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Research on Fire Prevention and Extinguishing Technology During the Shutdown and Withdrawal Period of Fully Mechanized Top-Coal Caving Face

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Abstract

To ensure safe equipment withdrawal from the 15102 fully-mechanized top coal caving face during production suspension at a coal mine, a comprehensive four-phase fire prevention strategy was developed based on precise delineation of spontaneous combustion "three zones" and thorough hazard analysis. The implemented measures included: ventilation system optimization with gas extraction adjustment, low-temperature nitrogen injection into goaf, 15-meter corner grouting for air leakage sealing, fire-retardant injection between supports with rear-side sealing, targeted retardant injection in abnormal zones, and continuous goaf monitoring. During the critical withdrawal period, all key gas indicators remained within safety limits without any spontaneous combustion incidents, enabling safe, efficient single-cycle equipment retrieval. These results provide valuable technical references for fire prevention in similar mining conditions.

Keywords

Coal Seam; High-Gas; Spontaneous Combustion-Prone; Fully-Mechanized Top-Coal Caving Face; Rapid Withdrawal; Fire Prevention and Extinguishing Technology.

1. Introduction

Mine fires are one of the five major disasters in coal mines, and the prevention and control of high gas spontaneous combustion and severe mine fires are the key to preventing major accidents in mines [1-3]. During the backfilling period of the fully mechanized top coal caving working face in high gas prone coal seams, due to slow advancement speed, long cycle, and the influence of factors such as air leakage, oxidation, and heat storage of residual coal in the goaf, spontaneous combustion and fire accidents are prone to occur, resulting in the inability of the working face equipment to retract normally, causing significant economic losses and resource waste, and easily triggering gas and coal dust accidents, seriously threatening the personal safety of on-site workers [4-7]. Most of the mines in the Heshun area mine coal seams that are prone to spontaneous combustion. During the retreat period of the fully mechanized mining face, accidents often occur where the working face is closed due to the exceedance of indicator gases such as CO [8-13]. Therefore, adopting effective fire prevention and extinguishing technology measures to ensure the safe, smooth, and rapid retreat of the fully mechanized mining face is the focus of fire prevention and control in the working face, and also the top priority of mine safety management.

A coal mine in Heshun, Shanxi, with a designed production capacity of 1.2 million tons per year, is a high gas mine with severe spontaneous combustion. It mainly mines the 15th coal seam of Taiyuan Formation, with a coal thickness of about 5.18 meters. The spontaneous combustion

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tendency of coal seam 15 is Class I, which is prone to spontaneous combustion. The shortest ignition period is about 31 days. Since the establishment of the mine, coal spontaneous combustion has occurred multiple times during the closure or shutdown of work, which has had a serious impact on the safety production of the mine. Therefore, in response to this major risk and disaster causing factor, combined with the results of the "three zones" measurement of natural combustion in the 15102 fully mechanized mining face, and focusing on the key points of fire prevention and control during the mining period, four phased prevention and control technical measures were analyzed and proposed. Through application and practice, certain results have been achieved.

2. Mine Overview

The cutting length of the 15102 fully mechanized mining face in this coal mine is 190m, and the area is 155610 m^2. The length of the conveyor belt transport channel is 1251m, the length of the auxiliary transport channel is 1199m, the mining direction of the working face is 819m, and the coal seam thickness is 5.18m. The working face roadway is arranged in a northeast direction, with the cutting eye at the southwestern edge of the working face, and the working face advances from southwest to northeast. The working face adopts a three lane layout. There are one tape transport chute, one auxiliary transport chute, and one high suction lane respectively. The belt transportation channel and auxiliary transportation channel are respectively arranged along the coal seam floor, the high pumping roadway is arranged along the roof of the 11 # coal seam, and the end 40m is arranged above the K2 limestone. The gas content in the area to which the 15102 comprehensive mining face belongs is greater than $8m^3/t$. The coal dust in the 15th coal seam is explosive and belongs to the spontaneous combustion coal seam, with a spontaneous combustion tendency of level I.

