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Full Length Research Paper

Safe and efficient mining technology for full-mechanized caving face of deep mine with capacity of ten million tons

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Based on a highly intensive mining mode of "one mine, one coalface, ten million tons", safe and efficient mining technology for full-mechanized caving face of deep mine with capacity of ten million tons is proposed to deal with technical problems such as high ground pressure, high ground temperature, high water pressure and easy spontaneous combustion of coal seam in Longgu coal mine. The surrounding rock control technology was researched to effectively control the high ground pressure. The treatment and utilization technology for high temperature and heat hazard was initiated to lower the average temperature in main workplaces by 8 L. The treatment and utilization technology of high-pressure massive water gushing was adopted to ensure safe mining under the condition of 8 MPa water pressure in deep mine. A precautionary and preventive technology for spontaneous combustion of coal seam of "coal body inhibition + air-leakage control + local inerting" is proposed to stop spontaneous firing of coalface in high ground temperature. The research results have effectively solved the technical difficulties and have realized safe and efficient production for deep mine with capacity of ten million tons.

Key words: Deep mine, high ground pressure, high ground temperature, high water pressure, easy spontaneous combustion.

INTRODUCTION

Among the coal reserves in China, those with the burial depth of over 1,000 m reach 2.95 trillion tons, which account for about 53% of the total. The average mining depth in China is increasing at a rate of 8~12 m/a. After the mines have been explored further deeply, mine production is generally made more difficult due to high strata pressure, growth of water gushing, and increased ground temperature (Wan et al., 2013).

Longgu coal mine covers an area of about 180 km^2 and has geological reserves of 1.68 billion ton. With 2301 coalface as its demonstration project, Longgu coal mine researches the mining technology for full-mechanized

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Figure 1. ZF15000/23/43hydraulic support.

caving face with capacity of ten million tons under the conditions of high ground pressure, high ground temperature, high water pressure, and easy spontaneous combustion, having formulated highly productive and efficient production technology for coalface with burial depth of 1,000 m to ensure coal output of ten million tons.

TECHNICAL DIFFICULTIES

Located -810 under the ground, the 2301 coalface of Longgu coal mine has an average burial depth of nearly 1,000 m, inclined length of 256 m, and strike length of 1,600 m. The main mining coal seam is No.3 coal seam, with coal thickness of 3.6~10.4 m (average: 9.2 m). The average thickness of thin bedrock on the coal seam is about 200 m, but there is extremely thick alluvium with an average thickness of 700 m on the bedrock. Long-wall method of full-mechanized caving is adopted, with mining height of 4.0 m, roof caving height of 5.2 m.

(1) High ground Pressure: The burial depth of mining roadway project is rather deep, and the roadway is overlaid with thin bedrock of extremely thick alluvium, which makes the supporting difficult.
(2) High ground temperature: The original rock temperature in the mining area is up to 46 L. The air temperature of the coalface is even above 35 L and its humidity reaches 95%.
(3) High water pressure: Aquifer is mainly the sandstone of roof and floor, and limestone of floor for No.3 coal seam, with water pressure up to 8 MPa.
(4) Easy spontaneous combustion: Because of the relatively higher ground temperature, the 34-day period of spontaneous combustion of coal seam is shortened to 29 days.

KEY TECHNOLOGY

Stability control of surrounding rocks

Structural features and movement law of overlying strata

Structural features and movement law of overlying strata of coalface were researched by using UDEC numerical simulation software (Qian et al., 1994; Itasca Consulting Group Inc., 2003). The results showed that the stress concentration factor of the largest vertical stress at the bottom of thick alluvium is about 1.15. With its weak self-carrying capacity, thick alluvium have integrated feature in the process of mining unloading, which means that the whole deposits sink to be tightly pressed with whole bearing capacity.

For thin bedrock thicker than 120 m, though impacted by thick alluvium loading, its caving zone height is about 25 m and the height of the fractured zone is about 105 m, which enable the bedrock to form a stable structure with loading capacity so that the roof face would not press in the form of “cut down by full thick”. The bedrock (fractured zone strata) can form a stable structure with loading capacity (Jin et al., 2013). The overlying thin bedrock can form a structure with loading capacity to transfer the pressure of surrounding rocks to the two sides of the mining area so as to ease the pressure of supports in the coalface.

