IOP Conf. Series: Earth and Environmental Science **100** (2017) 012171 doi:10.1088/1755-1315/100/1/012171

Research of Dust Field Optimization Distribution Based on Parameters Change of Air Duct Outlet in Fully Mechanized Excavation Face of Coal Mine

Xiao-Yan GONG, Zhi-Xin XIA, Yue WU, Jin-Ming MO, Xin-Yi ZHANG

Xi'an University of Science and Technology, Xi'an, Shaanxi 710054, China

E-mail: 932948299@qq.com

Abstract. Aiming at the problem of dust accumulation and pollution risk rising sharply in fully mechanized excavation face, which caused by the unreasonable air duct outlet airflow under the long distance driving, this paper proposes a new idea to optimize the distribution of dust by changing the angle, caliber and the front and rear distance of air duct outlet. Taking the fully mechanized excavation face of Ningtiaota coal mine which located in Shaanxi province as the research object, the numerical simulation scheme of dust field was established, the safety hazard of the distribution of original dust field was simulated and analyzed, the numerical simulation and optimization analysis of the dust distribution by changing the angle, caliber and the front and rear distance of air duct outlet was carried out, and the adjustment scheme of the optimized dust distribution was obtained, which provides a theoretical basis for reducing the probability of dust explosion and the degree of pollution.

1. Introduction

In recent years, the expansion of the fully mechanized excavation face and the long distance driving make the dust pollution increase greatly, which lead to the high risk occurrence rate of environment pollution and safety hazards. Extensive "air volume" control mode [1] ventilation efficiency is low, while the angle, caliber and the front and rear distance of air duct outlet cannot be changed. Along with the advance of excavation, the distance between the outlet and the heading face is different, and the airflow velocity of the jet reaches heading face is different [2-3], all of these conditions result in the unreasonable distribution of dust. When the distance from the heading face is too long, the airflow velocity at the end of the jet often cannot effectively dilute the dust concentration. Therefore the condition of dust accumulation is serious. At present, based on the theory of attached jetting, the domestic and foreign scholars have made a lot of research on the influence of the installation position and the diameter of the air duct to the dust distribution in the excavation face, and obtained reasonable parameters of air duct diameter, outlet airflow velocity and the distance from the heading face can greatly improve the distribution law of dust [4-7]. The author collected a large number of numerical simulation and found that the direction of the outlet airflow also has a great impact on the dust distribution law. Therefore, the numerical simulation method is used to study the dust distribution law under the comprehensive change of the outlet angle, caliber(velocity) and the front and rear distance, which provides the theoretical basis for the development of the outlet control device, and finally achieves the purpose of optimizing the dust distribution and improving the working environment of the fully mechanized excavation face.

2. Establishment of Simulation Scheme

2.1. Establishment of numerical simulation scheme on dust field

1) Theoretical analysis

The mathematical model of dust particle movement was established by using Euler-Lagrangian method, and the trajectories of particles in continuous flow field were investigated. The airflow field of forced ventilation in heading face is a confined wall -attached jet flow limited by space [8], and positions of the heading face of curvature larger, therefore, the continuous phase flow field is calculated by using Realizable k-ε turbulence model. The integral force differential equation is used to solve the orbit of the discrete phase particles, due to the process of the visual quality of force, lift and thermal resistance relative to the magnitude of gravity and drag force magnitude is small, negligible, therefore, the equilibrium equations of particle force are established as (1) and (2) [9].

$$\frac{du_p}{dt} = F_D\left(u - u_p\right) + \frac{g_x\left(\rho_p - \rho\right)}{\rho_p} \tag{1}$$

$$F_D = 0.75\frac{C_D\rho\left|\mu_p - \mu\right|}{\rho_p d_p} \tag{2}$$

Where $F_D(u-u_p)$ is the mass per unit mass drag force, N / kg; C_D is the drag coefficient; u is the fluid phase airflow velocity, m / s; u_p is the particle velocity, m / s; μ is the fluid viscosity, m^2 / s; ρ is the fluid density, kg / m^3; ρ_p is the particle density, kg / m^3; d_p is the particle diameter, m.

2) Finite element model

According to the actual situation of the S1200-III glue roadway in the coal mine, the geometrical model of the working face is simplified. The section is rectangular with a width of 6.25 m and a height of 3.75 m, the calculation area is 40m in length, the diameter of the air duct is 1m. The heading machine is simplified as a cuboid of 9.2 m (length) × 2.9 m (width) × 1.8 m (high). The computational domain is divided by a tetrahedral mesh, the total number of meshes is 910880.

