 0.6, 1.2, 1.8, 3.0, and 4.0 on open cut coal mine dust was analyzed under simulated room temperature conditions.

(1) Effect of different P treatment on pH and water solubility P of soil polluted by dust in open cut coal mine

The pH value of the open cut coal mines' dust-contaminated soil is significantly decreased when SSP is added to the soil samples. As the added dose level is increased, the pH value gradually decreases, with the range being between 0.5 and 1.5 units. Naturally, this is the case as acidity controls SSP in and of itself. On the contrary, if MPP is added to the dust contaminated soil samples of open cut coal mines, the soil pH value will be increased. The pH value of dust contaminated soil in open cut coal mine increases from 5.7 units to 6.3 - 6.8 units after the addition of MPP. The pH value of dust contaminated soil in open cut coal mine showed an increasing first and then decreasing trend. Among them, when the MPP dose level is 1.2, it reaches the peak, which may be caused by the competition of hydrogen phosphate for the adsorption point in the dust contaminated soil of open cut coal mine. KH_2PO_4 is a strong base and weak acid salt, which usually exists in the form of H_2PO_4- after it is added to the dust contaminated soil samples of open cut coal mine. The ion exchange of H_2PO_4 causes the desorption of OH ions adsorbed on the dust polluted soil of open cut coal mines, leading to an increase in soil pH value.

(2) Effect of different P treatments on water soluble Pb and Zn in soil polluted by surface coal mine dust

The concentrations of water-soluble Pb and Zn heavy metal elements in the dust contaminated soil samples of open cut coal mine after the addition of substance P have significant influences. However, due to the different varieties of substance P added, the influences are significantly different: The content of water-soluble Pb in the dust-contaminated soil of open cut coal mine treated by MPP is significantly higher than that of blank control (CK); When the phosphorus dosage level is below 1.8, the Pb content increases with the increase of phosphorus level. When it is above 1.8, the water-soluble Pb element content decreases with the increase of P level. On the contrary, the addition of SSP significantly reduced the content of Pb in the dust-contaminated soil samples of open cut coal mines, and the reduction range was 68% - 98%. Especially when SSP1.8 and SSP4.0 were used to treat the dust-contaminated soil samples of open cut coal mines, the content of water-soluble Pb in the soil was lower than the detection limit. The Zn content using SSP is less affected by the substance P contained, and the Zn content after MPP treatment changes very little, without reaching a significant difference. It can be seen that the difference in the influence of SSP and MPP on the concentration of water-soluble Pb and Zn heavy metals in soil samples contaminated by dust in open-pit mines is caused by the difference in PR. First, SSP contains abundant Ca^{2+} ions, but MPP does not. The existence of Ca^{2+} ions may promote the P-Pb precipitation reaction in the dust-polluted soil of open pit coal mine. Secondly, SSP is an acidic substance, while MPP is a neutral substance. After adding it to the dust pollution of open cut coal mines, the soil pH value in the samples will vary, and the impact of recent soil activities will also be different. The correlation analysis between the impact of dust pollution in open cut coal mines on the concentrations of water-soluble Pb, Zn, and Ca and the pH value of soil samples shows that the Zn content in the samples is negatively correlated with the soil pH value. This indicates that the activity of Zn in the dust polluted soil of open cut mines is relatively low. The content of Pb and Ca in soil samples contaminated by dust from open cut mines shows a significant negative correlation, indicating that Ca in polluted soil also plays an important promoting role in the chemical reaction process of P and Pb.

(3) Effect of different P treatments on the content of Pb and Zn in the soil polluted by opencast coal mine dust

The effects of the addition of different types and dosage levels of P-containing substances on the content of exchangeable Pb and Zn in soil contaminated by opencast coal mine dust are shown in Figures 4 and 5.

