

Water Injection and Dust Reduction Technology for Thick Coal Seam in 5011 Fully Mechanized Caving Face of Ma Di Liang Coal Mine

Lei Kan*, Guodong Wang

Inner Mongolia Intelligent Coal Co., LTD., Erdos 010400, Inner Mongolia, China

*Corresponding Author: kanlei@163.com

ABSTRACT

During the mining process of the 5011 comprehensive mining face of Ma Di Liang Coal Mine, the coal body is crushed, resulting in a large amount of dust being generated when the comprehensive mining machine cuts the coal body. Through the study of the temporal and spatial evolution laws of dust dispersion during coal mining operations, the sources of coal dust are analyzed, the influencing factors of the water injection effect in the coal seam are studied, the mechanism of dust reduction by water injection in the coal seam is revealed, and the water injection process for the 5011 comprehensive mining face is formulated. Finally, the dynamic and static collaborative water injection method is adopted to effectively ensure the uniformity and progress of water injection on the working face, thereby achieving significant dust reduction effects. The research results have significant implications for the dust control and safe production of Ma Di Liang Coal Mine.

KEYWORDS

Thick Coal Seam; Dust; Water Injection; Dust Removal.

1. INTRODUCTION

Currently, numerous scholars have conducted extensive and in-depth research on coal seam water injection dust suppression technology and low-permeability coal seam permeability enhancement technology, significantly improving mine safety production standards and underground working environments, thereby making proactive contributions to China's modernization efforts[1-3]. However, in practical applications, coal seam water injection technology still heavily relies on empirical approaches. Particularly in determining critical parameters such as injection pressure, flow rate, duration, and borehole spacing, decisions predominantly depend on accumulated practical experience[4-5]. Previous studies have largely focused on investigating water flow interactions with fracture-pore structures and optimizing wetting effects under specific coal mass conditions—specifically, within fixed fracture-pore configurations[6-7]. Coal seam water injection, as a critical mine safety technology, has drawn extensive attention in recent years regarding its operational mechanisms and implementation efficacy. However, significant research gaps persist in existing studies concerning the multi-field coupling response mechanisms of coal-rock masses during water injection processes. Particularly when pressurized water and in-situ stresses interact with coal-rock masses, the complex mechanical-seepage coupling effects often render traditional theoretical models inadequate for accurately predicting injection behaviors. This multi-field coupling phenomenon involves not only the progressive failure of coal matrix induced by hydraulic pressure but also the dynamic evolution of fracture networks and their continuous reshaping of seepage pathways, thereby establishing nonlinear permeability-stress coupling relationships. From a geological perspective, the

pore-fracture system in coal seams exhibits marked heterogeneity and anisotropy. Research indicates that the porosity distribution of coal-rock is influenced by multiple factors including coalification degree, depositional environments, and tectonic stresses. Such microstructural heterogeneity directly governs the water diffusion pathways and displacement patterns during injection operations.

In low-permeability coal seams, the insufficient connectivity of matrix pores and localized development characteristics of fracture systems often form "seepage barriers," making it challenging for conventional water injection techniques to achieve effective permeability enhancement. When the water injection pressure exceeds the tensile strength of the coal mass, it triggers sudden fracture propagation. This nonlinear fracturing behavior may alter the topological structure of the entire seepage field, leading to abrupt changes in water injection efficiency. Current experimental studies have predominantly focused on the impact of single factors on coal-rock properties, while quantitative characterization of fracture network dynamics under multi-field coupling conditions remains insufficient. The scarcity of field-measured data also hinders the validation and parameter optimization of theoretical models. This disconnection between theory and practice severely limits the refined design and intelligent control of water injection technology. To advance research on the multi-field coupling mechanisms in coal-rock systems, it is imperative to establish a coupled analytical framework encompassing the entire stress-strain-seepage process. The findings will not only provide scientific foundations for engineering practices such as gas drainage and outburst prevention/disaster mitigation but also offer critical technical reserves for emerging fields like groundwater resource development and carbon dioxide sequestration.