The geometric model is introduced into FLUENT for boundary condition setting, the ventilation is $381m^3$/min, the hydraulic diameter is 1m and the turbulence intensity is 3.06%, the dust source parameter is set by DPM model, as shown in Table 1.

Table 1. The main parameter setting table of dust source

Dust source	Parameter setting	Dust source	Parameter setting
Injection type	Surface	Max.diameter (m)	2e-04
Mid.diameter (m)	3.25e-05	Min.diameter (m)	5e-07
Diameter distribution	Rosin-Rammler	Spread parameter	1.42
Turbulent dispersion	Discrete Random Walk Model	Total flow rate (kg • s^{-1})	0.016

2.2. Verification to the numerical simulation scheme

According to the above numerical simulation scheme, the dust concentration distribution is numerically simulated and the underground dust concentration test is carried out at the corresponding position. When the outlet of the air duct is 8m from the heading face, the simulated results and the measured results of the dust concentration along the distribution on air return side are shown in Figure 1. The distance of dust measurement points from the heading face is 10m, 15m, 20m, 25m, 30m, 35m, 40m respectively.

IOP Conf. Series: Earth and Environmental Science **100** (2017) 012171 doi:10.1088/1755-1315/100/1/012171

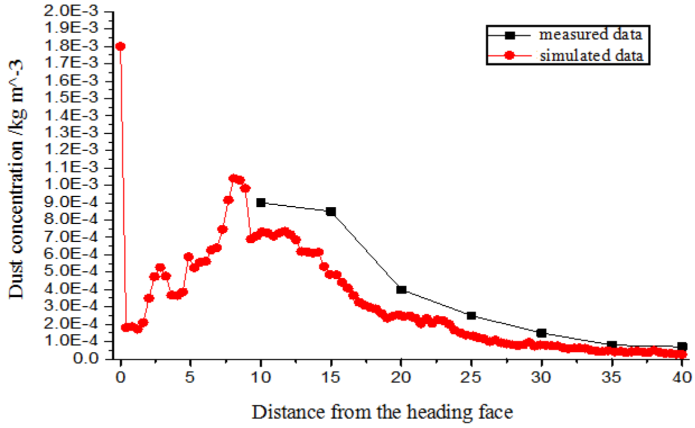


Figure 1. Comparison of dust concentration on air return side.

It can be observed from Figure 1 that the simulation results are basically the same as the measured results, the numerical simulation data is slightly lower than the measured data due to the influence of environment, personnel, instrument and other factors, and the feasibility of the numerical simulation scheme is verified.

3. Analysis on Distribution Law and Existing Problems of Original Dust Field

According to the actual work situation, when the distance between the outlet and the heading face is 5m, 6m, 7m, 8m, 9m, 10m, the dust distribution was simulated and analyzed. The distribution law and the existing problems were obtained by the analysis of the dust concentration distribution of the respiratory zone height section (y=1.5m section). The dust concentration distribution of the respiratory zone height section is show in Figure 2.

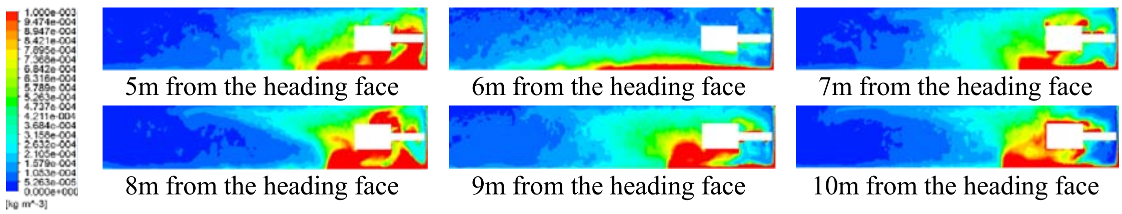


Figure 2. The dust concentration distribution of different distances between the outlet and the heading face.