Support selection

No.3 coal seam is medium hard but relatively soft coal seam (f = 1.44). If two-pillar full-mechanized rack is used, the head of the support is easy to go upward so that it is hard to control rib spalling and roof falling. The largest domestic four-pillar full-mechanized support ZF15000/23/43 for its working resistance is researched and developed since the two-pillar support is unreasonable for its improper position which results in difficulties in controlling the roof, as is shown in Figure 1.

Roof control

139 groups of sublevel top-coal carving hydraulic support ZF15000/23/43 are equipped on the coalface, with one group of transition support ZF15000/23/43 on both upper and lower sides, three groups and four groups of transition support ZFG15000/23/43F on the upper and lower sides respectively, and 148 groups of supports on the whole (Fang and Qian, 2006).

The average first weighting interval of the main roof is 36 m. During the period of initial weighting, the average circulation resistance is 13,300 kN, the support strength is 1.29 MPa, and the dynamic load coefficient is 1.40. The periodic weighting length of main roof is 19.6 m.

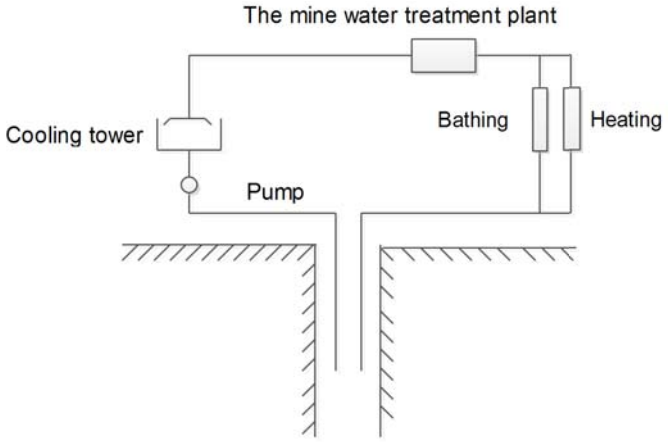

Figure 2. Centralized cooling and geothermal utilization.

During the periodic weighting, the average support resistance is 12,751 kN, the average support strength is 1.24 MPa, which is 85 % of the rated support strength.

Treatment and utilization of geothermal

Initiation of centralized cooling by pipes buried underground and geothermal utilization

The underground mine installed two refrigeration units KM3000 with refrigeration capacity of 6,600 kW. To solve the difficulty in discharging condensing heat of the intensive refrigeration model in the mine, surface borehole was initiated to establish a circulation system of the utilization of geothermal with high temperature, which are mainly responsible for bringing condensing heat in the mine back to the surface, through which condensing heat in the mine is discharged by taking the used waste heat back to the mine for recycling after it has been naturally cooled by cooling tower. The utilization system of refrigerated waste heat was established in the cold water circulation system to convert harm into benefit so as to use the waste heat in the mine, as is shown in Figure 2.

Not restricted by pipe diameter, the two refrigeration pipelines under the separate drilling holes can meet the demand of cooling in the mine; the freely selected drilling position and the cooling load center placed in the cooling chambers in the mine can greatly reduce the cold energy loss in the process of delivering chilled water; the minimum cold energy loss and the low temperature of water supply at the end of air cooler equipment enable the efficient cooling and the saving of operation cost (Du et al., 2013).

Integrated optimization of various cooling models

In light of the total cooling demand of 11,000 kW in the mine, multiple mine cooling models such as the centralized cooling by pipes buried underground, the freezing and low-temperature radiation cooling and the cooling of water-source heat pump have been established and all technologies have undergone integrated optimization. In combination with the optimized wind-blowing and cooling technology for the coalface under the mine, the integrated utilization of all cooling models has effectively solved the heat hazard in the main mining workplaces under the mine such as the coal coalface, roadway heading face, roadway, chambers and pumping rooms, etc., having realized the comprehensive cooling of the whole mine and lowered the average temperature in the main mining workplaces by 8 L so as to create a good working environment in the mine.

