Application of coal seam grouting to prevent and extinguish fire technology in Fusheng Coal Mine

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Abstract. Spontaneous combustion of coal not only releases toxic and harmful gases, but also may cause gas and coal dust explosions to endanger the lives of miners. The No.15 coal seam of Fusheng Coal Mine in Shanxi has a short period of spontaneous combustion and is prone to spontaneous combustion. In order to prevent spontaneous combustion of coal seams, it is proposed to use grouting to prevent fire extinguishing technology, mainly through the design of grouting system, the selection of grouting materials, the calculation of grouting parameters, the optimization of grouting technology and the selection of grouting equipment, etc. And it establishes methods for monitoring the effects of grouting zone temperature and gas composition, fire-fighting grouting accounts, etc. A series of grouting safety technical supporting measures such as grouting work system, prevention of pipe blockage, prevention of slurry running, setting of filter slurry sealing and drainage channels, etc. are proposed.

1. Introduction
Fusheng Coal Mine is located in Liujiazhuang Village, Hanwang Township, Zuoquan County, Shanxi Province. The coal mine field covers an area of 5.8196 km², and the retained resources/reserves of the No.15 coal seam in the mine field are 40.02 Mt. The mine adopts mechanical extraction ventilation. The air distribution at the working face is 19.0 m³/s, and the total air demand in the mine is 135 m³/s. The gas content of No.15 coal seam is 6.68~10.73 m³/t. The oxygen absorption of No.15 coal seam is 0.47 cm³/g, the spontaneous combustion tendency of No.15 coal seam is Class II, which belongs to the spontaneous combustion coal seam, and the test result of the short spontaneous combustion period is 65 days. Spontaneous combustion of coal not only releases toxic and harmful gases, but also may cause gas and coal dust explosions to endanger the lives of miners [1-3]. The research results show that: grouting to prevent fire is one of the effective ways to prevent coal spontaneous combustion [4-8]. Therefore, in order to prevent the spontaneous combustion of the No.15 coal seam, it is treated with grouting to prevent fire extinguishing technology.

2. Design of grouting fire prevention system
Preventive grouting is the most widely used and best-effect technology to prevent spontaneous combustion of coal [9-10]. The so-called preventive grouting technology refers to mixing water and
grouting materials in an appropriate ratio to prepare a certain concentration of slurry, and then use the spontaneous combustion pressure difference or slurry to be pumped to the area where spontaneous combustion of coal may occur through the laid slurry pipeline in order to prevent the occurrence of spontaneous fire. The loess resources near the coal mine are rich, and according to the applicable conditions of each grouting system, it is suitable to establish a ground grouting fire-fighting system.

2.1. Selection of grouting system
The grouting system is basically divided into centralized grouting and decentralized grouting. Centralized grouting is generally applicable to conditions such as deep coal seams and concentrated production in mining areas. Dispersed grouting is generally suitable for conditions such as shallow coal seams, abundant soil sources, and on-site mining.

2.2. Grouting material, grouting method
The pulping system adopted is that the slurry is transported from the mining site to the grouting station soil yard by truck, and the loess is sent into the slurry tank of the pulping machine by a scraper conveyor.

2.3. Calculation and selection of grouting parameters
① Grouting coefficient
The grouting coefficient (K) refers to the ratio of the solid volume of the grouting material to the volume of the goaf that needs to be grouted, and K is taken as 0.05. The fire extinguishing grouting coefficient can be increased correspondingly depending on the fire extinguishing situation.

② Soil-water ratio
It should be changed correspondingly with the inclination angle of the coal seam, grouting method, treatment object, grouting season, and grouting multiple line. The grouting in the goaf is usually 1:2~1:5. The design is 1:3 in summer and 1:4 in winter.

2.4. Calculation and selection of grouting amount
The determination of the preventive grouting amount mainly depends on the grouting form and the volume of the grouting zone. For the pre-grouting before mining and the closed stop production line after mining, the filling space shall prevail. The daily amount of loess (Q) that is mined and injected can be calculated as follows:

\[
Q = k \frac{G}{r_c} = \frac{0.05 \times 3636}{1.44} = 126.5 m^3/d
\]

Where: Q is mine daily soil demand, m³/d; k is grouting coefficient, taken as 0.05; G is mine daily coal production, 3636 t; \(r_c\) is coal seam bulk density 1.44 t/m³.

The actual amount of excavated soil required for daily grouting is: 1.1×126.5=138.83 t;
Water consumption per mud making: 138.88×3=416.64 m³/d;
The daily mud water consumption is calculated as follows: \(Q_{water} = 1.1 \times 416.64 = 458.30 m^3/d\);
Daily grouting quantity: \(Q_{grout}=(458.30+126.25)\times0.94=510.32 m^3/d\).