As can be seen from Figure 2:

(1) By the impact of the heading machine, when the airflow jet to the heading face, part of the airflow along the return side of the movement, part of the airflow to change the direction of movement to the air duct side, eddy current is appeared in front of the heading machine, dust accumulation, and resulting in a higher concentration of dust near the heading machine location, consistent with the conclusion of Qin Yueping [10] and others;

(2) When the outlet is 6-7m from the heading face, the dust concentration as a whole is relatively low; When the outlet is 5m from the heading face, the airflow velocity is too large, resulting in the dust on the air return side to rise again, dust concentration is high; When the outlet is 8-10m from the heading face, the airflow velocity is too small, which leads to the insufficient effective range of the airflow, the dust is difficult to discharge, and the dust concentration of the roadway is higher than the outlet 6-7m from the heading face.

4. Simulation and Optimization of Dust Distribution under the Change of Air Duct Outlet Parameters

4.1. Design of outlet adjustment scheme

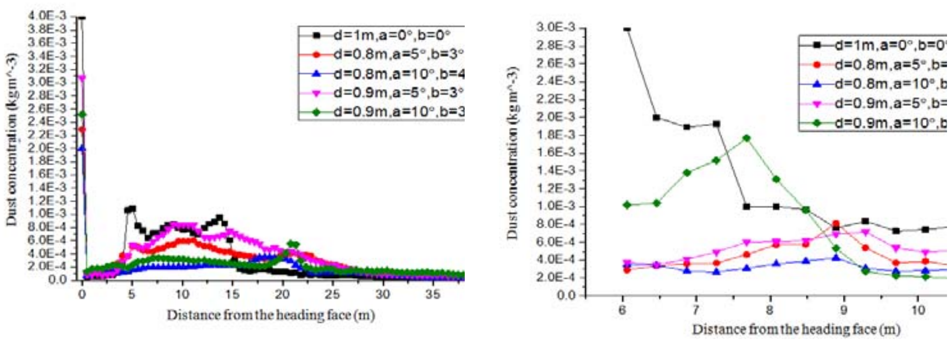
According to the above simulation and optimization of the original dust field, when the distance between the air duct outlet and the heading face is 6-7m, the airflow velocity is reasonable, so do not consider adjusting the outlet caliber; when the distance between the outlet and the heading face is 5m, the airflow velocity is too large, enlarging the caliber to decrease the airflow velocity; when the distance between the outlet and the heading face is 8-10m, the airflow velocity is too small, shrinking the caliber to increase airflow velocity, numerical simulation determine the outlet caliber adjustment range of 0.8-1.2m. At the same time, by adjusting the outlet angle to reduce the dust accumulation, the dust distribution of different outlet angle is simulated, and finally determine the upward deflection angle range is 5°-20°, the right deflection angle range is 5°-20°. The adjustment scheme to optimize the dust distribution at different distance from the heading face is shown in Table 2.

Table 2. Adjustment scheme of the air duct outlet

	5m from the heading face	6m from the heading face	7m from the heading face	8m from the heading face	9m from the heading face	10m from the heading face
Scheme 1	Caliber1.2m,right deflection 15°,up deflection 4°	Caliber1m,right deflection 15°,up deflection 4°	Caliber1m,right deflection 15°,up deflection 4°	Caliber0.9m,right deflection 20°,up deflection 2°	Caliber0.8m,right deflection 5°,up deflection 4°	Caliber0.8m,right deflection 5°,up deflection 3°
Scheme 2	Caliber1.2m,right deflection 20°,up deflection 4°	Caliber1m,right deflection 15°,up deflection 5°	Caliber1m,right deflection 15°,up deflection 5°	Caliber0.8m,right deflection 5°,up deflection 4°	Caliber0.8m,right deflection 15°,up deflection 2°	Caliber0.8m,right deflection 10°,up deflection 4°
Scheme 3	Caliber1.1m,right deflection 15°,up deflection 6°	Caliber1m,right deflection 20°,up deflection 2°	Caliber1m,right deflection 20°,up deflection 4°	Caliber0.8m,right deflection 15°,up deflection 2°	Caliber0.9m,right deflection 5°,up deflection 4°	Caliber0.9m,right deflection 5°,up deflection 3°
Scheme 4	Caliber1.1m,right deflection 20°,up deflection 6°	Caliber1m,right deflection 20°,up deflection 4°	Caliber1m,right deflection 20°,up deflection 5°	Caliber0.9m,right deflection 5°,up deflection 4°	Caliber0.9m,right deflection 10°,up deflection 3°	Caliber0.9m,right deflection 10°,up deflection 3°

4.2. Optimization analysis of dust distribution under comprehensive change of outlet parameters

The numerical simulation of dust concentration distribution in fully mechanized excavation face under different adjustment schemes was carried out. When the outlet is 10m from the heading face, the dust concentration distribution at the air return side (x=5.2m, y=1.6m) and the driver is shown in Figure 3 (d is the outlet caliber, a is the right deflection angle of the outlet, and b is the up deflection angle of the outlet).



