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Research on Distribution Regularities of Dust Concentration and Granularity in Large Mining Height Working Face

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Abstract

The key for dust control of coal mine is to clarify the dust concentration distribution and sedimentation in different areas. Both similarity experiment and numerical simulation method have certain restrictions and are quite different from the actual situation on site. In order to study the dust sedimentation regularity of coal mine in large mining height, "filter membrane method" is adopted in this paper, *i.e.*, to dry and weigh the filter membrane before and after sampling, collect the dust of respirable zone on mining face and calculate the dust concentration based on a main airway of 100 m. The result shows that: A large amount of dust will be produced during coal mining, wherein the maximum dust concentration from 6 m upstream to 100 m downstream of coal cutter is 121 mg/m^3, while the minimum dust concentration is 61 mg/m^3; The dust concentration in return airway is reduced with the distance increases, while the dust concentration at the entrance is 91 mg/m^3; A large amount of dust may fall from roof during section advancing and improves the dust concentration of hydraulic support in walking area obviously; The dust granularity of mining face and return airway is 0 - 100 μm, but the amount of respirable dust is higher than 80%, the larger the dust particle size, the higher the dust concentration. Besides, dust in small particle size can be suspended in air flow for longer, but that in large particle size may subside under the action of gravity; To reduce dust exposure, the mining position shall be located in the windward direction of advancing or coal cutter. This research can provide guidance for taking dust prevention measures of working face in large mining height.

Keywords

Safety Science and Engineering, Dust Concentration, Filter Membrane Method, Particle Size Distribution, Respirable Dust

1. Introduction

Currently, one of the main problems for safe mining of coal mine is dust control [1]. Dust produced during coal cutting and advancing may cause damage to the lungs of underground workers, and pneumoconiosis [2] often occur if respirable dust (particle size: less than 10 μm [3]) is inhaled for a long time. On the other hand, dust has explosion hazards [4], it may lead to explosion when exposed to fire under certain concentration and poses a serious threat to underground safe production.

Due to the limitations of experimental conditions, previous studies were mainly confined to a shorter area, while other scholars studied the change law of dust concentration through numerical simulation [5]-[10]. In fact, such studies cannot represent the actual situation on site due to hard determination of initial and boundary conditions. Therefore, in order to study the true change law of dust concentration, this research measures the concentration of total dust and respirable dust in testing area with "filter membrane method" and analyzes the distribution and sedimentation regularities.

2. Arrangement of Measuring Points

The tested working face is 5.8 m for mining height, 6.1 m for the airway width and 4.2 m for the height, as shown in **Figure 1**. Considering the measurement accuracy and safety, 11 measuring points shall be arranged on the mining face: three points (named as M_2 to M_4) arranged on the front roller (windward side), rear roller (downwind side) and middle position of coal cutter corresponding to the walking position of hydraulic support, one point (M_1) arranged at the position 6 m in front of coal cutter, and 7 points (named as M_5 to M_{11} respectively) arranged at the position 2 m, 6 m, 10 m, 20 m, 30 m, 50 m and 100 m at the back of coal cutter; 6 measuring points (H_1 to H_6) are arranged at the position 0 m, 5 m, 10 m, 30 m, 50 m and 100 m of the return airway entrance, as shown in **Figure 1**. The measuring height is equal to the height of respirable zone (1.5 m) [11]. The section of each point shall be measured for two times and the average value can be taken as the dust concentration of the position.

3. Testing Equipment and Steps

3.1. Dust Collection

1) An electronic scale (weighing accuracy: 0.0001 g) is used, as shown in **Figure 2(a)**.

2) A CCZ-20A dust concentration meter with two sampling heads (all dust

and respirable dust) is used, as shown in Figure 2(b). The measurement parameters are shown as Table 1.

3) 101-OS constant temperature drying oven, as shown in Figure 2(c).