2.5. Mud preparation process
The coal mine design adopts ground grouting method, and mechanical slurry preparation is used for slurry preparation. The grouting system is composed of soil borrowing and storage site, crushing and conveying system, quantitative pulping system, admixture adding system, and slurry pipeline network system. The quantitative pulping system consists of a mixer and a slurry pump. The admixture adding system is used to add colloid agent to loess. After the loess and water are quantitatively mixed and stirred into a slurry, it is transported to the slurry filter for filtration, and then static pressure transport or slurry pump transport to the underground grouting pipe network system, and finally to the grouting site.
2.6. Selection of grouting pipeline

The diameter of the main grouting pipe is selected according to the flow rate of the mud in the pipe. In the design, after the mud is given, the critical flow rate of the mud flowing in the pipeline is determined first, and then the actual working flow rate of the mud is calculated to be greater than the critical flow rate. Actual working flow rate:

\[
\nu = \frac{4Q_{\text{slurry max}}}{3600\pi d^2} = 1.55 \text{ m/s}
\]

Where: \( \nu \) is the actual working flow rate of the mud in the pipeline, m/s; \( Q_{\text{slurry max}} \) is the hourly grouting volume, 17.45 m\(^3\)/h; \( D \) is the inner diameter of the pipeline, taking 108 mm.

The actual working flow rate is at the maximum critical flow rate (the critical flow rate of the mud steel pipe is usually 1~4 m/s), which can meet the needs of the project. Surface grouting pipes generally use cast iron pipes; underground grouting pipes use seamless steel pipes with a diameter of 108 mm; the diameter of the working surface pipes is 4 inch rubber pipes. The underground slurry pipeline should avoid the arrangement of "high at both ends and low in the middle", and minimize elbows.

3. Grouting method and equipment

3.1. Grouting method

According to the sequence relationship between coal mining and grouting, preventive grouting methods can be divided into: pre-mining pre-injection, follow-up injection and post-mining grouting. In order to ensure timely and simple handling of hidden dangers of spontaneous combustion, the buried pipe grouting method is designed. Using buried pipe grouting method, grouting pipes (generally pre-buried 15~20 m steel pipes) are laid in the goaf along the return airway. One end of the pre-embedded pipe is connected to the goaf and one end is connected with a rubber hose. The length of the rubber pipe is generally 20~30 m, the grouting follows the advancement of the working face, the grouting pipe is gradually pulled by the column-returning winch, and a certain distance is drawn to inject the grouting once. It is required that sufficient mud can be injected into the goaf of the working face. The specific layout is shown in Figure 1.

**Figure 1.** Schematic diagram of buried pipe grouting

In order to prevent the collapse of the blocking wall during the grouting pipeline, the grouting pipeline can be buried in advance, that is, the grouting pipeline is buried in the goaf for a certain distance
(20~30 m) and then the grouting is started. The second grouting pipeline is buried in the goaf for circulation. The buried distance of the grouting pipeline can be adjusted according to the grouting effect. When the mine adopts the downward mining method, in order to prevent the grouting water from flowing from the goaf into the working face conveyor or down the trough, the grouting pipeline is buried in the goaf for a distance of 35~40 m, and then the grouting is started. Ditches and sump pits are arranged in the working face along the trough, and equipped with small water pumps, which can meet the discharge requirements of water gushing and slurry water separation when the working face is mined down. Fill and seal the working face and lower corners at regular intervals, and clean the coal falling between the supports in time to reduce the amount of coal left in the goaf. Every day, the maintenance team will block the two corners of the coal mining face, block the air leakage passages in time, and block the upper and lower corners of the full section with bagging.

3.2. Grouting equipment

The coal mine uses the SB160-37kw grouting pump produced by Cangzhou Zhongyou Solid Control Equipment Co., Ltd. The main performance parameters of the equipment include the following:

1. Impeller speed: 721r/min;
2. Mixing diameter: ≥1200mm;
3. Installation size: 880mm*640mm*460mm;
4. Weight: 680kg; Yellow mud mixer;
5. Explosion-proof self-propelled ZNJ-60/11+1.0KW.