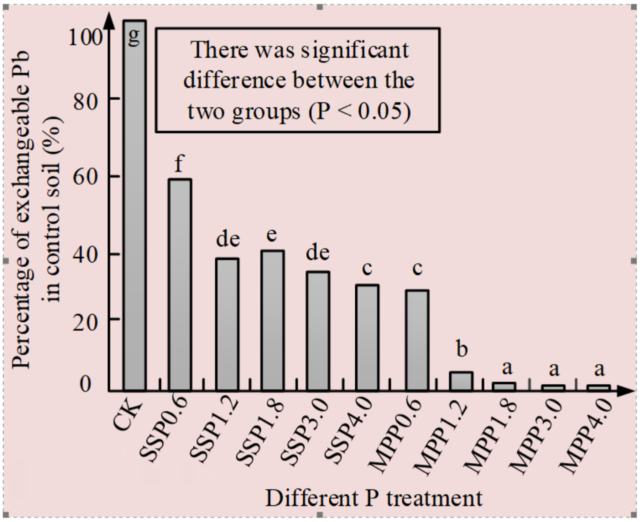

Figure 4. *Effect of P on the content of exchangeable Pb in soil polluted by coal mine dust.*

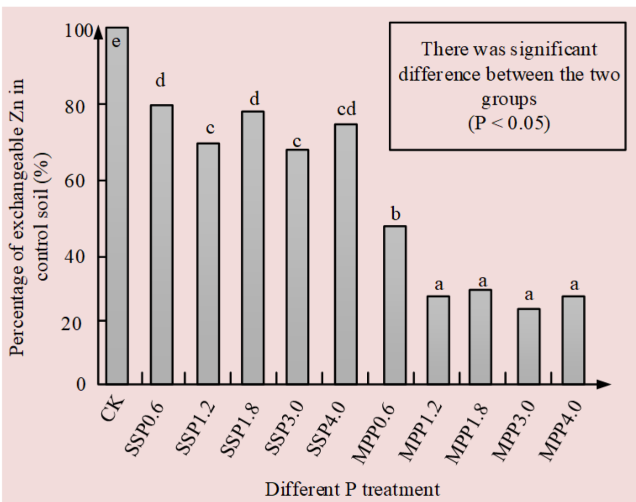

Figure 5. *Effect of P on the content of exchangeable Zn in soil polluted by open cut coal mine dust.*

This indicates that in soil samples contaminated by dust from open cut coal mines, the reduction effect of water-soluble P composite MPP on heavy metal Pb plants is significantly higher than that of water-soluble P composite SSP. This may be related to the concentration level of water-soluble P substances containing P. The experimental results indicate that after MPP treatment, the Pb content of soil samples contaminated with heavy metals in dust sharply decreases with the increase of phosphorus levels, and the trend of change is significant. It can be divided into two regions: one region is a rapidly decreasing region, which is $0.6 < P < 1.8$; The other area is a slightly decreasing area, that is, the $P > 1.8$. In this case, after the P level is increased, the content of exchangeable Pb heavy metals in the dust-polluted soil samples of open cut coal mines does not change significantly.

Through correlation analysis of Zn and Pb exchangeable heavy metal content in soil samples contaminated by dust from open cut mines, it was found that Pb is only negatively correlated with water-soluble P and soil pH value in the soil. However, the exchangeable heavy metal element Zn in the soil was negatively correlated with the soil pH value and water-soluble P. Previous studies have shown that the content of heavy metal elements Zn and Pb in soil contaminated by open cut coal mines dust is mainly affected by the water-soluble phosphorus content in the soil. In addition, MPP treatment is more beneficial for SSP to reduce the Pb content in the dust polluted soil of open cut mines, while the plant availability of Zn is influenced by phosphorus content and soil pH value.

3. Measures for control of dust pollution in open cut coal mines

3.1. Prevention and Control of Dust Pollution by Engineering Units

The engineering materials such as sand, cement, and crushed stones required for open cut coal mining projects should be stockpiled in designated places. Sealing facilities such as retaining walls and coverings should be installed around the area to prevent dust from spreading widely into the air. Fine, low density, small particulate materials that are prone to dust should be stored in a completely closed warehouse or container. In addition to the construction site set up soil or cement mixer construction units, the machine must be equipped with dust at the entrance and exit dust-proof devices. When there is a grade-4 or above wind in a construction city, it is necessary to prohibit the construction of all large open cut coal mines projects and the relevant earthwork construction on the foundation, the transportation of construction garbage and the transportation of relevant dregs. The Construction waste generated in the construction of the open pit coal mine can be treated and transported by taking corresponding dust spraying and pressure measures. The excavation, support, and transportation time of the foundation soil during the construction process of open cut coal mines should also be strictly controlled. When transporting vehicles to load and unload construction garbage, it is strictly prohibited to throw construction garbage directly into the air and unload them randomly so as to eliminate the pollution caused by secondary fugitive dust.