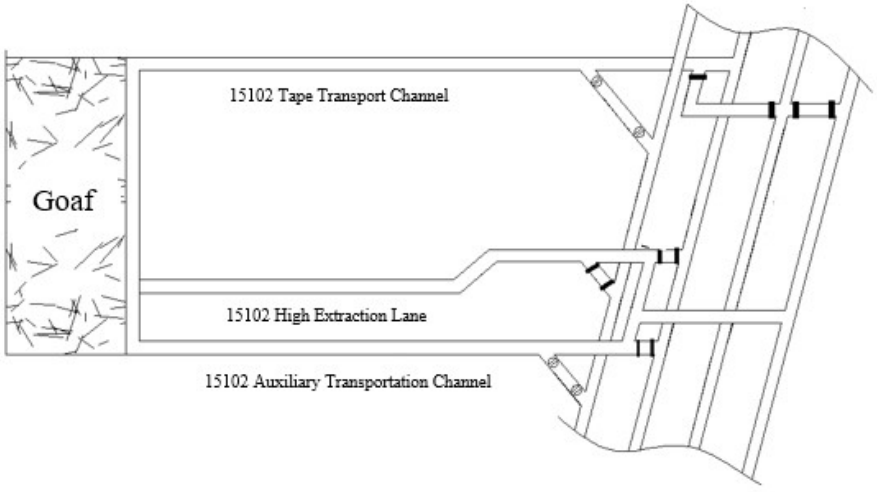

Figure 1. Layout of working face roadway

3. Analysis of the Risk of Spontaneous Combustion

3.1. Analysis of the Risk of Spontaneous Combustion During the Final Mining Period

1) Geological occurrence conditions. The 15 # coal seam in the mining area and the 14 # coal seam about 8 meters above it are both Class I coal seams that are prone to spontaneous combustion, with high sulfur content, and the 14 # coal seam contains phosphorus. After the working face advances, a large amount of naturally occurring floating coal is left in the goaf.

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2) Mining process for working face. Due to the constraints of the final mining process, steel mesh reinforcement support was carried out within a 20 meter range before the shutdown of the fully mechanized caving face, and coal discharge was stopped to ensure the integrity of the roof. As a result, the recovery rate was relatively low, and a large amount of floating coal was left in the goaf space, providing combustibles for natural combustion.

3) Air leakage in goaf. The wind and transportation lanes in the working face are supported by anchor mesh cables. After the frame is moved, the hanging range of the upper and lower corner roofs is large and not easy to collapse, resulting in significant air leakage in the goaf and providing a fuel for natural combustion.

4) Advance speed. The working face enters the stage of consolidation mining, with a slow recovery speed and a long oxidation time for the remaining floating coal in the goaf, providing continuous accumulation of heat for spontaneous combustion.

3.2. Analysis of the Risk of Spontaneous Combustion During the Retreat Period

1) Coal remains in goaf. The shortest spontaneous combustion period of coal seam 15 is 31 days, and the shortest spontaneous combustion period of coal seam 14 is 18 days. However, the withdrawal circumference of the working face after stopping mining is relatively long, often more than one month. The residual coal in the goaf oxidation zone will further intensify oxidation. When the energy accumulated in the goaf exceeds a certain critical value, spontaneous combustion is highly likely to occur.

2) Top broken coal. The retraction time of the working face bracket is about one month, and the oxidation time of the floating coal on the top of the bracket is relatively long, which easily accumulates heat and triggers spontaneous combustion.

3) Rear floating coal. Before stopping the mining and dismantling of the working face, measures such as laying flexible steel mesh, controlling the flow rate of high extraction tunnels, and grouting to block air leaks after the dismantling need to be taken. The large amount of floating coal that falls from the goaf, after implementing measures such as reducing working air distribution, controlling extraction flow rate, and blocking air leakage, further compresses the width of the heat dissipation zone in the goaf, and the oxidation zone moves forward accordingly, providing favorable conditions for the oxidation and heat storage of floating coal behind the goaf frame, making it more prone to spontaneous combustion.