Treatment and utilization of high-pressure massive water

Water drainage and pressure decrease in deep mine

According to the evolution law of the water pressure of the mining-induced fissure and pore space, drilling sockets for water drainage of the limestone and sandstone were installed at intervals of 200 m in the No.1 supplementary mine and the main roadways in No.2 supplementary mine (Hu et al., 2011). There were in total 20 drainage holes for the limestone and 10 for the sandstone. Meanwhile, along the transport entry and tail entry on 2301 coalface there are 26 drainage holes, 3 of which were for the limestone. The discharge amount of each hole was designed to be 30 m^3/h, which enables an accumulative discharge amount of 900 m^3/h for the limestone.

Since its operation in November 2006, the plan of water drainage and pressure decrease has reduced the water pressure -810 m from 8 MPa to about 2.8 MPa. The superpositioning and drainage and decrease effects of group holes in the process of water drainage and pressure decrease are shown in Figure 3. The water pressure of the limestone in No.1 league roadway is 2.1 MPa, as is shown in Figure 4. The water pressure of limestone and sandstone is greatly reduced and safe mining is strengthened.

Quick grouting and sealing

On the basis of water drainage and pressure decrease, quick grouting and sealing technology was used for water-conducting channels with local advantages in the process of mining and heading. Since the water outflow after the heading, five locations are applied grouting and sealing and 68 drilling holes are constructed with a total drilling depth of over 6,228 m, over 538 tons cement grouted, over 119 tons water glass, and over 60 tons chemical serum.

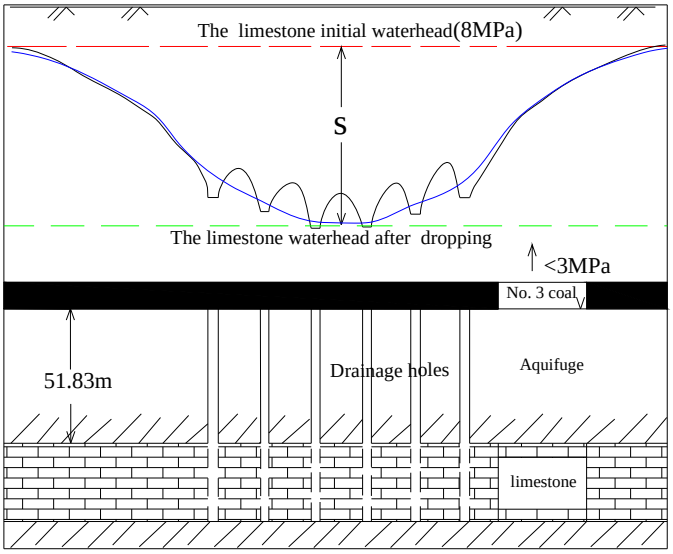

Figure 3. Design sketch of drained limestone.

