

# "Three Zones" Division of Spontaneous Combustion in Goaf of Y-type Ventilation Fully Mechanized Mining Face

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## Abstract

The goaf of coal mine is accompanied by residual coal, and the possibility of spontaneous combustion determines whether the mine can work safely. Therefore, the division of "three zones" of spontaneous combustion in goaf under different working conditions is of great significance. This paper takes the 3154 fully mechanized coal face of Longmen Xianan Coal Mine as the research background to explore the "three belts" distribution under the Y-type ventilation mode. Based on the laboratory measured coal related spontaneous combustion characteristic parameters, the division standard of "three zones" is determined. Combined with the daily monitoring of the temperature and gas collection devices deployed on the site and the numerical simulation of the wind speed in the goaf, the comprehensive division of "three zones" in the goaf is realized. The results show that the range of "three zones" divided by temperature is similar to the range of oxygen concentration. The average width of heat dissipation zone and oxidation zone in the transport lane is 34.7m and 48.8m respectively. The asphyxiation zone is located at an average distance of more than 83.4m from the working face; The average width of the heat dissipation zone of the return air lane is 30.6m, the average width of the oxidation zone is 42.7m, and the average distance from the working face is more than 73.3m. In the numerical simulation, the width of the heat dissipation zone of the transport roadway is 35.0m, the width of the oxidation zone is 50m, and the asphyxiation zone is more than 85m from the working face. The width of the heat dissipation zone of the return air lane is 30m, the width of the oxidation zone is 40m, and the asphyxiation zone is more than 75m from the working face. The simulation results are close to the measured range of "three zones" of spontaneous combustion, and the width of "three zones" of return air roadway with Y-type ventilation is obviously different from that of transport roadway.

## Keywords

Y-type Ventilation; "Three Zones" of Spontaneous Combustion in Goaf; Oxygen Concentration; Temperature.

## 1. Introduction

Coal mining goaf is often accompanied by residual coal, and the temperature and oxygen content of the goaf determine the possibility of spontaneous combustion of residual coal [1-2]. As one of the five major disasters in coal mines, fire prevention and control are particularly important.

At present, the prevention and control of spontaneous combustion in goaf mainly involves monitoring the "three zones" of goaf, which can be achieved through indoor experimental methods, on-site monitoring methods, and numerical simulation methods [3]. Many scholars at

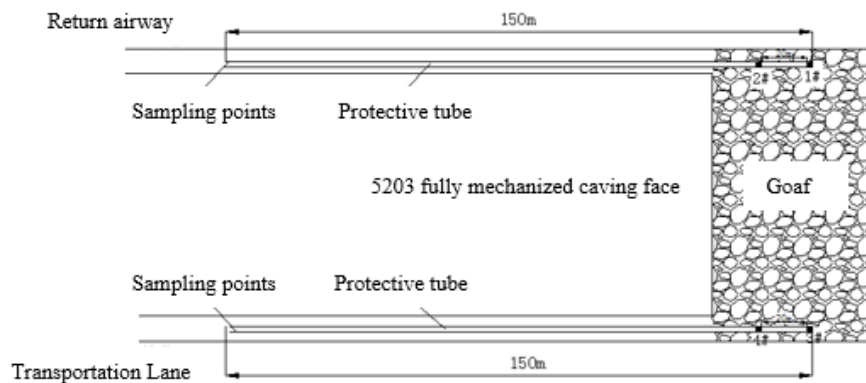
home and abroad have conducted extensive research on different working conditions on site. For example, Xu et al. [4-5] determined the relevant parameters through coal spontaneous combustion experiments and derived mathematical models to calculate the risk area of spontaneous combustion in goaf. Yu Tao [6] established a CFD model to analyze the composite disaster of gas and coal spontaneous combustion, and simulated and analyzed the effects of air volume and ventilation mode on the distribution of the "three zones" of spontaneous combustion in goaf from three aspects: ventilation, extraction, and fire prevention. Based on on-site monitoring data, Yu Minggao [7-8] used MATLAB to analyze gas content and temperature, and obtained the range of the "three zones" of spontaneous combustion in goaf. Based on the principle of chemical kinetics, Song Wanxin[9] proposed a standard for dividing the "three zones" of spontaneous combustion in goaf based on oxygen concentration. The above scholars have combined theoretical, experimental, on-site, and numerical simulation analysis to classify the "three zones" of spontaneous combustion in goaf, and achieved good results on site. There is also a wealth of research on the impact of different working conditions on the "three zones" of spontaneous combustion in goaf. For example, references [10-11] analyze the distribution pattern of the "three zones" of spontaneous combustion in goaf under different ventilation methods, and study effective fire prevention and extinguishing technologies. Wang Yaoqiang [12] conducted monitoring on a shallow and inclined working face, demonstrating the influence of coal seam inclination on the "three zones" of spontaneous combustion in goaf. Unlike traditional monitoring methods, Dong Jie [13] used fiber optic sensing technology to divide the "three zones" of spontaneous combustion in goaf. Cheng Long [14] used the stress distribution law of the goaf floor to divide the "three zones" of spontaneous combustion in the goaf.