2. 5011 COAL MINING FACE

The 5011 working face of Madi Liang Coal Mine is located in the middle-lower section of the eastern wing panel of Coal Seam 5. As the third fully mechanized top-coal caving, strike longwall mining face in the mine, it has an elevation range of +925.4 to 1080.0 m. The designed strike length is 2862 m with a dip width of 320 m, covering a horizontal area of 915,840 m² (as shown in Figure 1). The total coal thickness (including partings) ranges from 8.37 m (Borehole M14) to 19.10 m, averaging 12.34 m, with a coal seam dip angle of 3-14°. During coal shearer cutting operations, intense friction and fragmentation occur between the sharp cutting picks and coal-rock interfaces, directly generating substantial amounts of primary dust. Prior to cutting, certain quantities of dust particles already exist within coal-rock fissures. As cutting progresses, these latent dust particles become mobilized by violent mechanical actions, subsequently dispersing extensively through airflow and vibrations induced by the cutting process. The structural characteristics of thick coal seams typically manifest as loose and porous, dry, and hard. These physical properties enhance coal fragmentation under external forces, thereby intensifying dust generation. Particularly when cutting through relatively fragile coal sections, the inherent brittleness of coal leads to significant release of fine dust particles even under minimal mechanical stress. Consequently, dust control presents a critical challenge in thick coal seam mining operations, not only compromising operational cleanliness but also posing serious health risks to personnel.

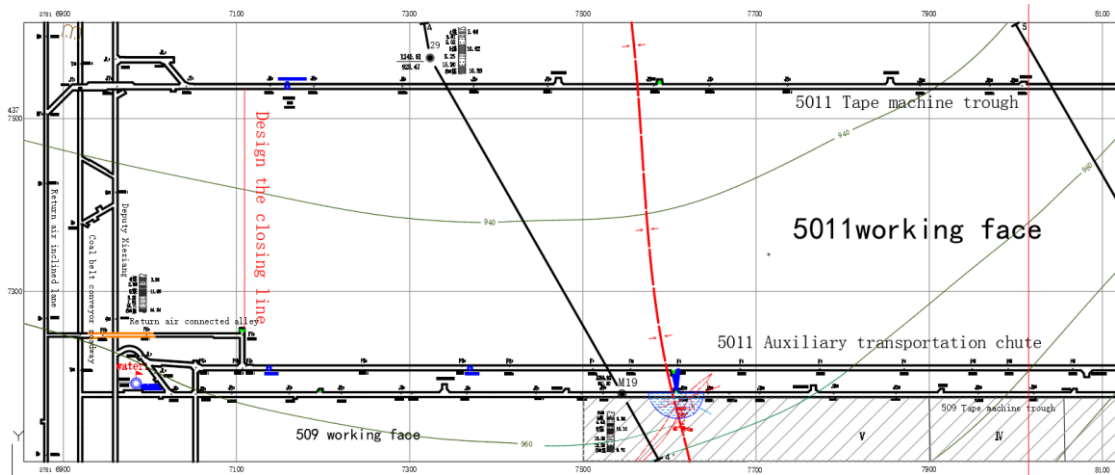


Fig. 1: Plan View of 5011 Coal Mining Face

3. ANALYSIS OF THE SPATIAL AND TEMPORAL EVOLUTION OF DUST EMISSION IN THE 5011 FULLY MECHANIZED CAVING MINING FACE

To measure dust concentration in the 5011 fully mechanized top-coal caving working face, multiple movable dust sampler brackets were installed in the experimental roadway, equipped with CCZ-1000 fully automatic dust monitors. Based on actual field conditions, four dust monitoring points were arranged at the same height on the downwind side of the shearer in the 5011 coal mining face, positioned at distances of 5m, 10m, 20m, and 40m from the shearer respectively. The layout of the monitoring points is illustrated in Figure 2.