3.2. Dust Concentration Measurement

"Filter membrane method" for measuring the dust concentration can achieve a higher accuracy [12], and the principle is mainly to collect dust with filter membrane in known mass and calculate the dust concentration based on its mass increase and gas production. The calculation formula is shown as below:

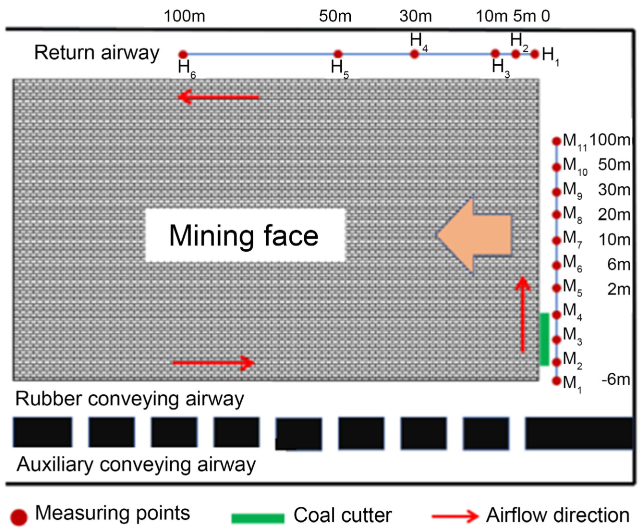

Figure 1. Mining face and measuring point diagram.

(a) (b) (c)

Figure 2. Measuring equipment. (a) Electronic scale; (b) CCZ-20A dust concentration meter; (c) 101-OS constant temperature drying oven.

Table 1. Measurement parameters of CCZ-20A dust concentration meter.

Parameter	Value
Sampling time	3 min
Sampling flow	20 L/min
Drying time before and after	2 h

$$c = \frac{m_2 - m_1}{V \cdot t} \times 1000 \quad (1)$$

where, c—Dust concentration in the air, mg/m^3; m_2—Filter membrane mass after sampling, mg; m_1—Film membrane mass before sampling, mg; V—Sampling flow, L/min; t—Sampling time, min.

According to the concentration determination requirements of dust in the air of industrial workplace [13], the measurement steps are as follows:

1) Filter membrane preparation: Dry the filter membrane at constant temperature of 60˚C, weight it with a dustless electronic scale, record the mass as m_1, then put the filter membrane in membrane box smoothly.

2) Sampling: Put the filter membrane into dust sampling apparatus, collect dust from the dusty air at the height of respirable zone in fixed sampling flow, put the membrane in a clean box and take it back to laboratory stably.

3) Sample weighing: Put the membrane in a constant temperature drying oven for drying, take it out to put it on a dustless electronic scale for weighing, and record the dusty membrane mass as m_2.

4) Concentration calculation: Calculate the dust concentration as per Formula (1).

3.3. Dust Granularity Measurement

The static image method [14] not only can measure the particle size, but also can represent the geometric shape and other parameters. Therefore, the method is used in this paper for granularity test, as shown in **Figure 3**, and the test apparatus is Rise granulometer. The main test steps are as follows:

1) Take out the dusty membrane from a self-sealing bag, put it in a beaker containing 2.5 ml absolute ethyl alcohol and mix it thoroughly with a glass rod.

2) Absorb dusty solution with a dropper, drip it on the slide, adjust the sight glass to keep the image clear and count the dust in different particle sizes.

3) Calculate the dust proportion in different particle sizes.

4. Result Analysis

4.1. Change Law of Dust Concentration

4.1.1. Change Law of Dust Concentration on Mining Face

After calculating the dust concentration of mining face with formula (1), the minimum dust concentration at the position 6 m in front of coal cutter is 61 mg/m^3, and the maximum dust concentration at the position 10 m at back of coal cutter is 121 mg/m^3.

The change of dust concentration in different positions between hydraulic supports on mining face is shown as **Figure 4**. It shows that the dust concentration from the position 6 m in front of coal cutter to the roller at back is doubled from 61 mg/m^3 to 121 mg/m^3 gradually. During spot test, the dust produced from cutting wall of coal cutter is discharged from cutting pick and spreads over the whole working face under the action of airflow. Since the airflow in front of

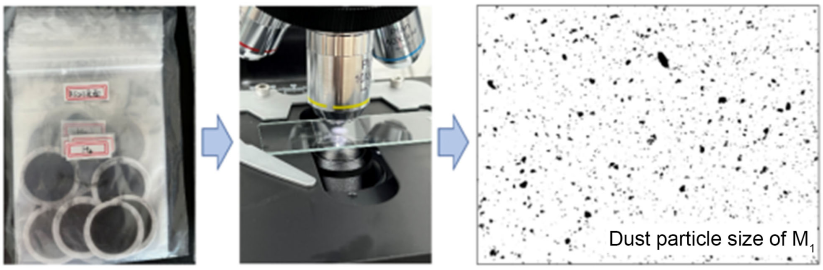

Figure 3. Dust granularity test with image method.

