Study on Safe Mining Speed of Coal Face to Avoid Goaf Fire

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Abstract. In view of the coupling problem of gas and coal spontaneous combustion in goaf of 2302 coal mining face in Weijiadi Coal Mine in Jingyuan Coal Area, if the control is not in place, it may cause serious accidents such as gas explosion. By means of fluent simulation, the spontaneous combustion period and oxygen distribution of residual coal in goaf are obtained, and the minimum advancing speed of coal mining face to prevent spontaneous combustion in goaf is calculated to be 1.43m/d. By implementing fire prevention measures such as blocking air leakage in upper and lower corners, grouting and nitrogen injection in goaf, the oxygen concentration in goaf is controlled within 11%, and the spontaneous combustion zone of oxidation is fast. Transferring to asphyxiation zone and preventing the residual coal from firing in goaf are of great significance for ensuring the safety of mine production.

1. Introduction
Weijiadi Coal Mine is a dual-energy mine in Gansu Province which produces both coal and coalbed methane. The mine is located in Dabaowei Coalfield of Jingyuan Mining Area. It belongs to the Middle-Lower Jurassic. The main coal seam is NO.1 or NO.3 coal seams. The gas content in the coal seam is 9.37-10.18m³/t. The gas content is high and easy to spontaneously ignite. The ignition period of the coal seam is 4-6 months, and the shortest ignition period is 21 days. Since 1992, 45 fire accidents have occurred. The fire hazard in goaf is serious. Since 1997, the technology of fully mechanized top coal caving has been popularized and implemented in coal mines, and the production capacity has been gradually increased. However, the loss of floating coal in goaf is high, and the risk of spontaneous combustion is high. Because of the desorption of coal gas in goaf, the gas accumulation in goaf is large. The coupling of gas and spontaneous combustion of coal is very easy to cause gas explosion accidents. For example, March 29, 2013, Babao Coal Industry Company in Jilin Province, occurred a particularly serious gas explosion accident, which resulted in 36 deaths, 12 injuries and a direct economic loss of 47089 million yuan. The direct cause of the accident was the spontaneous combustion of coal in goaf, which posed a great threat to the safety of mine production.

Many scholars have done a lot of research on the fire prevention and extinguishing technology in goaf and the influence of the advancing speed of coal face on the fire prevention in goaf [1-5], and have achieved fruitful results. The parameters of coal spontaneous combustion dangerous zone and period of fire danger have been obtained, which provides a theoretical basis for the prediction and prediction of coal spontaneous combustion. Because of the different geological conditions, mining methods and air leakage in goaf, the parameters of coal spontaneous combustion are also different. Therefore, this paper
studies the distribution characteristics of gas flow field, concentration and temperature field in 2302 goaf of Weijiadi Coal Mine, calculates the limit advance speed of coal face to prevent fire, and provides scientific guidance for coal mine fire prevention.

2. Overview of working face
2302 working face is the first mining face of the NO.3 coal seam in the West Wing of the second mining area, 2102 fully mechanized top coal caving face in the upper part of the NO.1 coal seam that has been mined, F3 fault in the northwest, No. 0 protective pillar in the eastern part of the second mining area in the west, 2104 fully mechanized face in the upper part of the southwest, 2104 fully mechanized coal seam in the NO.1 coal seam that has been mined, original NO.3 coal seams in the South and northeast, and 0.8m mining boundary in the western part of the NO.3 coal seam. The mining strike length is 932 m, the inclined length is 130 m, the average recoverable thickness is 4.1 m, the recoverable reserves are $6.12 \times 10^4 \text{t}$, the gas content of coal seam is $9.37 \text{m}^3/\text{t}$, the spontaneous combustion of coal seam is 4-6 months, and the shortest combustion period is 21 days.

3. Calculation of Minimum Propulsion Degree of Working Face
According to the coal sample ignition analysis of Xi'an University of Science and Technology about 1308 fully mechanized caving face sampling in Weijiadi Coal Mine, through experimental analysis and numerical simulation research, as well as on-site monitoring practice, the minimum advance speed to ensure the safety of fire prevention and extinguishing in goaf of coal mining face is finally obtained.

3.1. Estimation of Limit Propulsion Velocity of Fully Mechanized Caving Face
Using Fluent numerical simulation software, the seepage field and concentration field of active sink under steady-state conditions are obtained by numerical calculation, as shown in Fig. 1 and Fig. 2. As can be seen from the figure, the oxygen concentration in goaf is relatively high on the inlet side and relatively low on the return side. The oxygen gas integral of the air intake side of goaf reaches 18% at 21m, 16.5% at 43m, 14% at 62m and 5% at 116m.

![Fig.1 Isogram of Oxygen concentration distribution in Goaf](image-url)
From the isogram of seepage velocity, it can be seen that the seepage velocity is higher in the two goafs and lower in the middle of the goaf. It can be seen from the static pressure contour map and vector map that the seepage direction is basically from the inside of the goaf on the side of intake air and from the direction of the working face on the side of return air. The seepage velocity of two passages in goaf reaches $3.0 \times 10^{-3}$ m/s at about 25 m away from working face, $1.6 \times 10^{-3}$ m/s at 30 m away from working face, $1 \times 10^{-3}$ m/s at 70 m away from working face and $2 \times 10^{-4}$ m/s at 95 m.

