Prediction and optimization of air velocity and gas concentration under control of air flow at outlet of fully mechanized heading

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Abstract. Aiming at the problem that the traditional ventilation method can not control the wind speed and reduce the gas concentration, and cause the wind speed and gas concentration to exceed the limit, the new method of dynamic regulation of wind turbine outlet air flow to optimize the wind speed and gas concentration is studied. According to the actual problems, the influences of the air outlet parameters on wind speed and gas are simulated. The correlation mechanism between the air outlet and the wind speed and gas concentration and the regression prediction model are established. In the NingTiao Mine of Shaanxi Coal Group, the underground installation test and verification were carried out by using the self-developed control device, and the optimal wind field control plan for the Ningtiao Mine was determined. The results showed that the wind speed was too large or too small, and the parameters such as the diameter of the air outlet were adopted. The adjustment can control the wind speed to reach the 0.25m/s to 4m/s range required by the regulations, and the gas concentration is significantly reduced.

1 Introduction

At present, high-intensity excavation of fully mechanized excavation, low efficiency of traditional ventilation, and potential pollution hazards^[1]. Since the diameter, direction angle and front-to-back distance of the air duct cannot be dynamically changed at any time^[2,3], the wind speed can not meet the requirements of the regulations, easily cause gas and dust accumulation, increase the risk of explosion^[4], and the wind speed is too large, which will also cause ventilation comfort and secondary dusting problems. At the same time, the angle of the air outlet of the duct cannot be changed. Even if the air volume is increased, the gas accumulated in the dead zone cannot be effectively diluted^[5]. The research team proposed to establish a new method for the dynamic regulation of the air outlet to optimize the distribution of wind, gas and dust, and developed a new type of air duct air outlet intelligent control device, installed at the end of the air duct^[6]. According to actual needs, the caliber, direction angle and front-rear distance control are used to optimize the distribution of wind speed, gas and dust migration. Numerical simulation and downhole measurement^[7] were used to analyze the influence of wind flow regulation on wind speed and gas concentration distribution, and establish the correlation mechanism between wind regulation parameters and wind speed and gas concentration. The regression analysis method was used to establish wind speed and gas under control. The concentration prediction model, and the underground

installation test and application in the coal-bearing coal mine in NingTiao Mine of Shaanxi, provides a new way for efficient, safe and green ventilation of the comprehensive face.

2 Simulation analysis of original wind current and gas field distribution

2.1 Establishment of finite element model for wind speed and gas field

The NingTiao Mine uses press-in ventilation. The roadway is 20m long, 6.2m wide and 3.75m high. The diameter of the air duct is 1m. The distance from the axis of the air duct to the bottom and side walls of the roadway is 3.05m and 0.7m. The model is shown in Figure 1. X is the distance from the sidewall of the air cylinder, Y is the height, and Z is the distance from the tunneling end face.

Figure 1 Finite element model of the comprehensive face

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2.2 Analysis of hidden dangers of original wind speed and gas field distribution

The numerical simulation analysis of the wind flow field and gas field at the closest distance from the end of the

outlet to the end is 5m and the maximum distance is 10m. The variation law of the wind speed at the driver's position and the return air is obtained. As shown in Figure 3, the gas concentration distribution of the roadway is shown in Figure 4, 5.

Figure 2 Wind speed variation law at different distances from the end

It can be seen from Figure 3(a) that when the air outlet of the air duct is 5m away from the end, the wind speed on the return air side is large, some areas exceed the upper limit of the regulation by 4m/s, and after 10m, the wind speed decreases by 0.25~0.55m/s. It can be seen from Fig. 3(b) that when the outlet is 10m away from the

end, the wind speed of the driver is lower in the range of 5m, and the wind speed on the return air side and the driver's wind speed is between 0.15~0.3m/s after 5m, the local wind speed Below the lower limit of the procedure is 0.25m/s.

Figure 3 Distribution of gas concentration in the roadway section

It can be seen from Figure 3 that when the outlet is 5m away from the end, the gas is mainly concentrated on the return air side, and the gas concentration of the roadway section Z=0.5m is 0.15%, the dilution effect of the gas on the return air side is not good, and the gas concentration is as high as 0.18%. There is a safety hazard of gas accumulation when the outlet is too close or too far from the end.