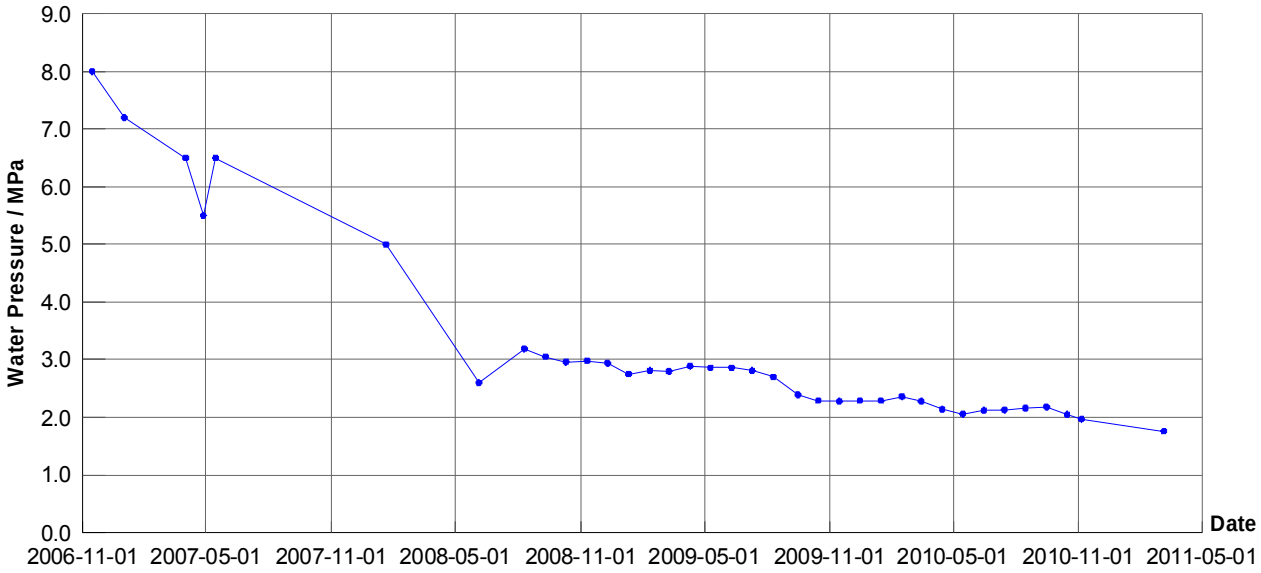

Figure 4. Water pressure of limestone corresponding to water drainage and pressure decrease.

The effectively decreased water pressure of the roof and floor of the aquifer by previous water drainage and pressure decrease creates a good condition for the quick grouting and sealing through water-conducting channels with local advantages to achieve good grouting effects and further improves the mining conditions of 1,000 m deep mine. The operation of water sealing is shown in Figure 5.

Highly efficient water drainage system

The key for large water gushing is to establish highly efficient water drainage system. Five (5) pumps of PJ200 × 10 were installed in the central pump room of the mine, while 6 pumps of PJ200 × 10 were installed in the pump room for expanded drainage. The water drainage pump can supply the largest water gushing volume of 3,150 m^3/h. The effective volume of -810 mine sump is 5,067 m^3; that of the mine sump for expanded drainage is 7,685 m^3; the volume for mine sump totals 12,752 m^3.

Recycled utilization of mine water

For integrated treatment of the mine water, water

Figure 5. Schematic diagram for operations of grouting and water sealing in the mine.

treatment plant was established to adopt the combined technology of clarification, filtration and disinfection corresponding with the quality of the mine water and the requirements on the quality of outflowing water (Vosloo et al., 2011). Water treatment capacity is 1,000 m^3/h. The quality of inflowing water with a pH value ranges from 7 to 9, SS (suspended matter) = 300~400 mg/L, COD_{Cr} ≤ 600 mg/L. The index for treated mine water with a pH value ranges from 6.55 to 8.5, SS ≤ 5 mg/L, COD_{Cr} ≤ 50 mg/L, particle size of suspended matter (mm) ≤0.3. The treated mine water is used by coal preparation plants for water pumping, circulation water for water source heat pump, fire-fighting sprinkling in the mine, grouting water for fire-prevention, and systematic cleaning of ground production.

Prevention for spontaneous firing of coalface with high ground temperature

Spontaneous combustion nature of coal under conditions of high ground temperature

From the experiment on spontaneous combustion of coal fired 2 t by using the "XK-β type" laboratory table of coal spontaneous combustion at low temperatures, the conclusion that the spontaneous combustion period of tested coal sample is shortened from 34 to 29 days is drawn and regular patterns of fastening spontaneous combustion oxidation at high ground temperature are discovered.

Distribution of "three zones" in Goaf

According to the superpositioned isoline mapping of the thickness of suspended coal, oxygen concentration and air-leakage intensity distribution, a static "three zones" distribution in Goaf of the 2301 coalface (workface) was made, as is shown in Figure 6.

When the heading speed of the coalface is less than 87.8 m per month, there is a danger of spontaneous combustion in the upper gate road. The "two roads" of serious air leakage are important areas to prevent combustion (Adamus et al., 2011).

Integrated technology for preventing and extinguishing fire

i) Coal Body Inhibition: By experimental analyses on the elements and constituents of yellow mud, pulping effect is the best at an optimal serum proportion of 4:5~1:1. According to the spontaneous combustion nature of coal on the 2301 coalface, a mobile and multi-functional fire-proof grouting system integrating grouting, colloidal gel grouting, composite gel grouting and pressure infusion of high polymer gel is developed on the basis of the testing of the spontaneous combustion nature of coal and on-the-spot observations of "three zones" distribution in Goaf.

