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Research on Comprehensive Fire Prevention and Extinguishing Technology in Dananhu No.1 Mine

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Abstract: This article starts from the characteristics of the 1303 fully mechanized top coal caving face in the first coal mine of Dananhu, combined with relevant data and drawings of the mine and experimental working face in the first coal mine of Dananhu, and based on the characteristics of spontaneous combustion of residual coal in the goaf after mining of the fully mechanized top coal caving face, using on-site measurement methods, calculates the limit parameters such as residual coal thickness, wind speed, oxygen concentration, etc. that cause spontaneous combustion of coal under different conditions on site, And calculate the distribution pattern of the "three belts" in the 1303 fully mechanized top coal caving face of Dananhu No.1 Mine under actual conditions. And divide the "three zones" of the goaf in the 1303 fully mechanized caving face. Based on the results of the division of the "three zones", the distribution pattern of spontaneous combustion in the goaf is calculated and determined, and combined with the shortest ignition period of residual coal in the 1303 working face measured through experiments, the safe propulsion speed is calculated. Finally, a reasonable set of fire prevention and extinguishing technologies and methods were summarized, providing important guidance for the future fire prevention and control of the Dananhu No.1 Mine and surrounding mines, and providing experience and reference for the application and development of fire prevention and extinguishing measures in the future.

Keywords: Spontaneous combustion; Safety promotion progress; The division of the "three belts"; Fire prevention and extinguishing.

1. Introduction

As the country with the highest number of coal mine accidents in the world, China accounts for about 70% of the world's coal mine accident fatalities[1-3]. In 2011, a total of 1201 accidents occurred in coal mines nationwide, resulting in 1973 deaths. The mortality rate per million tons decreased for the first time to around 0.564[4-6]. In recent years, the safety situation in coal mines has continued to improve, but compared to other countries in the world, the safety situation is still very severe.

Coal mining accounts for 91% of coal mines in China, which is the most complex form of coal mining[7-8]. During the production process, it is often threatened by natural disasters such as gas, water, fire, dust, roof, and weak disaster resistance, resulting in frequent occurrence of coal mine accidents. The spontaneous combustion of coal in goaf has always been one of the main disasters in coal mines in China[9-10].

The coal resources in Xinjiang region are mainly Jurassic brown coal and long flame coal, which generally have a short natural ignition period and have a direct impact on mine safety production. The 3 # coal seam, which was first mined at the Dananhu No.1 Mine, is a type of lignite that is highly prone to spontaneous combustion. Therefore, the spontaneous combustion period is short, and the tendency to spontaneous combustion is high. During the mining process, accidents with CO gas concentration exceeding the limit are very likely to occur. In addition, due to the use of fully mechanized top coal caving mining, there are more and thicker residual coal in the goaf, which increases safety hazards for spontaneous combustion in the goaf. In order to do a good job in comprehensive fire prevention and extinguishing of coal seams that are prone to spontaneous combustion, it is necessary to study the basic physical and chemical properties of coal seams to determine their shortest ignition period, and determine the width of the "three zones" in the goaf and their dynamic changes with the mining speed through on-site monitoring. Early prediction and prediction of coal spontaneous combustion should be done, and a relatively complete set of fire prevention and extinguishing technologies should be developed to ensure safe mining of coal seams.

2. Project Overview

The No.1 Dananhu Coal Mine is located in the eastern part of the Dananhu Coalfield (Zone 1), 84km south of Hami City, and approximately 50km northeast of Nanhu Township. The administrative area is under the jurisdiction of Nanhu Township. The road from Hami to Tuwu Copper Mine and Luobupo Potassium Salt Mine passes through the northern part of the mine. The Lanxin Railway and Ganxin Highway pass through the east side of the mine from northwest to southeast, approximately 60km from the mine boundary. The No.1 Dananhu Mine is 8km long from east to west and 8.0-11.8km wide from north to south, with an area of approximately 75.27km^2. There are a total of 29 coal seams and 23 minable coal seams, with a geological reserve of 5.01 billion tons and a minable reserve of 2.93 billion tons. The designed production capacity is 10.0Mt/a, and the service life is 195 years.

