

# Fire Prevention Technology Practice in Syncline Structure Area based on Inhibitor Spraying and Tube Bundle Monitoring

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## Abstract

To address the “water-gas-structure” multi-field coupling disaster encountered by the 9401 fully mechanized top-coal caving face at Hengsheng Coal Mine while passing through the Liujiashuang syncline axis, the three-dimensional compound air leakage mechanism composed of “boreholes, overlying goaf, and surface fissures” and the associated risk of residual coal spontaneous combustion were analyzed in depth. Consequently, an active prevention and control system centered on mobile calcium chloride inhibitor spraying was constructed. A calculation model for the inhibitor dosage based on mining parameters was established, determining the optimal daily spray volume at 9.98 m<sup>3</sup>, accompanied by the implementation of a hierarchical dynamic control strategy. Combined with a beam tube monitoring system, full-process dynamic tracking of key gas components in the goaf, including O<sub>2</sub>, CH<sub>4</sub>, CO<sub>2</sub>, and CO, was conducted. Field application results indicated that during the implementation, the gas flow field in the goaf remained generally stable. The peak methane concentration was controlled below 0.55%, and carbon monoxide levels consistently remained at low background values without abnormal fluctuations. This system effectively blocked compound air leakage channels, inhibited the oxidation process of residual coal, and ensured safe mining operations under complex geological conditions.

## Keywords

Syncline Axis; Compound Air Leakage; Inhibitor Spraying; Beam Tube Monitoring; Prevention of Coal Spontaneous Combustion.

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## 1. Introduction

The syncline axis presents severe “water-gas-structure” coupling risks, where structural stress and fractures induce compound air leakage and spontaneous combustion [1-4]. While existing research focuses on inerting and sealing technologies [5-8], the specific multi-hazard environment of the Hengsheng 9401 working face requires a targeted approach. This study analyzes the complex leakage mechanism in the syncline axis and constructs an active prevention system based on mobile calcium chloride inhibitor spraying, supplemented by tube bundle monitoring, to ensure safe mining in complex structural zones.

## 2. Engineering Background

The No.3 and No.4 mining areas in the northern wing of Hengsheng Coal Industry are strongly controlled by the Liujiashuang syncline structure. Striking northeast-southwest, this syncline crosses key successive working faces including 9401, 9402 and 9305. Affected by the asymmetric dip angles of rock strata on both wings (approximately 3° for the west wing and 7° for the east wing) and stress concentration at the synclinal axis, the coal and rock masses in this area are severely fractured. All

exposed zones present obvious abnormal emission of gas and hydrogen sulfide as well as increased water abundance, forming a complex disaster-causing environment coupled with water, gas and geological structures.

More severely, goafs of No.2 coal seam overlie this area. When water exploration and drainage projects are carried out in water-rich abnormal zones at the synclinal axis, boreholes tend to connect with the overlying goafs and further link up with surface fracture networks developed under mining disturbance. The three-dimensional composite air leakage passages composed of boreholes, goafs and surface fractures can continuously supply sufficient oxygen for the oxidation of residual coal in overlying goafs, thereby sharply increasing the risk of spontaneous coal combustion.

Therefore, in view of the special structural environment and multi-field coupling conditions at the synclinal axis of Hengsheng Coal Industry, an in-depth analysis on its composite air leakage mechanism and the establishment of targeted prevention and control technical system for coal spontaneous combustion are of great engineering significance for ensuring safe coal mining under complex geological conditions in the mine.

### 3. Fire Prevention and Control Measures

A mobile inhibitor spraying system using industrial calcium chloride ( $\text{CaCl}_2$ ) was implemented to create an oxygen barrier on residual coal. The solution is delivered to key oxidation zones (upper/lower corners, inter-support gaps) via high-pressure pipelines. Based on mining parameters (face length 239m, mining height 4.5m, advance rate 3.2m/d), the optimal daily spray volume was calculated as  $9.98 \text{ m}^3$  (approx. 1572 kg of solid  $\text{CaCl}_2$ ). A hierarchical dynamic control strategy is applied, increasing spray frequency from weekly to daily if gas anomalies are detected.

### 4. Arrangement of Tube Bundle Monitoring Points

For the “U”-shaped ventilation face, a tube bundle system with four monitoring points was arranged to cover the “three zones” of spontaneous combustion. One point monitors the return air corner, while three points are spaced 15 m, 45 m, and 75 m deep into the goaf. An 8-core main pipeline splits into 4-core branch lines to conduct continuous sampling of gas components ( $\text{O}_2$ ,  $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{CO}_2$ ), enabling real-time analysis of the oxidation environment.