This article is based on the on-site engineering of the 3154 fully mechanized mining face in Longmenxia South Coal Mine. Due to the use of Y-shaped ventilation in this face, the "three zones" of spontaneous combustion in the goaf also have differences with U-shaped ventilation. This on-site monitoring provides a guarantee for on-site safety production and a reference for the study of the division law of the "three zones" in the Y-shaped ventilation goaf.

## 2. On Site Self Ignition "Three Belt" Testing Plan

The 3154 fully mechanized mining face of Longmenxia South Coal Mine is located on the west wing of the K1 coal seam Longwangdong anticline and the south wing of the 315 mining area. The coal seam thickness of the working face is 1.6m~2.3m, with an average of 1.9m. The maximum inclination angle of the coal seam is 28 °, the minimum inclination angle is 18 °, and the average inclination angle is 25°. The ventilation method is central boundary ventilation, and the ventilation method is extraction ventilation. The oxygen absorption capacity of the coal seam is 0.63cm<sup>3</sup>/g, belonging to Class II spontaneous combustion coal seam, with the shortest spontaneous combustion cycle of 48 days.

Considering that the ventilation method of the fully mechanized mining face is a "Y" shape ventilation, based on the characteristics of "Y" shape ventilation, temperature measuring elements and gas extraction holes are arranged on both sides of the upper and lower alleys of the working face, and based on this, the distribution characteristics of the "three zones" of spontaneous combustion in the goaf are analyzed. Four measurement points are arranged along the upper and lower alleys of the working face: two measurement points are respectively arranged in the transportation lane and the return air lane. Measurement points 1 # and 2 # are arranged in the transportation lane, and measurement points 3 # and 4 # are arranged in the return air lane. Measurement points 1 # and 3 # are used, while measurement points 2 # and 4 # are for backup. The on-site layout diagram is shown in Figure 1.



**Figure 1.** Schematic diagram of on-site deployment

The underground testing system includes a gas extraction system and a temperature measurement system. The suction equipment adopts an automatic negative pressure sampler and uses a gas chromatograph to analyze the gas collected in the goaf on a daily basis. We use a high-precision "TES-1317" platinum resistance thermometer for temperature measurement, and the temperature measuring element adopts an integrated temperature sensor Pt100. Its temperature measurement range is large, ranging from  $-200^{\circ}\text{C}$  to  $+850^{\circ}\text{C}$ , and the nonlinear error can be controlled within  $\pm 0.3^{\circ}\text{C}$ . At the same time, steel pipes are buried towards the goaf on the side of the goaf retaining roadway at the rear of the transportation roadway and return airway. The direction of steel pipe burial is perpendicular to the roadway, located behind the support frame, and the distance between the end position of the steel pipe and the roadway is 15-20m. When a  $\phi 50\text{mm}$  steel pipe is buried in the goaf, the front end of the pipe is closed and the front end is made into a flower pipe. The diameter of the small holes on the flower pipe is not more than 10mm, and the number is 5-8. After the steel pipe is buried, thread the exhaust pipe (bundle pipe) and temperature measurement wire into the sleeve together. After arranging the temperature probe and exhaust pipe onto the protective sleeve, seal the space between the protective sleeve and exhaust pipe with cotton yarn, and then spray quick sealing polyurethane for sealing to prevent air from entering the exhaust pipe from the protective sleeve.

### 3. Analysis of Temperature and Oxygen Concentration Measurements

From February 26, 2022 to March 30, 2022, actual measurements were conducted on the spontaneous combustion of coal in the goaf of the 3154 fully mechanized mining face of Longmenxia South Coal Mine. Gas samples and temperature measurements were collected on site every day.