3. Classification of the "Three Zones" of Spontaneous Combustion in goaf and Determination of Hazardous Areas

3.1. Classification of the "Three Zones" of Spontaneous Combustion in goaf

Superposition the contour map of the distribution of floating coal thickness, oxygen concentration, and air leakage intensity observed on site, and based on the limit parameter values of coal spontaneous combustion in the Dananhu Mine, statically divide the "three zones" of the goaf in the 1303 fully mechanized top coal caving face. The division of the three zones in the goaf is shown in Figure 1.

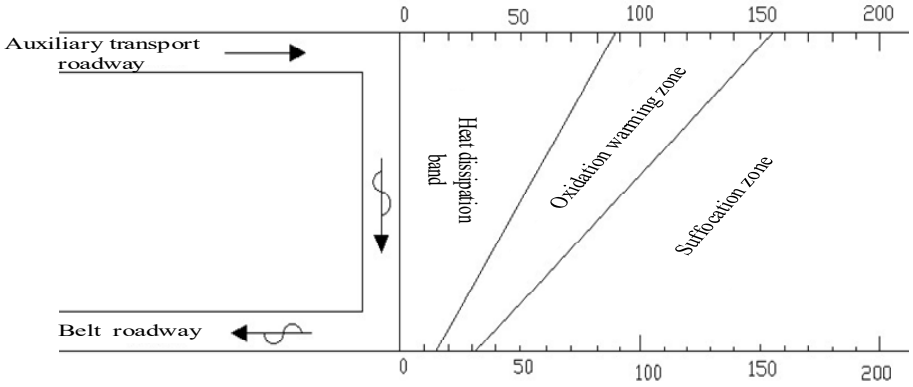

Figure 1. "Three zones" division diagram of goaf in 1303 working face

From Figure 1, it can be seen that due to the high intensity of air leakage on the inlet side of the 1303 working face of the first mine in Dananhu, the width of the heat dissipation zone is relatively wide. The suffocation zone is located in the deep part of the goaf more than 155m away from the working face. On the return air side of the working face, the depth of the suffocation zone is about 30m. The width of the oxidation temperature rise zone is the largest on the air inlet side of the working face, reaching about 65m. The natural temperature rise of coal seam first occurs in the oxidation temperature rise zone of the working face. The wider the oxidation temperature rise zone is, the longer the natural temperature rise time of coal body is, the easier the spontaneous combustion is. The width of the oxidation and temperature rise zone on the intake side of the goaf is the largest, so it is most likely to cause coal seam spontaneous combustion.

3.2. Air leakage intensity distribution

The air leakage intensity that can cause coal spontaneous combustion in goaf is very small, and the air leakage seeps into the goaf, continuously consuming oxygen in the air flow. Assuming that the air leakage flow only flows along one dimension, when the air leakage intensity in loose coal remains constant, the relationship between the air leakage intensity and oxygen concentration is as follows:

$$\overline{Q} = \frac{V_0(T)\cdot(x-x_0)}{C_0\cdot\ln(\frac{C_0}{C})} \tag{1}$$

In the formula: C and C_0 are the actual oxygen concentration and standard oxygen concentration (taken as 9.375×10^{-6} (mol. cm^{-3}) The oxygen consumption rates of loose coal at different temperatures in actual oxygen concentration and standard oxygen concentration, respectively, are the surface air leakage intensity of loose coal Coordinates of the interior and surface of the loose coal body, respectively.

According to the experimental test of spontaneous combustion of coal samples from the Dananhu Mine and the actual observation results of the 1303 goaf, the oxygen consumption rate of the coal sample at 40 ℃ is 88.94×10^{-11} mol/(cm^3·s), and using the measured distribution pattern of oxygen concentration in the goaf, the distribution of air leakage intensity on the inlet and return sides of the goaf can be calculated from equation (1).