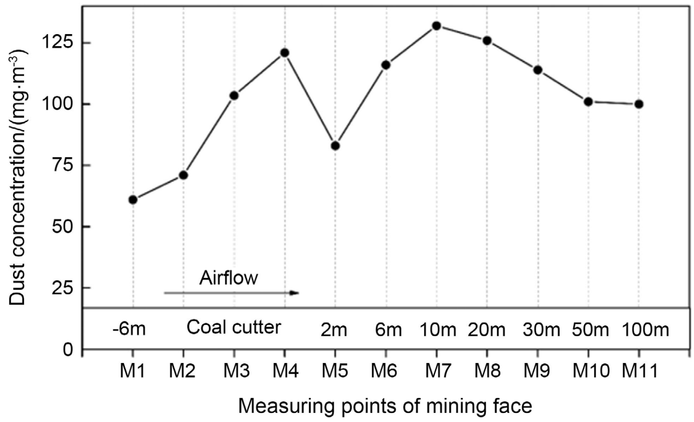

Figure 4. Dust concentration change of mining face.

coal cutter is against the wind, the dust concentration is minimum due to the airflow action opposite to the direction of initial speed. Dust discharged from the front and rear rollers gathers at the back of roller, so the concentration reaches a relative maximum value.

The dust source is far away as the distance increases, dust settles in airflow constantly, and the dust concentration at the position 2 m at back of coal cutter is reduced by 83 mg/m^3, showing an obvious downward trend. However, the dust concentration increases remarkably at the position 6 m at back of coal cutter and reaches the maximum value at the position of 10 m, such phenomenon is closely related to the synchronous advancing of hydraulic support, that is, the back of coal cutter is advancing while moving forward so as to support the roof, the coal body on roof is fractured due to stress imbalance, which leads to a large amount of dust falling into the walking area between supports and flows along with the airflow. Since advancing is a kind of movement within a section, the dust falling down naturally is large in quantity and strong in continuity, but the concentration at the position from 10 m to 100 m is slowly reduced by 24.2% only.

4.1.2. Change Law of Dust Concentration in Return Airway

The change of dust concentration in return airway is shown as **Figure 5**. To ensure measurement accuracy, the dusting water curtain in return airway shall be closed. According to the figure, the dust concentration at the entrance of return airway is 91 mg/m^3, and the dust concentration in whole section is reduced

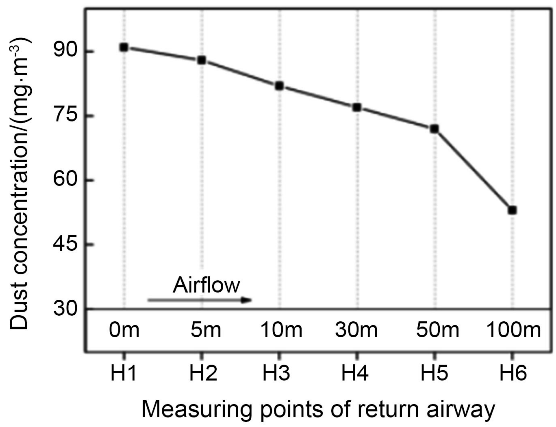

Figure 5. Concentration change of return airway.

obviously (*i.e.*, to 53 mg/m^3 at the position 100 m inside return airway) as the distance increases. The reason for this change is that there is no new dust source in return airway, all dust is produced by coal cutting and advancing, the airflow field in the whole airway is relatively stable after the dust enters from working face, so the dust in large size settles gradually under the action of gravity, while dust in small size moves continuously with the airflow.