(1) Temperature sampling results at measurement points 1 # and 3 #

When the mining progress of the working face is about 120-150 meters, temperature measurement sampling analysis is carried out on each measuring point to obtain the measured temperature and temperature rise rate changes of measuring points 1# and 3#. The temperature at measuring point 1 increases slowly within the range of 0-37.1m from the working face, changing around  $19^{\circ}\text{C}$ . The temperature of measuring point 3 increases slowly within the range of 0-32.2m from the working face, around  $20^{\circ}\text{C}$ . Due to the fact that measuring point 1 # is located within 37.1~85.4 meters from the working face, and measuring point 3 # is located within 32.2~73.3 meters, the temperature changes at each measuring point are relatively large, and the heating rate is significantly higher than in the early stage. The highest temperature at measuring point 1 is 85.4m away from the working face, with a maximum temperature of  $36.5^{\circ}\text{C}$ . The highest temperature at measuring point 3 is 73.3 meters away from the working face, with a maximum temperature of  $33.7^{\circ}\text{C}$ . The temperature in the goaf

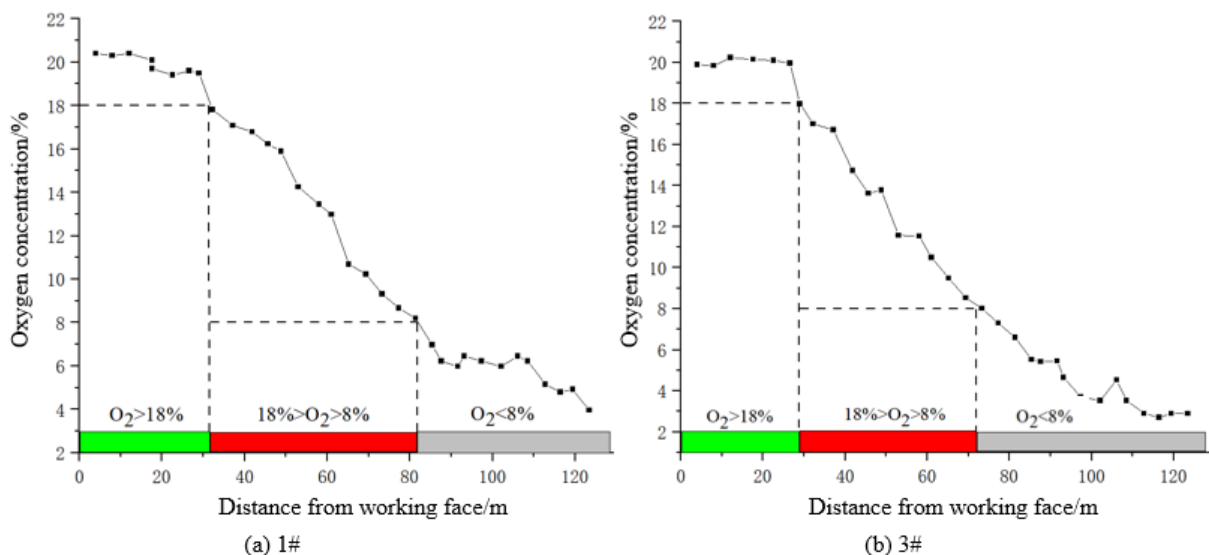
gradually decreases and remains in a relatively low temperature range after 85.4 meters from the working face. The preliminary division of the "three zones" of spontaneous combustion in goaf based on temperature rise rate is shown in Table 1.

**Table 1.** Distribution Table of "Three Zones" in goaf Divided by Heating Rate K

Measure point	Heat dissipation belt /m	Spontaneous combustion zone /m	Suffocation zone /m	Width of spontaneous combustion zone /m
1#	0-37.1	37.1-85.4	>85.4	48.3
3#	0-32.2	32.2-73.3	>73.3	41.1