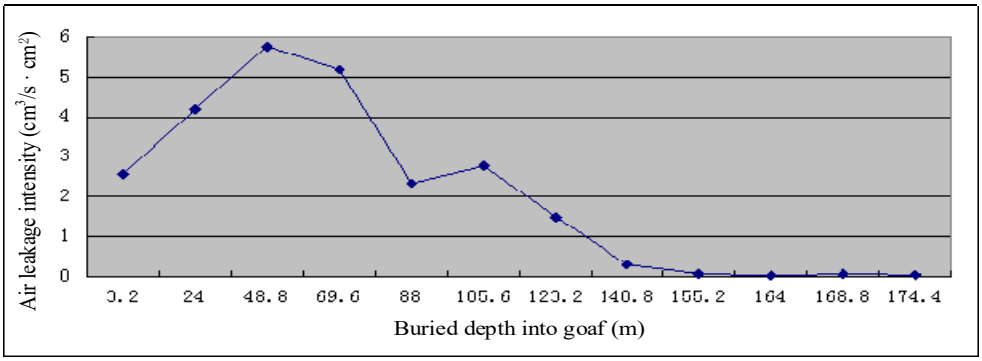

Figure 2. Relationship between Air Leakage Intensity and Distance from Working Face at Measurement Point 2# of Auxiliary Transportation Channel in 1303 goaf

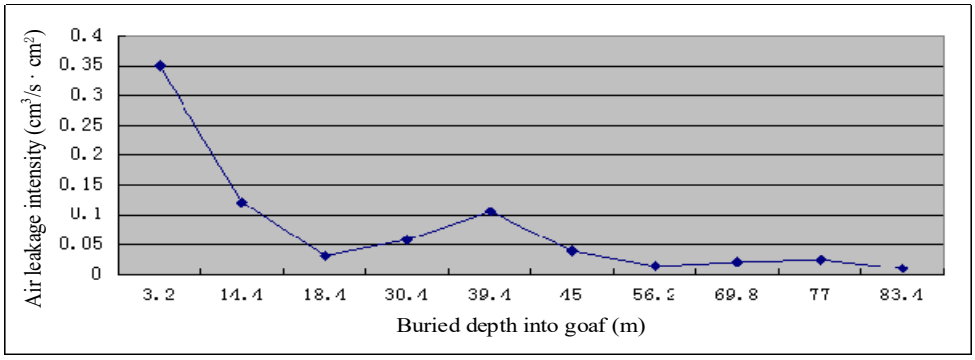

Figure 3. Relationship between Air Leakage Intensity and Distance from the Working Face at Measurement Point 2# of the Rubber Transportation Trough in the 1303 Goaf

From the above analysis, it can be seen that there is significant air leakage in the inlet and outlet air tunnels of the 1303 goaf of the Dananhu No.1 Mine, which puts forward high requirements for the prevention and control of coal spontaneous combustion in the goaf.

3.3. Dangerous areas of spontaneous combustion in goaf and safety promotion speed

Floating coal in goaf is only possible to self ignite within the range of oxidation temperature rise zone, that is, the range of oxidation self ignition zone is less than or equal to the oxidation temperature rise zone. Therefore, only based on the actual advancing speed of the working face and the dynamic changes in the oxidation temperature zone can the danger zone of oxidation and spontaneous combustion in the goaf be determined.

Based on the shortest natural ignition period of the coal seam τ_m and the advancing speed of the working face L_0, the advancing distance of the working face during the shortest natural ignition period can be calculated:

$$L_0 = \tau_{\min} \times v_0 \tag{2}$$

In the formula: v_0 is the designed working face propulsion speed or the actual average working face propulsion speed (m/d).

In the area where the length L of the oxidation temperature rise zone in the goaf of the fully mechanized top coal caving face is less than L_0, floating coal will not undergo spontaneous combustion. The area with a length greater than L_0 the oxidation zone may cause spontaneous combustion of floating coal, and the area within L-L_0 the oxidation temperature rise zone of the goaf is the danger area of oxidation spontaneous combustion.

Based on the length of the oxidation zone in the goaf and the actual shortest natural ignition period of the coal seam, the safety progress of the working face can be calculated.