It is necessary to purchase 2 sets (one use and one standby) ZHJ-6/5 type downhole mobile grouting device to take targeted grouting to prevent and extinguish fires at local high temperature points in the well and the spontaneous combustion hazard areas during the suspension and withdrawal period. The grouting parameters are shown in Table 1.

| Grouting device model | Limit data | Screw grouting pump | Metering pumps | Blender |
|-----------------------|------------|---------------------|----------------|---------|
|                       | m³/h       | Motor Power kW      | Horizontal conveying distance m | Maximu m flow L/h | Motor Power kW | Effectiv e volume m³ | Motor Power kW |
| ZHJ-6/5               | 6          | 5                   | 22             | 1500     | 400       | 5                 | 2.2               | 0.4             | 3               |

4. Investigation on the effect of grouting to prevent fire

(1) Monitoring of temperature and gas composition in the grouting zone
Special personnel are sent to regularly inspect the gas, coal temperature and outlet water temperature in the grouting fire extinguishing area, grouting fire prevention working face and the goaf, and use the fire bundle tube monitoring system to inspect the gas distribution in the "three zones" of the goaf. The gas collection locations are: return air lane, upper corner, return air side of the oxidation zone in the mined-out area; inside the enclosed wall of the ventilation fire area or inside the borehole. When manual sampling is used for gas analysis on the ground, special sampling bags or samplers must be used for sampling. After sampling, it should be sent to the ground laboratory for chromatographic analysis within 5 hours. The grouting fire prevention area shall regularly sample and test each sampling point. Take samples once a day in the enclosed area of grouting and fire extinguishing. Samples will be taken for testing and analysis every shift at the working face or other locations during the fire period (when not closed).

(2) Establish grouting account for fire prevention and fire prevention
The grouting and fire prevention account mainly includes the location of the grouting area, drilling engineering, grouting engineering, grouting volume, fire prevention and fire containment wall engineering, mud distribution, etc.
5. Safety technical measures for grouting

(1) Grouting work system
Combining the characteristics of coal seam spontaneous combustion, mine mining technical conditions, ventilation conditions and other factors that affect the spontaneous combustion of coal, the safety prevention and fire-fighting measures based on nitrogen injection are adopted under normal mining conditions. No grouting to prevent and extinguish fires under daily conditions.

(2) Prevent pipe blockage
In order to prevent mud pipe blockage during grouting, in addition to strictly controlling large particles (greater than 2 mm) into the slurry pipeline, flush the slurry pipeline with clear water before grouting, and then grouting. After the grouting is finished, clean with clean water to prevent mud from settling in the pipe and blocking the pipe.

(3) Prevent running pulp
During the grouting period, careful inspection should be carried out on the pipeline joints and the coal and rock near the seal to avoid running out of slurry. When adopting the preventive grouting method of mining and injection, if the management is not proper, the mud overflowing to the working surface will often occur. For this reason, the grouting site should have a certain safe distance from the working surface, generally 15~20 m. The working surface can also be made of wood plank to block the grout. After grouting for a period of time each time, when the working face shows signs of water outflow and grouting, the grouting should be stopped.

(4) Observation of water regime
The amount of water injected into the goaf and the amount of water discharged should be recorded and calculated in detail. Attention should be paid to the mud content of the water discharged from the grouting area. If the mud content in the water increases, it means that a grout is formed in the goaf, and the mud is not evenly distributed in the goaf, but flows directly from the goaf, which is bound to reduce the grouting effect. Therefore, it is necessary to appropriately increase the amount of sand in the mud and fill the waterway with sand in order to increase the distribution range of the mud.

(5) Set up filter slurry airtight and drainage channels
In the transportation lane of the grouting face, the filtering area is separated from the working area with water filtering. The mud water flows out through the filter slurry and leaves the mud sand in the grouting area. In this way, the water can be smoothly discharged from the ditch, and the accumulation of mud in the transportation lane will not occur, which will hinder transportation and worsen the working conditions.

(6) Drainage measures in the grouting area
The dehydration time of the grout injected into the goaf is generally 7 to 15 days. Part of the water released from the grout is absorbed by the surrounding rock, and part is retained in the lower space of the grouting area. The drainage measures in the grouting area mainly adopt the following measures:
① Set drainage holes or overflow holes at the bottom of the closed wall at the lower part of the grouting area. After grouting, the changes in the drainage of these closed walls should be observed at any time. ② Before excavation in the lower part of the grouting area, drilling holes or other measures must be taken to discharge water in the grouting area. ③ According to the spontaneous combustion level of the coal seam and the actual situation on site, the method of buried pipe grouting is determined. ④ When the mine adopts the downward mining method, the mine grouting adopts the mining-and-injection method. Part of the grouting water will flow from the mined area into the working surface conveyor or the drainage channel. At this time, it is better to construct a filter slurry in the tunnel Seal the mud in the goaf to release the water.

6. Conclusion
(1) The working face has been treated with grouting fire prevention technology, mainly through the design of grouting system, the selection of grouting materials, the calculation of grouting parameters, the optimization of grouting technology and the selection of grouting equipment, etc. Establish a series
of effect inspection methods such as monitoring of temperature and gas composition in the grouting zone, and fire prevention and grouting accounts.

(2) Practice has proved that the grouting prevention and fire fighting technology has been well applied in the No. 15 coal seam, and the coal seam spontaneous combustion phenomenon occurs at the end of the working face, which ensures the normal working of the working face.

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