(2) Changes in oxygen concentration at measurement points 1 # and 3 #

The measured results of oxygen concentration at measurement points 1 # and 3 # of the 3154 fully mechanized mining face are shown in Figure 2. The "three zone" interval is obtained from the variation of oxygen concentration in the goaf: (1) Due to the backward collapse of the roof in the goaf, the collapsed roof was not compacted near the working face, resulting in a large amount of air leakage in the goaf. Therefore, it was not until the working face advanced to 29.0-32.2m that the O<sub>2</sub> volume fraction decreased to below 18%. The position where the O<sub>2</sub> volume fraction at measurement point 1 decreased to 18% was 32.2m away from the working face, and the position where the O<sub>2</sub> volume fraction at measurement point 3 decreased to 18% was 29.0m away from the working face. (2) Starting from 85.4m away from the working face, the measuring point 1 enters the suffocation area with an oxygen concentration of 6.97%. The measuring point 3 starts from 77.3m away from the working face and enters the suffocation area, with an oxygen concentration of 7.29%. The trend of O<sub>2</sub> concentration changes at two measuring points can preliminarily delineate the "three zones" of spontaneous combustion in the goaf of the 3154 fully mechanized mining face. The results are shown in Table 2.



**Figure 2.** Changes in Oxygen Concentration

**Table 2.** Distribution table of "Three Zones" in goaf divided by oxygen concentration

Measure point	Heat dissipation belt /m	Spontaneous combustion zone /m	Suffocation zone /m	Width of spontaneous combustion zone /m
1#	0-32.2	32.2-81.4	>81.4	49.2
3#	0-29.0	29.0-73.3	>73.3	44.3

According to Table 2, temperature and oxygen concentration can be comprehensively utilized to divide the "three zones" of the 3154 fully mechanized mining face in Longmenxia South Coal Mine. The width of the heat dissipation zone in the transportation roadway is 34.7m, the width of the spontaneous combustion zone is 48.8m, and the distance from the working face greater than 83.4m is considered as the suffocation zone. The width of the heat dissipation zone in the return airway is 30.6m, the width of the self ignition zone is 42.7m, and the distance from the working face greater than 73.3m is considered as the suffocation zone. In summary, the width of the scattered heat zone in the 3154 fully mechanized mining face is 30.6~34.7m, the width of the spontaneous combustion zone is 42.7~48.8m, and the width of the suffocation zone is greater than 73.3~83.4m. The range of self ignition "three zones" preliminarily determined by the measured temperature change trend and temperature rise rate is similar to the range determined by the analysis of the distribution law of oxygen concentration in the goaf, indicating that the self ignition "three zones" divided based on temperature rise rate and oxygen concentration change in the goaf are in line with the actual situation.

#### 4. Simulating the Airflow Velocity in Goaf to Determine the "Three Zones"

By using Fluent numerical simulation and establishing a three-dimensional calculation model for the goaf of the 3154 fully mechanized mining face, combined with on-site practice, the distribution of airflow velocity in the "three zones" of the goaf is solved. One method is to reflect the width of the "three zones" with airflow velocity. During the simulation process, the porous medium in the goaf is considered isotropic, ignoring the buoyancy effect of gas in the goaf, and assuming that the gas in the goaf is incompressible and flows in an isothermal steady state. Due to the small air leakage of the research object, the airflow in the goaf is approximated as a laminar distribution, and the airflow flow law follows Darcy's law. In addition, due to the small numerical value of the collapse height of the goaf compared to its length and width, the goaf flow field is considered as a two-dimensional flow field. Fluent's porous media model adds a source term representing momentum consumption to the momentum equation. This source term consists of two parts: inertia loss term and viscosity loss term [15]. The momentum loss source term in two-dimensional porous media can be represented by the following equation:

$$S_i = -\left(\sum_{j=1}^2 D_{ij} \mu v_j + \sum_{j=1}^2 C_{ij} \frac{1}{2} \rho |v_j| v_j\right) \quad (1)$$

Where,  $S_i$  is the  $i$ -th momentum loss source term;  $\mu$  is the dynamic viscosity coefficient of the fluid;  $\rho$  is the airflow density in the goaf;  $v$  is the velocity of the fluid;  $D$  and  $C$  are given matrices. According to the assumption of porous media in goaf, equation (1) can be simplified as:

$$S_i = -\left(\frac{\mu}{e} v_i + C_2 \frac{1}{2} \rho |v_i| v_i\right) \quad (2)$$

Where,  $e$  is the permeability of the porous medium;  $C_2$  is the coefficient of inertial resistance;  $v$  is the velocity of the fluid.

Based on the above formula and the actual geological conditions and mining conditions on site, simulate the distribution of wind speed in the goaf as shown in Figure 3.