When the advancing speed of $v(\tau) \geq v_A$ the working face increases, there will be no spontaneous combustion of floating coal in the goaf. For the 1303 fully mechanized caving face, the critical advancing speed of the working face is:

$$v_{\min} = \frac{L_{\max}}{\tau_{\min} \cdot \kappa} = \frac{67}{37 \times 1.36} = 1.33\text{m/d} \tag{3}$$

Therefore, under continuous nitrogen injection conditions, when the advancing speed of the coal mining face is greater than 1.33m/d, there is no risk of natural ignition in the goaf; When the average advancing speed of the working face exceeds 37 consecutive days and is less than 1.33m/d, there will be a risk of natural ignition in the goaf. According to the normal daily average advance speed of Working Face 1303 being 3.35m/d, which is greater than the safe progress of spontaneous combustion in the goaf. Therefore, under normal mining conditions, the goaf will not cause spontaneous combustion of floating coal. However, due to severe air leakage, the "two channels" are still key areas for fire prevention.

4. Mine Fire Prevention and Extinguishing Technology

4.1. Grouting fire prevention and extinguishing

To prevent spontaneous combustion in the goaf and ensure safe production, preventive grouting is adopted in the design, and grouting is carried out simultaneously with mining. To facilitate management and improve efficiency, a centralized grouting system has been determined. According to the geographical location and ground conditions of this mine, fly ash from nearby power plants is used as grouting material. The amount of grouting materials is determined based on parameters such as daily mine volume and grouting coefficient. The grouting pipeline is determined based on the hourly grouting volume and the economic flow rate of mud in the pipeline.

(1) Grouting system

A fixed ground grouting and glue injection fire extinguishing system is adopted, and a centralized fire prevention grouting mixing station and mud pool are set up near the air shaft of the industrial site. After passing through the colloid preparation machine, the fly ash enters the buffer pool through a slurry filter. The fly ash is lowered into the air shaft through a slurry pump, and then sent to the upper groove of each mining face through a main pipeline. Finally, the coal mine in the groove is injected into the goaf of the mining face using a grouting machine.

(2) Grouting method

According to the characteristics of coal seam mining in this mine, preventive grouting is carried out by burying pipes in the goaf, and the mining face is grouted as it is mined. Embed 10-20m steel pipes along the upper groove of the working face in the goaf, with one end in the goaf and one end connected to a high-pressure rubber pipe. The rubber pipe is

20-30m long, and grouting begins after coal mining. As the mining face advances, use a column winch to gradually pull the grouting pipe, pull a certain distance, and then pour once.

4.2. Chemical inhibitor fire prevention and extinguishing

The inhibition technology of inhibitor is to inject or spray a certain proportion of inhibitor solution through pressure injection or spray system, which is carried into loose coal by air flow. The inhibitor solution forms a liquid film that wraps around the surface of floating coal or coal cracks, isolating the contact between coal and oxygen, and slowing down the oxidation rate. When the water in the inhibitor solution evaporates, it absorbs the heat of coal oxidation, preventing the accumulation of coal heat and making it difficult to reach the self ignition temperature, thus achieving the goal of fire prevention.

(1) Selection of Inhibitors

Based on the coal quality of this mine, magnesium chloride ($MgCl_2$) is selected as the inhibitor.

(2) The ratio and dosage of inhibitor

The concentration and dosage of the inhibitor are related to the permeability, porosity, liquid absorption capacity, fire prevention and extinguishing effect of coal, as well as the cost per ton of coal. After considering various factors comprehensively, the concentration of MgCl2 solution is preliminarily selected to be 15-20%;

(3) Inhibitor fire prevention process

There are two main processes for preventing and extinguishing fire with chemical inhibitors: pressure injection of chemical inhibitors and spraying of chemical inhibitors. The pressure injection inhibitor is mainly used for the prevention and control of coal spontaneous combustion in working faces, such as cutting holes, stopping mining lines, and grooves. Spraying inhibitors is the use of atomizing nozzles to spray atomized inhibitors into the goaf.