3 Analysis of influence of wind flow regulation on wind speed and gas field

3.1 Wind speed and gas field simulation experiment program

Table 1 Wind flow and gas simulation experiment scheme under wind farm regulation

	The outlet is 5m away from the end	The outlet is 10m away from the end
1	Caliber 1.1m 3°up 15°right	Caliber 0.7m 3°up 15°right
2	Caliber 1.1m 6°up 5°right	Caliber 0.7m 6°up 5°right
3	Caliber 1.2m 3°up 15°right	Caliber 0.9m 3°up 15°right
4	Caliber 1.2m 6°up 5°right	Caliber 0.9m 6°up 5°right

3.2 Influence of wind flow regulation on wind speed and gas concentration

Figure 4 The variation of wind speed under the control of parameters at 5 m from the end

Figure 5 Distribution of gas concentration under the control of parameters at 5 m from the end

Through simulation analysis, the wind speed and gas concentration distribution can be known: when the outlet is 5m away from the end, the wind speed is large, and some areas have exceeded the upper limit of the regulation. The diameter of the outlet is increased, the wind speed can be reduced, the wind flow range can be increased, and the gas dilution effect is higher. When the air outlet is 10m away from the end, the wind speed is too low, and some areas are lower than the lower limit of the regulation. By reducing the diameter, the effective range is increased, and the wind speed on the return air side becomes larger, and a large amount of gas is taken out from the return air side. The angle of the air outlet can effectively dilute the gas concentration on the air cylinder side and the return air side, and the air outlet angle is rightly offset, which can effectively dilute the gas concentration on the return air side.

4 Wind speed and gas field prediction model under wind field regulation

4.1 Wind speed prediction model establishment

Multivariate linear regression analysis was used to establish high wind speed ($X=5.2m$, $Y=1.6m$, $Z=5m$) and low wind speed ($X=2.3m$, $Y=1.85m$) at the driver's position and at the end of the wind outlet at 5m and 10m. ($Z=9m$) Two wind speed prediction models. Let the wind speed be y , the distance from the air outlet of the air duct to the head end is x_1 , the diameter of the air outlet is x_2 , the vertical deflection angle is x_3 , and the horizontal deflection angle is x_4 .

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \varepsilon \tag{4-1}$$

Table 2 Regression model								
Multiple R	0.9155	R ²	0.8382	regression Residual	df	SS	MS	Significant F
Adjusted R	0.8001	Standard	0.0616		4	0.3346	0.0836	1.5319E-06
Observations	22				17	0.0645	0.0037	

Table 3 Regression coefficients

	coefficient	Standard error	t Stat	P-value
Intercept	1.2062	0.1020	11.8203	0.0000
X ₁	-0.0396	0.0073	-5.4110	0.0000
X ₂	-0.7025	0.1028	-6.8364	0.0000
X ₃	0.0033	0.0120	0.2742	0.7872
X ₄	-0.0015	0.0033	-0.4703	0.6441

It can be seen from Tables 3 that the judgment coefficient R^2 of the model is 0.838, $F=22.023$, and the standard error is 0.062. Under the significant level of 0.05, the significance F is much less than 0.05, and the linear relationship between the dependent variable and the independent variable is close Significant, the optimal regression equation is: $\hat{y}=1.2018-0.0393x_1-0.6985x_2$ (4-2)

It can be known from equation 4-2 that the main influencing factors of wind speed at the driver's position are the distance from the end of the air outlet and the size of the aperture. The size of the aperture has the greatest influence on the wind speed at this position. The wind speed prediction model at 5m and 10m from the end of the air outlet is established at the same position as the driver. The wind speed is y , the diameter is x_1 , the vertical deflection angle is x_2 , and the horizontal deflection angle is x_3 . The regression equation is:

$$\hat{y}=9.5374-4.4211x_1-0.2347x_3 \quad (4-3)$$

$$\hat{y}=0.3225-0.2302x_1+0.0068x_3 \quad (4-4)$$

Figure 6 downhole experimental test plan

4.2 Establishment of gas concentration prediction model

Similarly, the gas concentration in the dead space of the return air side is y , the distance from the end of the air outlet is x_1 , the diameter is x_2 , the horizontal deflection angle is x_3 , and the vertical deflection angle is x_4 . The regression equation of the gas concentration in the dead zone is:

$$\hat{y}=0.1281-0.0053x_1-0.0028x_4 \quad (4-5)$$

It can be seen from Equation 4-6 that the main influencing factors of the gas concentration in the dead zone are the distance from the end of the outlet and the horizontal deflection angle.

4.3 Downhole measurement and model verification

The experimental test scheme is shown in Figure 6. Figure 7 is a comparative analysis of the wind speed predicted value and the measured value when the wind outlet is 10m away from the end. The distribution law is similar, and the relative error range is 0.909~8.568%. The mine is a low gas mine at the end of the air outlet. When the head is 5m and the horizontal deflection angle is 5° , the gas concentration at the upper corner of the return air side is more obvious. The measured value is 0.08%, the predicted value is 0.087%, and the error is 8.75%.