4. Four Stage Fire Prevention and Extinguishing Technical Measures

4.1. Fire Extinguishing Technical Measures within a Range of 25m from the Shutdown Line During the Closing Period

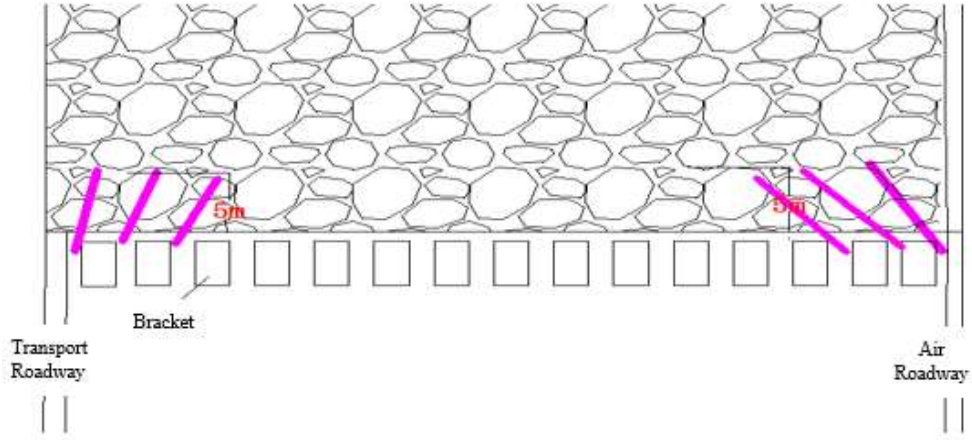

Figure 2. Schematic diagram of grouting with corner tube insertion

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1) Corner blockage. With the backfilling of the working face, at 8 o'clock every day, woven bags of coal are used to block the upper and lower corners, and yellow mud is used to fill the edge gaps. Then, a 1-inch flower tube is inserted within a range of 15m from the corner, cut the top and arrange it, and inject Shidafu (inorganic fire extinguishing material) slurry into the goaf 5m. A windproof curtain is formed at the upper and lower corners to reduce air leakage in the goaf (as shown in Figure 2).

2) Continuous low-temperature nitrogen injection. A lazy injection pipeline (ø 80mm) is laid along the cutting hole 50m away from the production line. An air outlet is set every 30m, and a nitrogen refrigeration device is installed in the transport roadway to cool the nitrogen injected underground to -25 ℃ before injecting it into the goaf.

3) Lay the air duct cloth on the top of the bracket. When the working face is 12 meters away from the stopping line, the top of the support is supported by a double-layer mesh, with a wind tube cloth (10 × 1.1m) sandwiched between the two layers of mesh. By laying the wind tube cloth, the contact area between the floating coal at the back of the support and oxygen is reduced, which slows down the oxidation rate of the floating coal behind the support.

4) Low temperature normal nitrogen injection. During the closing period, continuous low-temperature nitrogen injection was carried out at the inlet corner to reduce the oxygen content in the goaf and slow down the oxidation rate of residual coal in the goaf.

4.2. Fire Extinguishing Technical Measures Taken During the Final Mining Period

1) Change the ventilation system and adjust the extraction volume. After the mining of the working face is stopped, the rear slide and three sets of end frames are withdrawn, and a 2-meter-thick sealed structure is constructed at a distance of 8 meters from the cutting eye in the transport lane to form local positive pressure ventilation between the transport lane and the cutting eye. The flow rate of the high extraction lane is controlled from 300 m^3/min to around 60 m^3/min, and the extraction volume of the upper corner is controlled at 20 m^3/min. In this way, reduce the air supply to the goaf and shrink the area of the oxidation zone.

2) Drill holes and inject grout behind the bracket. After the mining is stopped, retract the side guard plate of the support and use an anchor rod machine to connect hollow drill rods to drill holes at the top of every two sets of supports. The drill holes are cut to the top and arranged 3 meters deep into the goaf. Inject Staff slurry into the goaf through the drill holes to form a windproof curtain within 3 meters behind the support, reducing air leakage in the goaf. Then spray all the coal walls behind the support with Stuff slurry to cover the exposed coal behind the support and suppress the oxidation of residual coal behind the support.