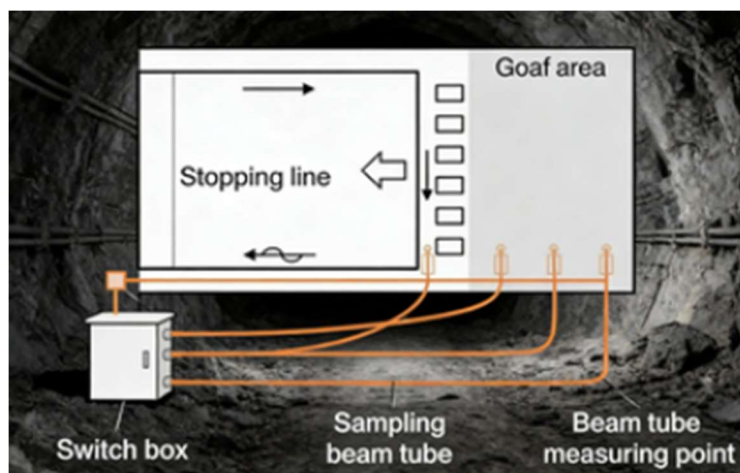


Fig. 1 Layout of measuring points

The eight-core bundled tubes are led out from the gas preprocessing substation inside the north-wing substation, laid along the main north-wing track roadway to the upper yard of the north-wing main track roadway. No.1 shunt box is installed at the upper yard to divide the eight-core bundled tubes into two four-core bundled tubes. The main pipeline is 100 meters long.

For branch pipelines: The four-core bundled tubes for working face 9401 are arranged from No.1 shunt box along the track dip roadway of the No.4 mining area and the 9401 air roadway to the working face, with a total branch pipeline length of 1100 meters.

### 5. Analysis of Tube Bundle Monitoring Results

As shown in Figs 2, 3, and 4, field monitoring during the syncline passage indicated a stable gas flow field.

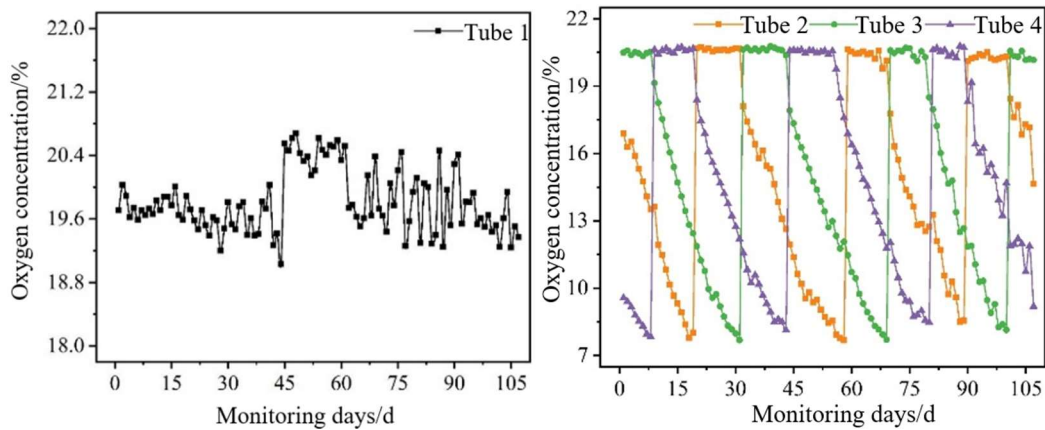


Fig. 2 Oxygen concentration monitoring curve

Sealing Effectiveness: O<sub>2</sub> concentrations showed no sustained decline and CO<sub>2</sub> remained stable, indicating that compound air leakage channels were effectively blocked.