There is an inhibitor spraying system installed in the mine, which uses a matching atomization nozzle to spray atomized inhibitor into the goaf, and can also be sprayed on floating coal in the working face and goaf. Its use depends on whether there is a possibility of ignition in the goaf. Inhibitor spraying equipment: 2 WJ-24 type, with a working pressure of 2-3MPa, a working flow rate of 2.4m^3/h, and a power of 2.2kW.

4.3. Nitrogen injection fire extinguishing system

4.3.1. Selection of nitrogen injection fire extinguishing system

The 1303 fully mechanized caving face adopts a ground pressure swing adsorption nitrogen production system, which has the following advantages: unlimited raw materials and low operating costs; Simple structure and small footprint; Flexible application, the purity, pressure, and gas volume of nitrogen can be adjusted according to needs; The use of internationally advanced molecular sieve loading technology has effectively improved the molecular sieve loading technology, effectively improved the adsorption efficiency of molecular sieves, prevented molecular sieve pulverization, and extended the service life of molecular sieves; Nitrogen can be directly transported over long distances without the need for pressurization; It can be arranged together with the air compressor room, using the compressed gas produced by the air compressor room as the nitrogen gas source, thereby saving project costs; Once nitrogen injection is required to extinguish the fire underground, the specialized nitrogen injection pipeline in the mine can be used to conveniently and quickly transport nitrogen with a large flow rate to the accident site for firefighting operations; The purity range is large, with a high flow rate of 95% -97% for nitrogen supply during firefighting, and a low flow rate of 99% -99.9% for oxygen reduction; The fixed nitrogen generation device is located far from the accident site and can continuously supply oxygen with a large flow rate through pipelines, quickly suppressing and extinguishing the forced interruption of operations, or affecting the firefighting effect due to insufficient equipment output caused by on-site air turbidity, high temperature, and other reasons.

In addition, based on the investigation of nitrogen injection intensity and the characteristics of natural combustion in adjacent mining areas, while continuously injecting nitrogen, nitrogen injection can be focused on the mining line, stop mining line, coal pillar, both sides of the inlet and return air duct, and the uneven and irregular mining face, which cannot be pushed forward normally. This can achieve the goal of preventing and extinguishing fires while reducing costs.

4.3.2. Nitrogen injection process

According to the different conditions of the mine, nitrogen injection processes include buried pipe nitrogen injection, dragging pipe nitrogen injection, drilling pipe nitrogen injection, inserting pipe nitrogen injection, sealed nitrogen injection, and bypass nitrogen injection. For fire prevention design, dragging pipe nitrogen injection is mainly considered as the main nitrogen injection method, and for fire extinguishing, sealed nitrogen injection is mainly considered as the main method.

4.3.3. Monitoring of nitrogen injection gas

In order to facilitate sampling and analysis in the goaf and grasp the gas changes in the goaf, a beam tube monitoring probe is pre embedded in the goaf for sampling observation.

4.4. Tube monitoring system

To ensure safe production in the mine, an SG-2003 bundle tube monitoring system is also installed for underground environmental monitoring, mainly used for analyzing the composition of underground gas, achieving 24-hour online continuous monitoring of CO, CO_2, CH_4, O_2, N_2 (calculated values) gas content, and predicting its changes in content. The system adopts a high-precision and low-drift gas analyzer, which can detect the critical point of spontaneous combustion in the early stage. The bundle tube monitoring points are set up at the mining face, goaf, etc., with 4 monitoring points set up for each working face. The gas composition measured by the bundle tube monitoring system is displayed in real-time on the display screen and used for early prediction of coal spontaneous combustion.

4.5. Prevention of spontaneous combustion in the goaf during the stopping and dismantling period of the working Face

4.5.1. Monitoring of goaf in the working face during final mining and frame removal

When there is a risk of spontaneous combustion in the goaf, due to the dilution effect of air flow, it is difficult to timely monitor the changes in the sign gas of spontaneous combustion in the working face. In order to monitor the gas concentration in the goaf in a timely manner during the shutdown and removal of the mining rack, and to deal with

the phenomenon of oxidation and temperature rise in the goaf in a timely manner, it is necessary to embed a bundle tube on the sealing wall near the side wall when the working face is within 100m from the shutdown line.