4.3. Fire Extinguishing Technical Measures Taken During the Retreat Period

1) Disposal of collapsed coal. Each time a set of supports is withdrawn from the working face, the collapse area is fully covered and sprayed with Staff fire prevention and extinguishing materials. Then use flower tubes with lengths of 4m and 6m (drill 8-10 holes with a diameter of 1cm within 1m of the end and flatten the end) to inject grout into the collapsed area until there is grout seepage at the bottom of the collapse. Inhibit the oxidation of collapsed coal.

2) Handling of abnormal CO area at the top of the bracket. During the retreat process of the working face, some of the supports showed CO at the top, especially near the high pumping position. Using the fan-shaped through layer sprinkler holes previously arranged at a distance of 30 meters from the cutting hole in the wind and transportation lane, a blocking agent (calcium chloride) was sprayed onto the CO abnormal area. The abnormal area of CO between the supports generally occurs at the top of the middle part of the two rear tail beams. To suppress the oxidation of coal at the top of the supports, a pipe is inserted from the front beam

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of the supports and injected with Stuff fire extinguishing slurry into the rear tail beam area. These two measures are comprehensively utilized.

3) Inject liquid CO_2 into the goaf. Considering the long retreat time, both the 15 # coal seam and the adjacent 14 # coal seam are prone to spontaneous combustion. After controlling the air flow and extraction volume of the working face, the oxidation zone in the goaf is moved forward. To prevent spontaneous combustion of residual coal in the oxidation zone, a nitrogen injection pipeline reserved 20 meters away from the cut-off line is used to continuously inject low-temperature nitrogen while intermittently injecting liquid CO_2 into the goaf, effectively suppressing spontaneous combustion in the goaf.

4) During the retreat period, bundle tubes laid at corners extending 50m and 30m into the goaf were used to closely monitor the indicators of spontaneous combustion gas in the goaf using surface chromatography and underground mobile bundle tubes. The top and back of the support were manually inspected and gas samples were taken for chromatographic analysis to timely grasp the coal oxidation situation and actively take measures.

4.4. Take Fire Extinguishing Technical Measures after Closure

1) Temporary closure. When retracting the remaining three sets of end frames, pull these three sets of frames as quickly as possible to a distance of 8 meters from the cutting eye in the wind tunnel, and construct a 2m thick sealed wall 8 meters away from the cutting eye to quickly form a closed area on the working face.

2) Strengthen attention to Sui. Continuously inject CO_2 or low-temperature nitrogen through a sealed pre embedded injection pipe on the inlet side of the airway, stop pumping until the oxygen concentration on the return side drops below 8%, and continue to observe changes in other indicator gases.

3) Permanent closure. After the last three sets of end frames and other equipment on the side of the wind tunnel have been fully withdrawn, a permanent sealed wall will be constructed at the entrance of the wind tunnel for permanent closure. During this period, nitrogen gas will be continuously injected into the goaf at low temperature to ensure that the oxygen concentration in the goaf is below 5%, no CO appears, and stable for one week before injection can be stopped.

5. Conclusion

During the retreat and closing of the working face, different fire prevention and control measures were implemented across four stages: the 25-meter range near the stopping line during the closing phase, the final mining phase, the retreat phase, and post-sealing. Through the rigorous and scientific application of these comprehensive fire prevention measures-particularly the local ventilation and targeted handling of abnormal CO concentration areas-no CO exceedances were detected in the goaf or above the support canopy of the working face. This ensured the smooth retreat and sealing of the working face equipment within 23 days, achieving a rapid one-time withdrawal of the high-gas, prone-to-spontaneous-combustion fully mechanized top-coal caving face. The process provided valuable experience for fire prevention and control management during the retreat of high-gas, spontaneous-combustion-prone fully mechanized mining faces.

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