Figure 7 Comparison of measured and predicted values of wind speed

5 Optimization Analysis of Wind Field in NingTiao Mine

5.1 Wind speed regulation effect analysis

Table 4 Wind speed regulation effect when the outlet is 5m and 10m away from the end

Air outlet parameter control value	position	Before regulation m/s	Compliance	After regulation m/s	Compliance
5m from the end, Caliber 1.2m, horizontal and vertical deflection angles of 15°, 0°	Driver location	1.70	yes	0.71	yes
	High wind speed	4.20	no	1.16	yes
10m from the end, Caliber 0.7m, horizontal and vertical deflection angles of 15°, 0°	Driver location	0.25	yes	1.32	yes
	low wind speed	0.15	no	0.27	yes

As shown in Table 5.1 when the outlet is 5m away from the end, the wind speed of the driver is reduced from 1.7m/s to 0.71m/s, and the high wind speed is 4.2m/s, which is 4m/s above the upper limit of the regulation. At 1.16m/s, when the outlet is 10 m away from the end, the wind speed of the driver rises from

0.25m/s to 1.32m/s, and the low wind speed is lower than the lower limit of 0.25m/s from 0.15m/s, which rises to 0.27. m/s, to meet the wind speed regulations.

5.2 Analysis of gas concentration control effect

Table 5 Gas control effect

Air outlet parameter control value	position	Concentration before regulation (%)	Regulated concentration (%)	Gas concentration drop percentage
5m from the end, horizontal and deflection angles of 15°	dead space	0.071	0.053	25%
10m from the end, horizontal and deflection angles of 15°	dead space	0.079	0.033	58%

As shown in Table 5.2: the gas concentration in the dead space of the return air side decreased from 0.071% to 0.053% and the gas concentration decreased by 25% when it was 5 m away from the head end. At 10 m from the head end of the excavation, the gas concentration in the dead zone of the return air side decreased from 0.079% to 0.033%, and the gas concentration decreased by 58%.

concentration in the dead space of the return air side decreased from 0.079% to 0.033%, a decrease of 58%.

6 Conclusion

(1) The relative error range of the established wind speed prediction model is 0.909 ~ 8.568%, The determination coefficient R^2 of the gas concentration prediction model is 0.8374, the standard error is 0.0077, and the linear relationship is significant at the significant level of 0.05.

(2) The optimal control scheme when the air outlet is 5m away from the end: the outlet diameter is 1.2m, the horizontal deflection angle is 15°, and the wind speed of the driver is reduced from 1.7m/s to 0.71m/s, and the comfort is improved. The high wind speed decreased from 4.2m/s to 1.16m/s, reaching the requirement of the wind speed. The gas concentration in the dead space of the return air side decreased from 0.071% to 0.053%, a decrease of 25%.

(3) The optimal control scheme when the air outlet is 10m away from the end: the air outlet diameter is 0.7m, the horizontal deflection angle is 15°, the driver's wind speed is increased from 0.25m/s to 1.32m/s, and the low wind speed is increased from 0.15m/s to 0.27m/s, reaching the requirement of the wind speed, and the gas

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References

1. NIU Chao, SHI Longqing, XIAO Lele, ZHAI Peihe, WU Shulei, ZHAO Yanhong. Study on Accidents Classification of Coal Mine from 2001 to 2013[J]. Safety in Coal Mines, 2015, 46(03): 208-211.
2. GONG Xiaoyan, YAN Donghui, XUE He. Predictive model of excavation ventilation gas concentration in high gas coal mine[J]. Journal of Xi'an University of Science and Technology, 2012, 32(03): 275-279+294.
3. WANG Haiqiao, SHI Shiliang, LIU Ronghua, LIU Heqing. Numerical simulation study on ventilation flow field of wall-attached jet in heading face[J]. Journal of China Coal Society, 2004(04): 425-428.
4. YANG Chunli, YANG Chunyan, LIU Qi. Research status and development direction of gas explosion[J]. Journal of Safety Science and Technology, 2012, 8(03): 64-69.
5. GONG Xiaoyan, QIN Shaoni, ZHANG Yongqiang, MO Jinming, ZHANG Xinyi, XIA Zhixin, XUE He. Study on Optimization of Air Duct Outlet

Parameters of Wind Flow Field in Fully Mechanized Excavation Face of Coal Mine[J].Safety in Coal Mines,2017,48(12):168-171+175.

6. Gong X Y, Hou Y J, Cui J, et al. Study on intelligent control device for airflow of air duct outlet in fully mechanized heading face[J]. Coal Technology, 2018, 46(12):8-14.
7. Gong X Y, Zhang X Y, Wu Y, et al. Study on Gas Field Optimization Distribution with Parameters Adjustment of the Air Duct Outlet for Mechanized Heading Face in Coal Mine[C]// 2017:012174.