Fig. 2: Schematic Diagram of Dust Monitoring Points in the 5011 Mining Face

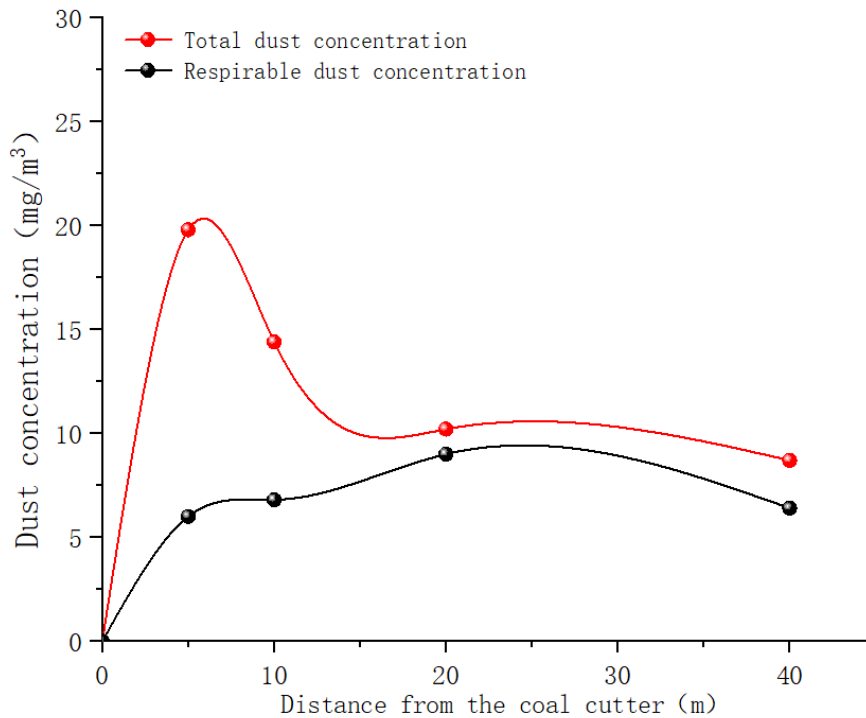


Fig. 3: Dust Distribution Curve in the 5011 Mining Face

As shown in Figure 3, during the coal-cutting process of the shearer, the airflow induced by drum rotation intertwines with the intense impact airflow generated by coal collapse, collectively acting on the produced dust. Driven by these complex airflow patterns, dust particles rapidly migrate from the coal wall toward the working face side, causing a sharp surge in dust concentration within the operational area within a short period. This phenomenon severely impairs the visibility of the working environment. With continuous dust dispersion and the steady influx of fresh ventilation, dust particles gradually disperse along the airflow direction, resulting in a gradual decline in dust concentration along the ventilation path. The maximum total dust concentration recorded was 20.5 mg/m³, while the maximum respirable dust concentration reached 10.22 mg/m³.

4. DUST SUPPRESSION MECHANISM THROUGH COAL SEAM WATER INJECTION IN THE 5011 FULLY MECHANIZED CAVING MINING FACE

4.1. Sources of Coal Dust Generation in the 5011 Fully Mechanized Caving Mining Face

Coal dust pervades nearly every corner of underground mines, continuously generated regardless of whether mining operations are actively underway. Based on its formation mechanisms, coal dust can be categorized into two distinct types: primary coal dust and secondary coal dust. Primary coal dust, akin to hidden inhabitants within coal seams, exists long before mining activities commence. As a porous medium, coal contains intricate networks of pores and fractures that serve as reservoirs for dust. Under prolonged geological stress, the coal matrix undergoes continuous compression and deformation—a process resembling nature's grinder—gradually generating dust particles. These particles accumulate within the coal's pores and fractures, awaiting eventual release. In contrast, secondary coal dust demonstrates greater dynamism and constitutes the primary source of mine dust. Generated during exploration, excavation, coal cutting, and transportation processes, it fundamentally differs from primary coal dust. Rather than geological processes, secondary dust arises directly from human production activities. Under the cutting and fracturing actions of heavy machinery like shearers, coal masses disintegrate into fine particles that exhibit complex airborne trajectories,

swirling with ventilation currents. While some dust particles are carried afar by airflow, the majority gradually settle under gravity, transforming into deposited dust that coats every surface in the mine.

4.2. Factors affecting the water injection effect of the 5011 fully mechanized caving face

4.2.1. Influence of Fracture Development Degree on Water Injection Feasibility

The permeability coefficient of fracture systems in coal seams is 1-2 orders of magnitude higher than that of coal matrix pores. The overall permeability of coal seams primarily depends on the fracture system, making fracture development the dominant factor governing water permeability. In coal seams with well-developed fractures, water can rapidly and uniformly permeate through these interconnected pathways, resulting in excellent permeability. This facilitates water injection operations, requiring relatively low injection pressures. Conversely, in compact coal seams with underdeveloped joints, permeability is significantly reduced. Even under high injection pressures, achieving desired water saturation becomes challenging. However, in coal seam sections subjected to intense tectonic activity or concentrated mining-induced stress damage, extensive exogenous and secondary fractures may form, drastically increasing permeability. In such zones, water tends to flow rapidly through these fractures and escape, failing to effectively infiltrate the coal matrix pores. This issue is particularly pronounced during water injection in areas such as pressure-relief zones of longwall faces, stress-damaged coal pillars, and geologically complex regions. Large fractures (e.g., faults, fracture planes) within the injection zone further exacerbate difficulties in pre-wetting the coal mass, as water preferentially channels through these pathways and dissipates.