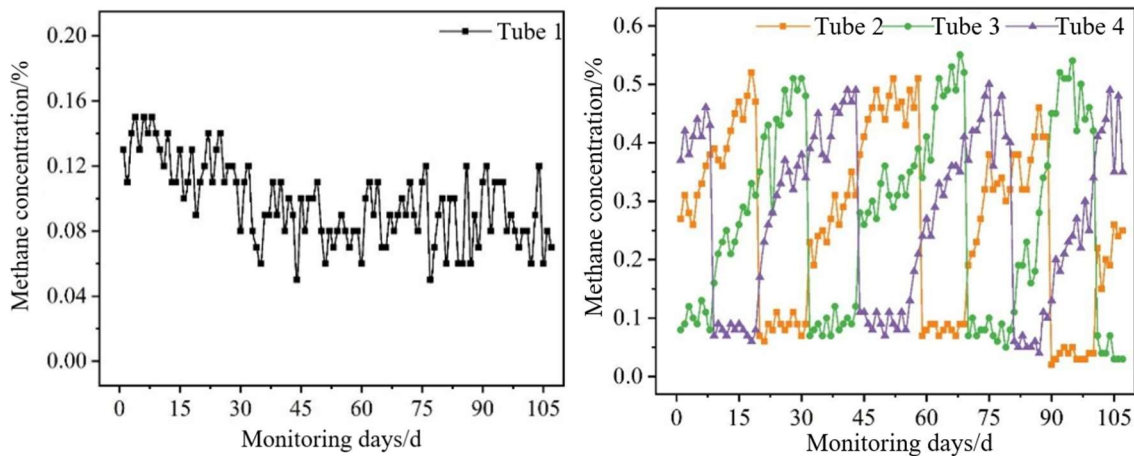


Fig. 3 Methane concentration monitoring curve

Gas Control: Although methane (CH<sub>4</sub>) is not an indicator gas for coal spontaneous combustion, its concentration field evolution serves as an important auxiliary index to invert air leakage conditions and gas occurrence environment in goafs.

Monitoring results show that during the passing of working face 9401 through the synclinal axis, the methane concentration in the goaf remained steadily at a low level with a peak value no higher than 0.55%, and no abnormal gas accumulation occurred. It indicates that the air leakage flow field in this area is well regulated, no obvious coupling superposition effect is formed between gas distribution and oxygen supply via air leakage, and the gas environment inside the goaf is safe and controllable.

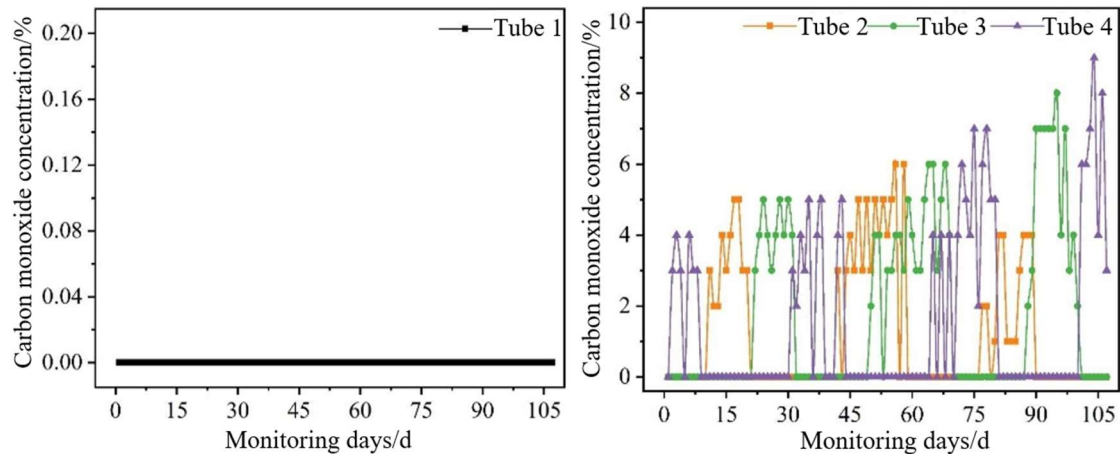


Fig. 4 Carbon monoxide concentration monitoring curve

Fire Prevention: The spontaneous combustion marker gas CO remained at low background values without abnormal fluctuations. These results verify that the inhibitor spraying effectively suppressed the low-temperature oxidation of residual coal.

## 6. Conclusion

Addressing the "borehole-overlying goaf-surface fissure" compound air leakage risk in the syncline axis of the 9401 working face, this study established a fire prevention system based on mobile inhibitor spraying (optimized at  $9.98 \text{ m}^3/\text{d}$ ) and tube bundle monitoring. Field application confirmed that the system effectively suppressed residual coal oxidation, maintaining methane concentrations below 0.55% and carbon monoxide at low background levels, thereby ensuring safe mining in the complex structural zone.

## Acknowledgments

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