In the upper and lower alleys of the working face, a bundle pipe is left at the rear of the stop mining line at 90m, 60m, 30m, and a bundle pipe is left at the return air alley at 70m, 50m, 30m, and 0m, to strengthen the monitoring and early prediction of residual coal in the goaf during the final mining and removal period. During the shutdown period, gas samples are collected through bundle tubes to predict and analyze the development trend of coal spontaneous combustion in the goaf near the final mining line.

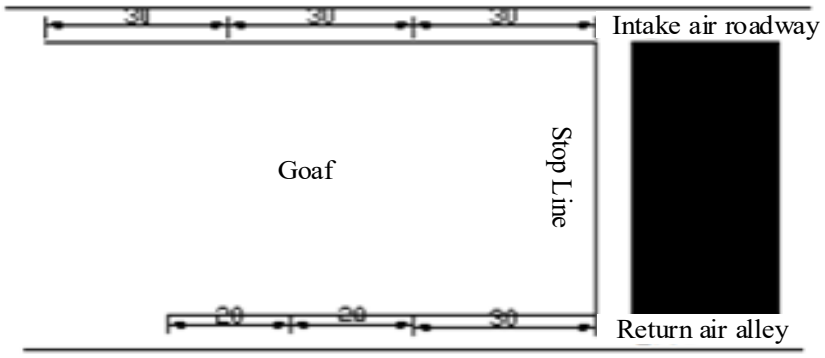

Figure 4. Layout of goaf monitoring points

4.5.2. Fire prevention and extinguishing measures during the final mining and suspension of mining and removal of frames

(1) Measures for blocking and reducing air flow before stopping mining and removing frames

In order to reduce air leakage in the goaf during the period of stopping mining and removing the support, when the fully mechanized top coal caving face is advanced to a distance of 170m from the stopping mining line, a sealing wall is constructed at the ends of the upper and lower alleys, mainly constructed with fly ash. Construction will be carried out every 50m of the working face, and a total of 5 sealing walls will be constructed at the stop line position.

After the working face is pushed into the area without top coal caving, in order to reduce the risk of spontaneous combustion and ignition in the fully mechanized top coal caving working face during this period, while ensuring that the gas return flow at the tail, upper corner, and working face does not exceed the limit, the air supply to the working face is minimized as much as possible, achieving low air volume and low negative pressure air supply. And timely adjust according to the actual situation, ensuring that the gas in the upper corner does not exceed 1% and the return air gas does not exceed 0.5%, in accordance with the relevant provisions of the "Coal Mine Safety Regulations". During the temporary shutdown period, in order to reduce the diffusion and leakage of air into the goaf, it is necessary to reduce the air volume of the working face from the normal 900m^3/min to 400m^3/min. And set up wind curtains in the secondary alleys.

(2) Injecting liquid CO_2 into the goaf for fire prevention and extinguishing

From the perspective of combustion, the inert gas in goaf fire prevention has a inhibitory effect on the oxidation of coal. From the perspective of coal oxidation and spontaneous combustion, except for oxygen gas, carbon dioxide, nitrogen, and other inert gases can be considered in the gas components of the goaf. So injecting CO_2 can effectively reduce the oxygen concentration in the goaf, thereby achieving the goal of preventing coal spontaneous combustion. Oxygen plays a role in supporting the spontaneous combustion of coal, so the effect of nitrogen and CO_2 injection in the oxidation zone of goaf can be seen from the changes in oxygen concentration. Therefore, the inerting index of goaf can be measured by the critical value of oxygen content. Practical experience and theoretical analysis indicate that when the oxygen content in the goaf decreases to 5-10%, it can suppress the oxidation and spontaneous combustion of coal.