4.2.2. Influence of Pore Development Degree on Water Injection Feasibility

Porosity, a critical physical property of coal seams, directly and significantly affects the difficulty of water injection. It serves as a reliable and universal criterion for evaluating injection feasibility and exhibits a close functional relationship with the natural water saturation of coal seams and the permeability of fractures. Specifically, the natural water saturation and fracture permeability jointly determine the ease of water injection and wetting efficiency. In high-porosity coal seams, abundant microspaces provide extensive pathways for water infiltration, enhancing permeability. Consequently, natural water saturation increases with porosity, allowing coal seams to absorb and retain water more readily. Conversely, low-porosity coal seams lack sufficient microspaces, restricting water infiltration and reducing permeability, thereby complicating injection efforts. The permeability coefficient of coal seams is also closely tied to porosity. As a key indicator of water permeability, the permeability coefficient follows predictable trends with porosity variations. Generally, higher porosity corresponds to larger permeability coefficients and stronger water permeability, while lower porosity results in smaller coefficients and weaker permeability. This relationship underscores the critical role of pore development in optimizing water injection strategies for coal seam management.

5. WATER INJECTION TECHNOLOGY FOR THE 5011 FULLY MECHANIZED CAVING MINING FACE

The working face adopts 5011 auxiliary transportation chute single-sided dynamic and static pressure coordinated long drilling water injection. In the vertical direction, the main position of the water injection hole is designed to be 1.5m away from the floor, which can be adjusted within a small range according to the convenience of drilling rig erection; The drilling spacing is 10m, and the tracking water injection is 300m. The drilling layout diagram is shown in Figure 4. The design inclination angle is 0.75-1.5°. During the construction process, the construction unit can adjust the angle according to the coal seam inclination. The drilling is constructed along the coal seam inclination, and the drilling angle can be adjusted according to the drilling conditions to ensure that the drilling is always arranged within the coal body; The position of the hole can be adjusted according to the actual

conditions on site. If rock is encountered during drilling, drilling should be stopped and the next hole should be drilled; A single-sided long-hole water injection method is used, with a designed drilling length of 280m. A ZDY8500LX coal mine crawler-type full hydraulic tunnel drill is used for drilling, with a drill bit diameter of 94mm and a sealing device with a diameter of 85mm for construction. The average wetting radius of the drilling hole is 5m, and the wetting range of the two drilling holes can reach 10m, which means that the spacing between water injection holes should be about 10m to fully wet the coal body and achieve the best water injection effect. Generally, the advanced time for stopping water injection is 0.5 to 1 month. According to the progress of the 5011 fully mechanized mining face, the water injection holes should be arranged within 200m of the advancing direction of the working face. The water injection holes should be arranged at a distance of 100m from the working face advance support in the 5011 auxiliary transportation chute.

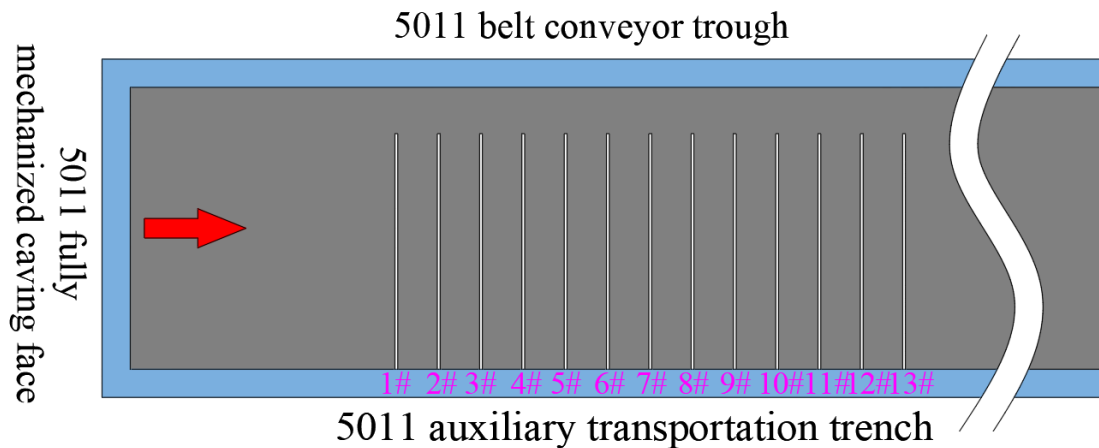


Fig. 4: Schematic Diagram of Water Injection Drilling Layout for the 5011 Fully Mechanized Caving Mining Face