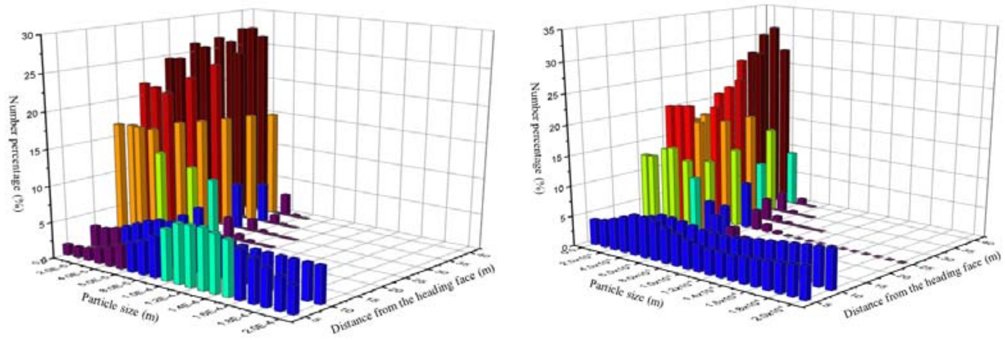
(a) The air return side (b) The driver

Figure 3. Dust concentration distribution of the air return side and the driver under different adjustment schemes.

Comparison of the dust concentration along the distribution of the air return side and the driver of original dust field and four kinds of adjustment scheme, get the following conclusions:

(1) When the outlet caliber is 0.8m, right deflection angle is 10°, up deflection angle is 4°, the dust concentration at the air return side and the driver is the lowest, and the dust distribution is optimized. This is due to the reduction of the outlet caliber increased the airflow velocity, which is beneficial to the dust discharge; Deflecting the angle changed the direction of the outlet airflow, improved the eddy current distribution and reduced dust accumulation.

(2) The dust concentration of the original dust field is up to 1.1×10^{-3} kg/m^3, the dust concentration of the driver reaches 3×10^{-3} kg/m^3. After optimization, the maximum dust concentration on the air return side is about 6×10^{-4} kg/m^3, which is 45% lower than that when it is not optimized; the maximum dust concentration at the driver is about 4×10^{-4} kg/m^3, which is 86% lower than that when it is not optimized.



(a) Before optimization (b) After optimization

Figure 4. Comparison of dust particle size distribution before and after optimization

Figure 4 shows the comparison of particle size distribution before and after optimization. Before the optimization, the number of 100μm-150μm particles in the 10m from the heading face is relatively large. More than 10m from the heading face, the number of less than 50μm particles is relatively large, and the proportion of particle size less than 10μm of the body can be inhaled larger; After the optimization, the number of 100μm-150μm particles in the 10m from the heading is reduced, which is favorable for the settlement of the coarse particle size, the particle size of the dust that less than 50μm is still relatively large after 10m from the heading face, but the percentage is significantly lower than that before the optimization, dust particles of the body can be inhaled are also significantly reduced.

Based on the same method, when the distance between the air duct outlet and the heading face is 5m, 6m, 7m, 8m, 9m, the dust distribution was simulated and optimized in fully mechanized excavation face, and the optimal adjustment scheme of the air duct outlet parameters was obtained, such as Table 3 Show.

Table 3. Optimal adjustment scheme of the air duct outlet parameters

The distance from the heading face	Optimal adjustment scheme	Optimization effect on air return side	Optimization effect at the driver
5m	Caliber 1.1m,right deflection 15°,up deflection 6°	Dust concentration reduced by 55%	Dust concentration reduced by 83%
6m	Caliber 1m,right deflection 20°,up deflection 4°	Dust concentration reduced by 40%	Dust concentration reduced by 82%
7m	Caliber 1m,right deflection 15°,up deflection 5°	Dust concentration reduced by 40%	Dust concentration reduced by 82%
8m	Caliber 0.9m,right deflection 20°,up deflection 2°	Dust concentration reduced by 35%	Dust concentration reduced by 82%
9m	Caliber 0.8m,right deflection 15°,up deflection 2°	Dust concentration reduced by 38%	Dust concentration reduced by 80%
10m	Caliber 0.8m,right deflection 10°,up deflection 4°	Dust concentration reduced by 45%	Dust concentration reduced by 86%

5. Conclusions

In this paper, the fully mechanized excavation face of Ningtiaota coal mine was selected as the research object, a numerical simulation scheme of dust field was established. Aiming at the unreasonable existence in original dust field, the adjustment scheme of air duct outlet for optimizing the dust distribution was designed and the numerical simulation and optimization analysis were carried out. The main results are shown as followings.