Based on the actual need on the spot, the mobile and multi-functional fire-proof grouting system can prevent and extinguish fire by grouting such fire extinguishing materials as common slurry, colloidal gel, composite gel, and high polymer gel, etc. Without excessively long transport pipelines for slurry, the mobile and multi-functional fire-proof grouting system, by which grouted slurry can reach the target areas quickly, and can achieve effects of preventing and extinguishing fire at the quickest speed when combined with measures of air-leakage control and local inerting (Boleslav and Zdeněk, 2011).

ii) Air-leakage control: For each roadway heading of 40 m, the coal sack with the carving width of about 2 m at the upper corner of intake entry is injected with nitrogen through grouting pipelines, and it takes 8 h to infuse nitrogen each day.

iii) Local Inerting: According to the "three zones" distribution, optimal grouting conditions, intervals of nitrogen injection openings, nitrogen injection time and transition period of nitrogen injection openings are confirmed.

Nitrogen exit should be at the spontaneous combustion area of oxidized risky zones of spontaneous combustion in Goaf. According to the "three zones" distribution, the shortest distance between zones of spontaneous combustion and coalface is 20 m and the longest distance

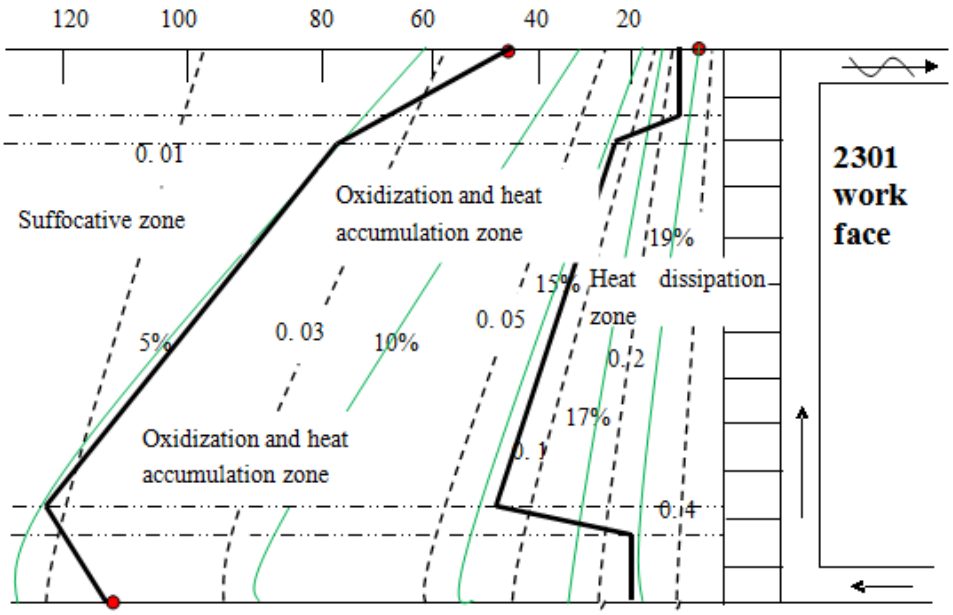

Figure 6. Schematic diagram for “three zones” distribution in Goaf.

is 120 m. The width of zones of spontaneous combustion of coalface is 100 m, within which the nitrogen exit should be placed to inject nitrogen.

IMPLEMENTATION EFFECT

The longgu coal mine was officially put into operation in November, 2009. The 2301 coalface began its operation in the morning shift on 18th, November, 2010. Its annual capacity has reached 10 Mt in 2011. The highest daily yield is 33 thousand tons, and the death rate of coal production of one million tons is zero. The work efficiency of coalface is 100.7 t per miner. The work efficiency of the staff in the mine is 9.3 t per miner.

Conclusions

(1) Features of support stress and support resistance are confirmed. Full-mechanized mining support ZF15000/23/43, face-end support ZTZ20000/25/50, and ahead support rack ZTC30000/25/50 are used to effectively control the coalface surrounding rock with high ground pressure.
(2) Centralized cooling model by high-power pipes buried underground was initiated to transfer condensing heat in the mine to the earth’s surface for recycling and further utilization. The largest integrated mine cooling system in China was established, having realized overall cooling of the mine so as to meet the demand of production.
(3) The technology of water drainage and pressure decrease in deep mine by “group-hole - large flow - long delaying - interfering mine” has achieved safe mining under the condition of 8 MPa roof and floor water pressure.
(4) The precautionary and preventive technology for spontaneous combustion of coal seam of “coal body inhibition + air-leakage control + local inerting” is proposed to fit coalface with capacity of ten million tons in high ground temperature.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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