4.2. Distribution Law of Particle Size

As shown in **Figure 3**, the actual form of dust is not spherical but irregular and hard to describe. Therefore, equivalent area diameter is used to represent the particle size, that is, the diameter of spherical particle in the same protection area of measured particles. Particle size can be divided into six kinds: 0 - 2 μm, 2 - 5 μm, 5 - 10 μm, 10 - 20 μm, 20 - 100 μm and 100 - 200 μm, and the calculation formulaof quantity differential distribution is:

$$v_i = \frac{N_i}{\sum_{j=1}^{n} N_j} \times 100\% \tag{2}$$

4.2.1. Dust Particle Size Distribution of Working Face

Table 2 shows the quantity differential distribution of dust in different particle sizes within mining face. The dust differential distribution of all measuring points in mining face has similar characteristics. The particle size of most dust is 0 - 100 μm. Among the eleven measuring points, the quantity of respirable dust (<10 μm) exceeds 80%, which indicates that most dust in the air of walking area of hydraulic support is respirable dust. More specifically, the quantity of dust in particle size of 2 - 5 μm at all positions exceeds 50%. Generally speaking, the smaller the particle size, the larger damage to the lungs, which proves that the mining dust of coal cutter cannot be ignored. On the other hand, the overall proportion of dust in particle size of larger than 10 μm is gradually reduced, but dust in particle size of 2 - 5 μm is increased with the distance increases. Therefore, dust concentration can be affected by large particle size and sedimentation, which has been proved by the above analysis.

4.2.2. Dust Particle Size Distribution of Return Airway

Table 3 shows the quantity differential distribution of dust in different particle sizes within return airway, and the dust granularity range of all measuring points remains 0 - 100 μm. As shown in **Table 3**, compared with the mining position, when dust enters the return airway, the t quantity proportion of dust in particle size of 10 - 100 μm is reduced to some extent, but those in particle size of 20 - 100 μm is lower than 1.5%. This result shows that respirable dust can be suspended in airflow for a long time after long-time movement, while non-respirable dust would settle gradually during movement.

Table 2. Quantity differential distribution of dust in different particle sizes within mining face (%).

Measuring points	Granularity range (μm)				
	0 - 2	2 - 5	5 - 10	10 - 20	20 - 100
M_1	5.08	54.2	26.88	11.19	2.65
M_2	7.07	47.44	28.06	13.56	3.86
M_3	8.21	50.29	26.49	10.67	4.34
M_4	7.03	48.57	27.29	12.21	4.9
M_5	5.92	46.69	30.65	12.67	4.06
M_6	6.92	48.05	27.9	13.28	3.85
M_7	6.46	51.16	28.98	10.68	2.72
M_8	5.42	52.06	29.02	11.41	2.08
M_9	7.01	55.66	27.06	8.25	2.02
M_{10}	4.61	53.85	30.51	9.32	1.72
M_{11}	6.44	53.89	29.12	9.48	1.07

Table 3. Quantity differential distribution of dust in different particle sizes within return airway (%).

Measuring points	Granularity range (μm)				
	0 - 2	2 - 5	5 - 10	10 - 20	20 - 100
H_1	6.67	48.58	32.01	11.39	1.35
H_2	6.53	50.91	31.37	10.03	1.16
H_3	5.71	52.53	30.73	9.63	1.4
H_4	7.03	53.58	27.75	10.29	1.35
H_5	6.18	51.37	29.05	12.09	1.3
H_6	9.09	47.89	32.59	9.98	0.44

4.3. Suggestions for Dust Prevention on Site

First, personal dust exposure shall be reduced. Workers shall strengthen personal protective measures and stand in windward direction when controlling coal cutter and the upwind side of moving support during advancing; Second, dust prevention equipment shall be used accurately. So far, the negative pressure suction technology has been applied for dust control, since physical dust control can reduce the dependence on water dust removal and suitable for small range of dust control like hydraulic support. Future scientific researches shall focus on the following aspects: First, to control the dust falling from roof during movement of hydraulic support; Second, to study the effective capture of dust in different particle sizes by fogdrop as well as develop the high-efficiency atomization dust removal equipment based on dust shape.

5. Conclusions

1) When mining the tested working face, dust concentration at the position 6 m from the windward current of coal cutter to 100 m of leeward current are 121 mg/m^3 Max. and 61 mg/m^3 Min.; The dust concentration of return airway is reduced with the distance increases, while the dust concentration at the entrance is 91 mg/m^3.

2) A large amount of dust may fall down from the roof during advancing and increase the dust concentration of walking area of hydraulic support obviously.

3) The dust granularity of mining face and return airway is 0 - 100 μm, while the quantity of respirable dust is higher than 80%, and the larger the particle size, the greater impact on dust concentration.

4) To reduce the dust exposure, mining position shall be located in the leeward direction of advancing or the windward area of coal cutter.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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