3.2. Control of Dust Pollution in Open Cut Coal Mines

Based on the people's enthusiasm for living environment and human health, the typical dust pollution events in open cut coal mines are discussed openly and universally. Especially after large-scale open cut coal mine pollution incidents or medical and health incidents occur, reasonable public opinion guidance can be used to raise public awareness of dust pollution in open cut coal mines. This can attract more attention, promote the formation of a sense of crisis among the public, and spontaneously supervise urban construction activities. In addition, the relevant streets, neighborhood committees can organize people-oriented supervision team, directly involved in the construction of open cut coal mines supervision. Relevant departments can set up air monitoring points in densely populated areas of urban construction projects. This method enables the supervision team and the public to clearly and in real-time observe the concentration data of pollution dust generated during the construction process of open-pit coal mines. This intuitive data expression can make the public more aware of the seriousness of the dust pollution during the construction of opencast coal mines and can have direct contact with the activity of air concentration than the medical health report and the numbers described by reporters and relevant experts in the public media. In addition, for some long-term environmental protection volunteer teams, it is necessary to change the mode of urban environmental protection activities. In addition to the environmental protection department's own fixed environmental protection volunteers, the majority of the public are random, short-term one-time participation. This kind of participation cannot meet the requirement of popularization of dust pollution knowledge and continuous improvement of environmental protection.

3.3. Improving Government Governance Initiatives

Clarifying the overall positioning standards is the basis for taking measures to protect the atmospheric environment and control the dust pollution of surface coal mines. Relevant environmental protection departments need to improve the positioning standards for dust pollution of surface coal mines. The relevant governance departments should take into account the protection of public health and the protection of the atmospheric environment, and formulate and clarify standards for atmospheric dust pollution during the construction of open cut coal mines. In addition, government departments need to rationally use economic means to change surface coal mine dust pollution control into government behavior. The concept of urbanization has led to the continuous increase of new construction projects in modern cities and serious dust in the open cut coal mine construction.

4. Conclusions and recommendations

Based on the above analysis and tests, the following conclusions have been drawn:

(1) Adding SSP to the soil samples polluted by coal mine dust in the open cut obviously reduced the pH of the soil; Adding MPP increased the pH of the soil, which was related to the acidity and alkalinity of the soil added with substance containing P.

(2) With the addition of phosphorus containing substances, the water-soluble phosphorus content in the dust polluted soil of open cut coal mines significantly increases, but the impact of different varieties on their phosphorus content is different, with MPP>SSP.

(3) The decrease in Zn content in soil samples contaminated by dust from open-pit coal mines is similar to that of Pb, with MPP>SSP, but different from Pb.

(4) Both SSP and MPP can significantly reduce the heavy metal content of Pb and Zn in the soil polluted by open coal mine dust, and the order of decreasing is MPP > SSP.

(5) The exchangeable heavy metal element Pb was only negatively correlated with water soluble

P in soil; While the exchangeable heavy metal element Zn was negatively correlated with both soil pH and water soluble P, but was mainly controlled by soil pH.

Although this study can effectively analyze the dust pollution characteristics of open cut coal mines, only the LSD method and Duncan method were used to test the significance of the data during the experimental process. To ensure the effectiveness of the dust pollution control methods proposed in the study, more methods need to be used to validate them, including practical applications, in order to improve the effectiveness of testing.

From the point of view of monitoring, evaluation and control, there are a lot of research work to be done in depth, such as: Improving the real-time monitoring system and early warning system for open cut dust; Studying the calculation model of dust concentration in open cut mines; Studying the influence of dust on the production cost of mines, revealing the harm of dust pollution, and improving the subjective initiative of mine enterprises in controlling dust; Studying the measures for reducing, suppressing and removing dust in open cut mines, etc. The further in-depth research will help promote the development of green mining technology, reduce the impact of coal mining on the environment, improve the society's awareness of coal damage to the environment, and contribute to the healthy development of the coal industry.

Funding

The research is supported by the general project of National Natural Science Foundation of China "integrated technology of ecological environment restoration and mining in open pit coal mine based on green degree". Project Number: (No. 51474119).

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