In the same coordinate point of (x, y) in goaf, the maximum oxygen concentration is $C_{\text{min}}$, and the minimum air leakage intensity is $Q_{\text{max}}$ plotted on the same plane map. That is to say, the distribution
of "three zones" in goaf is obtained. From Fig. 3., it can be seen that the oxidation heating zone of fully mechanized top coal caving face mainly distributes in the range of 0-5m from the intake side to the coal pillar, 28-116m from the working face, and 0-5m from the return side to the coal pillar and 28-65m from the working face. The maximum oxidation heating bandwidth is 116-28=88m.

From Figure 1 and Figure 2, it can be seen that the maximum distance from heat dissipation zone to suffocation zone in goaf (i.e. the maximum width of oxidation heating zone) is $L_{\text{max}}=88m$. According to the oxygen concentration curve, the average oxygen concentration in the range from the intake side to the asphyxiation zone is $\overline{C_{o_2}}=15\%$ (volume fraction), and the ratio coefficient of the experimental oxygen concentration to the actual oxygen concentration is $\kappa=\frac{C_{o_2}^0}{\overline{C_{o_2}}} = \frac{21\%}{15\%} \approx1.4$. The oxygen concentration of fresh air flow was 21%. The minimum spontaneous combustion period of floating coal in goaf is equal to 44 days when the average temperature of goaf is 25$^\circ $C. It can be seen that the maximum propulsive speed of working face where spontaneous combustion may occur in goaf may be as follows:

$$v_{\text{min}} = \frac{L_{\text{max}}}{\tau_{\text{min}} \cdot \kappa} = \frac{88}{44 \times 1.4} \approx1.43\text{m/d}$$

Therefore, when the advancing speed of the working face is greater than 1.43m/d, there is usually no spontaneous combustion danger in the goaf; when the advancing speed of the working face is less than 1.43m/d, the goaf will have spontaneous combustion danger.

3.2. Determining the Limit Propulsion Speed of 2302 Fully Mechanized Caving Face under the Conditions of Implementing Fire Prevention and Extinguishing Measures

The limit propulsive velocity formula of working face where spontaneous combustion may occur in goaf is as follows:

$$v_{\text{min}} = \frac{L_{\text{max}}}{\tau_{\text{min}} \cdot \kappa}$$

$L_{\text{max}}$ — Maximum oxidation heating bandwidth

$\tau_{\text{min}}$ — Minimum firing period of floating coal in Goaf

$\kappa$ — Proportional Coefficient of Similarity between Experimental Oxygen Concentration and Actual Oxygen Concentration

The maximum oxidation temperature rise bandwidth of goaf is certain, the shortest ignition period of floated coal in goaf is 44 days, which is certain, and only change is $\kappa$. Therefore, we can only consider the measures to reduce the actual oxygen concentration in goaf to reduce the limit advancing speed of working face which may spontaneous combustion in goaf. If fire prevention measures are adopted, the actual oxidation temperature rise zone in goaf can be realized. When the oxygen concentration is reduced to 11%, then:

The ratio coefficients of the experimental oxygen concentration to the actual oxygen concentration are as follows:

$$\kappa=\frac{C_{o_2}^0}{\overline{C_{o_2}}} = \frac{21\%}{11\%} = 1.91$$

The limit propulsive speed of working face where spontaneous combustion may occur in goaf is as follows:

$$v_{\text{min}} = \frac{L_{\text{max}}}{\tau_{\text{min}} \cdot \kappa} = \frac{88}{44 \times 1.91} \approx 1.05m/d$$
Therefore, when the 2302 coal mining faces implement fire prevention and extinguishing measures, the oxygen concentration in the oxidizing zone of goaf is reduced to 11%, and the ultimate advancing speed of the working face is 1.05m/d. When the advancing speed of the working face is greater than this value, there is usually no danger of spontaneous combustion in the goaf; when the advancing speed of the working face is more than 44 days continuously, it will be less than 1.05m/d, and the goaf will be in danger of spontaneous combustion.

4. Fire safety measures in Goaf
(1) Take the upper and lower corners to block in time, and 10 pairs of supports on the working face are laid with air duct cloth to ensure the reduction of air leakage in the goaf.

(2) Real-time implementation of goaf grouting and nitrogen injection measures ensures that oxygen concentration in the oxidation zone of goaf decreases and is controlled below 11%.

5. Conclusion
(1) The spontaneous combustion period of coal oxidation in goaf is obtained by fluent numerical simulation, and the minimum advancing speed of coal mining face to prevent goaf combustion in 2302 working face is calculated to be 1.42m/d.

(2) In order to ensure the safety of fire prevention in goaf, the oxygen concentration in goaf is controlled below 11% by implementing measures such as blocking air leakage in upper and lower corners, grouting and nitrogen injection in goaf, so that the oxidation spontaneous combustion zone in goaf can be quickly transformed into asphyxiation zone.

Acknowledgments
This work was financially supported by Gansu Youth Science and Technology Fund Plan(18JR3RM240), Gansu Safety Production Science and Technology Project (GAM00011), China Coal Industry Association Science and Technology Research Project(MTKJ2018-279, MTKJ2018-277) and Longdong University Youth Fund Project(XYZK1610) fund.

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