Based on the characteristics of comprehensive dynamic pressure water injection and static pressure water injection, a hybrid water injection method combining dynamic pressure and static pressure is adopted for water injection. During the water injection process, set the maximum dynamic pressure and adjust the water injection process reasonably according to the water injection parameters to achieve the best effect of dynamic and static pressure mixed water injection. The maximum pressure is an important factor affecting the dynamic pressure water injection. A reasonable water injection pressure is beneficial to the mutual communication of pores and fractures inside the coal seam. Analyzing the relationship between pressure, flow rate, and time, it was concluded that the optimal maximum water injection pressure was 5 Mpa. The entire process of dynamic and static pressure collaborative water injection should be regulated in an orderly manner to ensure that the water injection time for both methods is basically equal, while also arranging the single-round water injection time for each method appropriately. After the connection of the water injection drilling, firstly start the static pressure water injection pipeline, and use static pressure water injection with a static pressure of 1.2 MPa. After 4 hours of static pressure water injection, stop water injection for 2 hours (the longer the interval, the greater the impact on the water injection progress; The interval time is short, and the water inside the coal seam pores cannot be fully wetted and diffused. Then, dynamic pressure water injection is carried out, with a maximum water injection pressure of 5 Mpa. The dynamic pressure water injection is carried out for 4 hours, and the water injection pump is turned off to allow time for the water to diffuse and wet the coal seam. The setting is set to 2 hours, and the static pressure water injection pipeline is turned on again. This process is repeated until the drilling water injection volume or the surrounding coal wall "sweats", at which point the water injection can be stopped. The specific water injection time is based on the actual water injection effect on site.

6. DUST SUPPRESSION EFFECT OF COAL SEAM WATER INJECTION IN THE 5011 FULLY MECHANIZED CAVING MINING FACE

After the water injection was completed, the coal surrounding the water injection borehole experienced significant moisture increase. The closer the coal body area is to the water injection borehole, the more prominent the increase in water content. The moisture increase of the coal body around the water injection hole can reach up to 6.02%, and the average moisture increase is stable at around 2.33%. The increase in the water content of the coal seam is crucial for improving the working environment and reducing dust concentration. The threshold for increasing the water content of the coal body by 1% is roughly distributed at a distance of about 2.5m from the drilling hole. From the perspective of dust reduction efficiency. The dust removal efficiency of the whole dust has increased by 6.7%, which means that the number of dust particles suspended in the air has been effectively controlled. The dust reduction efficiency of respiratory dust has increased by 16.8%, and the dust reduction effect is significant.

7. CONCLUSION

(1) Friction and crushing between the teeth and coal/rock on the coal mining face generate a large amount of primary dust. During the cutting process, dust originally present in the cracks of the coal/rock will spread as the cutting progresses. The dust moves from the coal wall towards the working face side, causing a sharp increase in dust concentration in the working area. Subsequently, due to continued diffusion, the dust concentration gradually decreases along the airflow.

(2) The movement of water within the coal seam primarily relies on a few natural fractures and new fractures generated during the water injection process. Its ability to uniformly wet the coal body is poor, resulting in minimal water injection effectiveness.

(3) By adopting a dynamic-static collaborative water injection method, the periodically changing water injection pressure allows water to infiltrate different fracture pores. The fracture pores in the coal body undergo repeated "expansion-contraction-expansion" effects under different pressures. During the expansion phase, the mechanical properties of the coal body are altered to the greatest extent, causing the fractures to continuously connect and the fracture pores to further expand. The contraction phase prevents widespread interconnection of the expanded fractures.

REFERENCES

- [1] ZHANG Q. Design of a wireless shearer cutting tracking and dust suppression system for fully mechanized mining faces [J]. *Coal Technology*, 2025, 44(1): 242-244.
- [2] FU D Y, LI X C, SHEN Y X, et al. Influence of mist-film distribution state on the performance of wet dust collectors [J]. *Coal Technology*, 2025, 44(1): 145-149.
- [3] CHEN X J, YE X Y, LI Y B, et al. Spatial distribution characteristics and transport patterns of respirable dust in fully mechanized mining faces [J]. *Coal Mine Safety*, 2025, 56(1): 62-71.
- [4] LI X. Research on low-pressure deep-hole water injection dust control technology in fully mechanized caving faces [J]. *Jiangxi Coal Science & Technology*, 2025, (1): 179-181+184.
- [5] LIU Z Q. Optimization of coal seam water injection parameters and analysis of dust reduction effects [J]. *Coal*, 2024, 33(9): 105-108.
- [6] LONG Z J, XIAO G S, CHEN T, et al. Experimental study on integrated coal dust and gas control through coal seam water injection in mining faces [J]. *Coal Technology*, 2025, 44(1): 212-215.
- [7] ZHAO Z P, HUANG L N, ZHANG L K. Numerical simulation of radial seepage evolution in coal seam water injection boreholes [J]. *Coal Mine Machinery*, 2025, 46(1): 222-227.