During the period of stopping mining and lifting the mining frame, it is recommended to inject liquid CO_2 with high intensity when starting to prevent spontaneous combustion in the working goaf. Observe the changes in CO concentration, and then adjust the injection amount. The initial gas injection volume Q_1 can be calculated using the following formula:

$$Q_1=W•H•L•K_1•K_2$$

Where W is the width of the inerting zone, H is the height, L is the length of the inerting zone, and K_1 is the gas replacement coefficient in the goaf; $K2$ is the loose coefficient of the goaf.

During the period of injecting liquid CO_2 into the goaf, the tile inspector needs to check the CO_2 concentration at the end support of the working face. When the concentration exceeds the relevant requirements of the Coal Mine Safety Regulations, the working face is prohibited from working, and the staff should immediately withdraw. Finally, during the injection of liquid CO_2 into the goaf, if there is a leakage in the pipeline, it is necessary to immediately shut down the liquid CO_2 injection machine, stop injecting liquid CO_2 into the goaf, and take corresponding sealing measures for the liquid CO_2 injection pipeline.

At the same time, the flow rate of CO_2 injection is directly proportional to the air leakage in the oxidation zone of the goaf. As long as the air leakage in the goaf is reduced, the flow rate of CO_2 injection can be reduced, and the effectiveness of CO_2 injection can be improved. During the removal period, CO_2 injection will not be stopped for 24 hours. Increase the amount of CO_2 injection into the goaf, reduce the oxygen concentration in the goaf, and adopt a combination of overall CO_2 injection and local CO_2 injection.

(3) Strengthen the sealing of the "two channels" in the goaf

Improve the quality of the currently implemented sealing

work for the two coal (sand) bag walls in the goaf. Inject polymer colloids 65m, 35m, and 15m away from the stoping line on the air inlet side of the goaf to form a sand bag sealing wall with a direction of 4-7m, a inclination of 9-13m, and a height of 3-5m. Press the injection pipeline inside the wall, and at the same time, construct injection drilling after the sealing wall on the air inlet side of the goaf in the working face, and inject glue into the sealed wall, as shown in Figure 5.

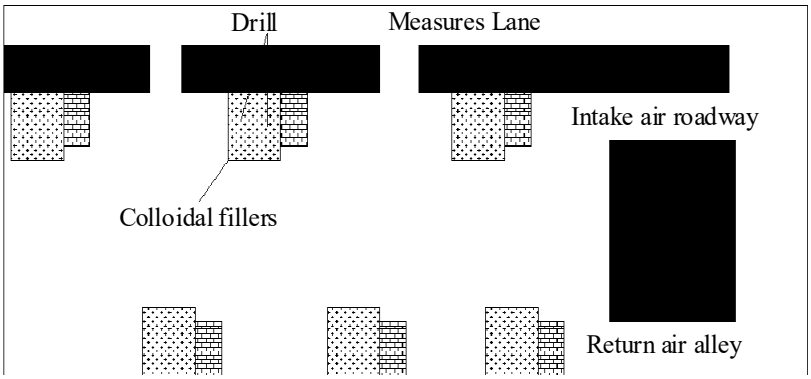

Figure 5. Two Fire Protection Diagrams

(4) Post rack processing after stopping mining

During the suspension and dismantling of the fully mechanized top coal caving face, in order to prevent the spontaneous combustion of a large amount of floating coal that was not released before the suspension of the face, it is necessary to drill and inject polymer colloids into the goaf to effectively block and cool the floating coal, ensuring the normal dismantling of the face. Spray inhibitor into the goaf within the last 50m of the stop mining line to extend the spontaneous combustion period of floating coal. The inhibitor inhibition technology is to press or spray the inhibitor solution prepared in a certain proportion into the loose coal body through the pressure injection or spray system and bring it into the loose coal body by air flow. The inhibitor solution forms a liquid film to wrap the surface of the floating coal or the crack of the coal, isolate the contact between the coal and oxygen, and slow the oxidation rate. When the water of the inhibitor solution evaporates, it absorbs the oxidation heat of the coal body, making it difficult for the heat of the coal body to gather and reach the spontaneous combustion temperature, Thus achieving the purpose of fire prevention. The use of flame retardants has a good fire prevention effect on preventing spontaneous combustion of floating coal in working face cuts, stoping lines, goaf areas, and adjacent goaf areas along goaf slots. This technology not only blocks the spontaneous combustion of goaf, but also prolongs the spontaneous combustion period of coal. Inhibitor materials have the characteristics of wide source, low cost, simple pressure injection or spray process and easy operation.