According to the wind speed classification standard and Figure 4 of the "three zones" of spontaneous combustion in the goaf, it can be concluded that the range of the "three zones" of spontaneous combustion in the goaf of the 3154 fully mechanized mining face is 0-35m for the heat dissipation zone on the machine roadway side of the goaf, 35-85m for the oxidation zone, and 50m for the oxidation zone width. The heat dissipation zone of the goaf on the side of the wind tunnel is 0-30m, the oxidation zone is 30-75m, and the width of the oxidation zone is 40m.

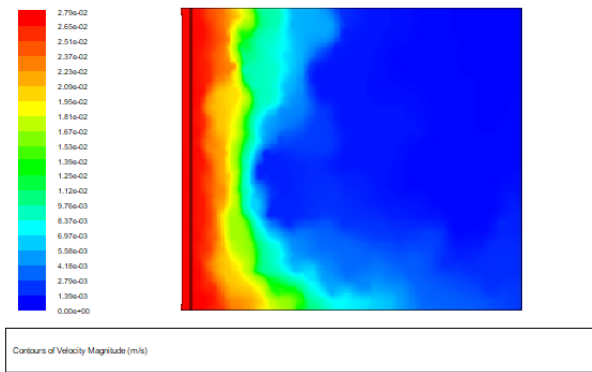


Figure 3. Wind speed distribution in goaf

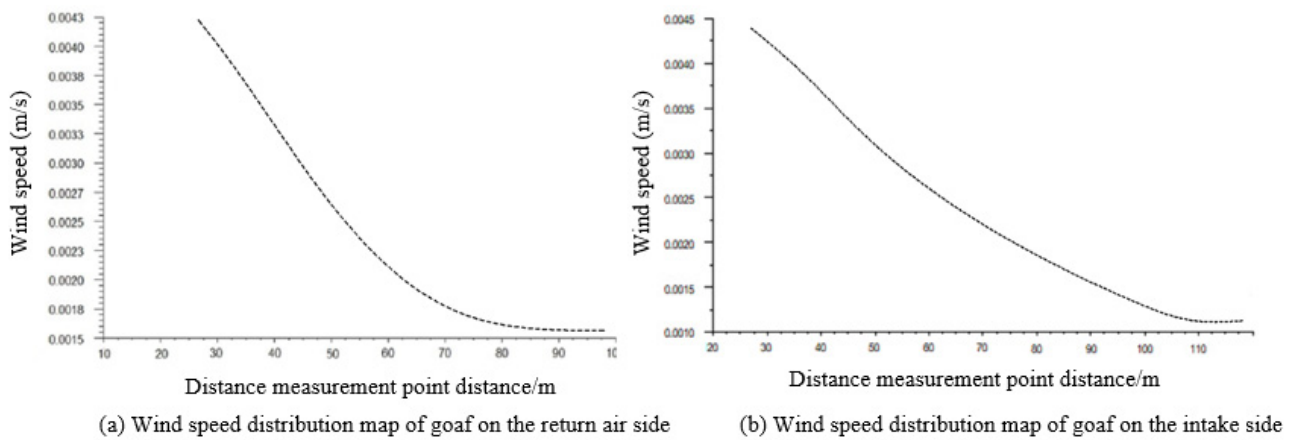


Figure 4. Wind speed distribution in goaf at different locations

### 5. Conclusion

(1) The range of the "three zones" of spontaneous combustion in the goaf divided by the oxygen concentration and temperature rise rate of the 3154 fully mechanized mining face is as follows: the average width of the heat dissipation zone in the transportation roadway is 34.7m, the average width of the oxidation zone is 48.8m, and the suffocation zone is defined as a distance greater than 83.4m from the working face. The average width of the heat dissipation belt in the return air alley is 30.6m, the average width of the oxidation belt is 42.7m, and the suffocation zone is located at an average distance of more than 73.3m from the working face.

(2) Using Fluent software to numerically simulate the "three zones" of spontaneous combustion in the goaf of the 3154 fully mechanized mining face, the range is: the width of the heat dissipation zone in the transportation roadway is 35.0m, the width of the oxidation zone is 50m, and the distance from the working face greater than 85m is considered as the suffocation zone. The width of the heat dissipation zone in the return air alley is 30m, the width of the oxidation zone is 40m, and a distance greater than 75m from the working face is considered as the suffocation zone.

(3) The numerical simulation results are basically the same as the on-site measurement results, indicating that the on-site measurement results are true and accurate.

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