(1) The simulation results of the original dust distribution showed that the dust concentration of the air return side and near the heading machine is obviously higher than that of other areas, thus it is the focus of the dust distribution optimization . At the same time, the distance between the air duct outlet and the heading face is an important parameter affecting the distribution law of dust, when the air duct outlet is close to the heading face, the velocity of air duct outlet is so large that the dust near the air return side will rise again; when it is far from the heading face, the effects of dust-removal is not good because of the lack of wind speed.

(2) The angle and caliber of the air duct outlet have a great influence on the dust distribution, and enlarge (shrink) the outlet caliber can decrease (increase) the outlet velocity; the outlet angle has a significant effect on the eddy current distribution. Only comprehensive adjustment of the angle and caliber of the air duct outlet can optimize the dust distribution.

(3) The dust distributions under the different adjustment schemes and different distance between the air outlet and the heading face (5m, 6m, 7m, 8m, 9m, 10m) were simulated and analyzed, and the adjustment scheme of optimization to dust distribution was obtained. The dust concentration near the air return side was reduced by more than 35% , and the dust concentration near the driver was decreased by 75% before optimization. The optimization method gets verified and confirmed by the comparison of dust particle size in roadway during improvement.

Acknowledgment

This dissertation was supported by Shaanxi Science Research and Development Program Project (2017GY-170).

Reference

[1] Niu Chao, Shi Longqing, Xiao Lele, Zhai Peihe, Wu Shulei, Zhao Yanhong., 2015, “Study on Accidents Classification of Coal Mine from 2001 to 2013”. *Safety in Coal Mines, 46*(3).

[2] Zan Jun, Liu Zude, Zhao Yunsheng., 2010. “Influence of Characteristic Parameters of Restricted Attachment Jet on Flow Field in Blind Drift”. *China Safety Science Journal, 20*(03), 24-28.

[3] Wang Haiqiao, Chen Shiqiang, Li Yiqun., 2015, “Theoretical research and numerical calculation of effective range for restrained wall－attached jet flow in heading face”. *Journal of Safety Science and Technology, 11*(11), 41-45.

[4] Hu Fangkun, Lu Xinxiao, Wang Deming, Wang Shuailing., 2012, “Analysis on dust migration on heading face based on CFD numerical simulation”. *China Coal, 38*(6), 94-98.

[5] Fan Tao, Bai Ruonan, Qiu Han, Zhang Qi., 2016, “Numerical Simulation of Diffusion Laws for Vortex Dust at fully mechanized Excavating Face Based on Time Scale”. *Safety in Coal Mines, 47*(7).

[6] Wang Kai, Guo Hongguang, Wang Fei, Liu Ruzheng, Cao Wanpu., 2015, “Dust Movement Rule in Ventilators with Different Diameters in Full-mechanized Driving Face”. *Coal Mining Technology* (5), 80-83.

[7] Li Yucheng, Li Zhi, Gao Lun., 2014, “Arrangement of air duct in tunneling working face based on the distribution laws of airflow and dust”. *Journal of China Coal Society, 39*(S1), 130-135.

[8] Wang Haiqiao., 1999, “Study on jet ventilation flow field in heading face”. *Journal of China Coal Society* (5), 498-501.

[9] Jiang Zhongan, Chen Jushi, Wang Jingjing, Niu Wei, Gao Yang., 2012, "Numerical simulation of dust movement regularities in belt conveyer roadway". *Journal of China Coal Society, 37*(4), 659-663.
[10] Qin Yueping, Jiang Zhenjun, Zhang Miaomiao, Liu Yanqing., 2014, "Comparison of simulation on dust migration regularity in fully mechanized workface". *Journal of Liaoning Technical University（Natural Science）*(03), 289-293.