5. Conclusion

The distribution of floating coal thickness in the goaf is determined based on the measured coal heat release intensity and oxygen consumption rate through natural ignition experiments, the actual situation of the working face, and the recovery rate; By burying pipes or drilling holes in the goaf, the oxygen concentration distribution in the goaf can be measured, and the distribution of air leakage intensity can be calculated from the oxygen concentration distribution; Using the mathematical model of floating coal spontaneous combustion to calculate the limit parameters of floating coal spontaneous combustion in the goaf, dividing the "three zones" and dangerous areas of spontaneous combustion in the 1303 fully mechanized top coal caving face of Dananhu Coal Mine, and calculating the safe propulsion speed, it can be concluded that:

(1) There is significant air leakage in the inlet and outlet air tunnels of the 1303 goaf of the Dananhu No.1 Mine. Necessary measures should be taken to reduce air leakage during the mining process of the working face to prevent spontaneous combustion of residual coal in the goaf.

(2) The minimum safe advance speed of 1303 coal mining face is 1.33m/d. When the propulsion speed is less than 1.33m/d, there is a risk of natural ignition in the "two" goaf. Even if the progress exceeds 1.33m/d, the "two lanes" are still the key areas for fire prevention.

(3) In order to reduce the risk index of spontaneous combustion in goaf, firstly, measures should be taken to reduce the range of heat dissipation zone and oxidation temperature rise zone in goaf, and secondly, to improve the advancing speed of the working face. The purpose is to quickly throw the heat dissipation zone and oxidation temperature rise zone into the suffocation zone, in order to reduce the risk of spontaneous combustion in goaf.

(4) During the shutdown and removal of the working face, due to the significant decrease in the progress of the push, stricter fire prevention measures need to be taken to prevent coal spontaneous combustion.

References

[1] Wang Shuo. The heavy chemical industry is the main cause of air pollution in North China: the phenomenon of coal dominance is common Chemical Management 2016, 1.

[2] Dai Deli. The Energy World in 2011: Fractures and Continuation [J]. BP World Energy Statistical Yearbook, 2012, 1.

[3] Wu lilong, Jiang zhongan, Cheng weimin Major accident analysis and prevention of coal mines in China from the year of 1949 to 2009 [J] Mining Science and Technology (China) 2011, 21:693-699.

[4] State Council Information Office of the People's Republic of China. Current Situation of Energy Development [J]. White Paper on China's Energy Policy (2012), 2012, 10.

[5] State Administration of Work Safety. In 2011, there were 1973 deaths in coal mine accidents in China, and the total number of accidents decreased significantly [EB/OL] China News Network, http://www.chinanews.com/gn/2012/01-14/3605009. shtml. 2012, 1.

[6] State Administration of Work Safety. 12th Five Year Plan for Coal Mine Safety Production. General Coal Loading of Work Safety Supervision (2011) 187 [EB/OL] http://www.china.com.cn/policy/txt/2011-12/07/content_24092977. htm. 2011-12.

[7] Tang Mingyun Coal Spontaneous Combustion Prediction Method and Discussion in Goaf [J] Coal Technology, 2004,23 (10): 1008-8725 (2004) 10-0104-02.

[8] The Relationship between Coal Mine Safety and the Value of Coal Resources: An Analysis of Wang Yuhuai and Li Xiangyi -"China's Land and Resources Economy"-2005-06-25.

[9] Chakharov E И. Chemical activity identification of coal spontaneous combustion [J]. Industrial Labor Safety, 1989, (7): 38-39.

[10] Deng Jun, Xu Qiaojing, Ruan Guoqiang, Wang Xiulin Summary of prediction and prediction technologies for coal spontaneous combustion at home and abroad [J] Journal of Xi'an Institute of Mining and Technology, 1999, 12.