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Technologies of Preventing Coal Mine Water Hazards for Sustainable Development in North China

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Abstract As hydrogeological conditions of coal field in North China are complicated, coal mine water hazards have been occurring frequently. Nearly 80% of coal mines are affected by Ordovician and Permo-Carboniferous Karst water. According to rough statistics, 200 incidents of water inrush have occurred since 1950, 1,500 persons have died, and there is an economic loss of 3 billion Yuan (RMB). The climate of North China belongs to drought or semi-drought zone. So the recharge amount of ground water by infiltration of precipitation is limited. Stronger coal mine water drainage has brought a series of environmental problems, such as water resource and lots of famous Karst springs exhausted, surface collapse emerged, mine water contaminated. Coal mine water hazards are so serious that the economic benefit of coal mines is dropping. Sustainable development of coal mines is affected. So, preventing coal mine water hazards and protecting geological environment are essential. This thesis focuses on preventing coal mine water hazards technologies. The technologies include four aspects: exploration of hydrogeological conditions; prediction and forecast of water inrush; mining under safe water pressure; and sealing off groundwater by grouting.

Keywords Coal mine water hazards · Hydrogeological condition · North China · Sustainable development

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1 Introduction

China is abundant in coal resource, less in petroleum and natural gas. Coal accounts for 70% in China's primary energy system. China's coal production ranks first in the world. In 2008, the coal production came up to 2.716 billion tons. Stronger coal exploitation has brought a lot of problems. The healthy development of coal industry is critical to China energy safe and economic development (e.g., Jialin and Minggao 2007). According to China Coal Society, the concept of sustainable development of coal industry is defined as: the economic development, social development, environmental protection and utilization of coal resources coordinate each other, and coal industry provides clean fuel, raw materials and electricity to the society.

Coal field of North China is located in Shanxi, Hebei, Henan, Shandong, Jiangshu, Anhui province. Its area is about 727,600 km^2. Its coal production is about 60% of the whole country, so it has an important role in china energy system. But there is a problem of coal mine water hazards in North china, 80% of coal mines are affected by Ordovician and Permo-Carboniferous Karst water. According to rough statistics, in recent 50 years, 200 incidents of water inrush have occurred, 1,500 persons have died, and there is an economic loss of 3 billion Yuan (RMB) (e.g., Weiyue 2005).

Ordovician and Permo-Carboniferous Karst water inrush has following properties: groundwater yield is huge and steady. Once water inrush occurred, the working condition would become worse. More seriously, working face, mining area and coal mine would be flooded and thus many persons would die. Besides, the water hazards caused the replacement of mining area and level stretch very difficult and influenced the production of coal mines. Water inrush would also increase coal mine water drainage. The cost of electricity to drain water would increase. For example, in Jiaozuo coal field (Henan province), 62 cubic meters mine water was drained in the process of excavating 1 ton of coal. Stronger coal mine water drainage would bring a series of environmental problems, such as water quality worsen, water resource exhausted, surface collapse emerged, mine water contaminated(e.g., Hanhu et al. 1999). For example, in 1954, Jinci Spring (Shanxi province) yield was 2.0 cubic meters per minute, when Xishan coal field was exploited, the yield was dropping. Until May1994, Jinci Spring exhausted.

In recent 50 years, technologies of preventing coal mine water hazards have developed greatly in China (e.g., Jinkai 1990, 1991; Weiyue 2005; Yunlai 2008). Summarizing achievements of practices and theory researches, the technologies of preventing coal mine water hazards include following four aspects: exploration of hydrogeological conditions; prediction and forecast of water inrush; mining under safe water pressure; sealing off groundwater by grouting. The technological frame is shown as Fig. 1.

2 Technology of Exploration of Hydrogeological Conditions

Exploration of hydrogeological conditions is essential for preventing coal mine water hazards (e.g., Jinkai 1990, 1991; Weiyue 2005). Since the mid-term of 1980's, with the need of producing development, there have been two changes on the exploration of hydrogeological conditions: firstly, the research object varied from the large to the small, that was from coal field to mining area and working face. Secondly, exploration engineering transformed from surface to ground. Accompanied with above two changes, the contents of exploration and the corresponding technologies differed. These changes were very significant. The first transition made us study and recognize geological and hydrogeological problems from macrocosm to microcosm. The second transition made the aims and scope of exploration more specific and more practical to serve for the production directly. In a sense, these changes were a qualitative leap. Up to present, researchers on preventing coal mine water hazards have accumulated many experiences and found some effective exploration methods. For example, the exploration methods for coal field included: analysis of natural geographical features and geological condition, tracer test, oxidation and reduction potential, environmental isotope, dissolved oxygen, hydrogeological chemistry simulation, wireless wave perspective, mine direct current exploration, transient electromagnetic methods, high sensitive seismic exploration, ground radar

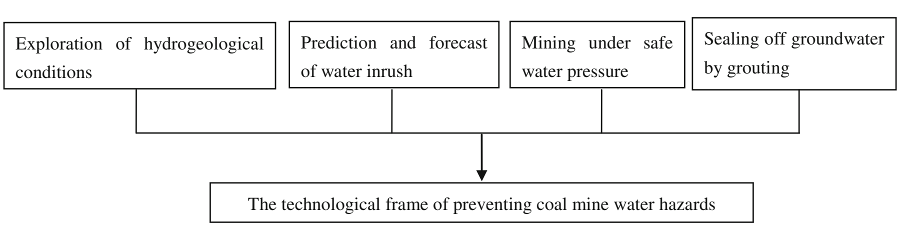

Fig. 1 The technological frame of preventing coal mine water hazards in North China

and borehole radar, pumping test, ground water level observation etc. The exploration methods for mining area and working face included: description of geological and hydrogeological condition in roadway, direct current exploration, working face perspective, hydrogeological drilling before excavation; stress and strain supervision, groundwater pressure and temperature measurement in the process of excavation.

According to the geological condition of coal field and mining area, the above mentioned exploration methods could be used respectively or combined. For example, in Zhangshuanglou coal mine of Xuzhou coal field, 3D high sensitive seismic exploration was used to detect geological structures. More than 20 faults were discovered and the results were proved in production. Another example was in No. 9102 working face of Dongpang coal mine, working face perspective and direct current exploration were combined to detect mine goaf. The results determined the area of mine goaf precisely (e.g., Weiyue 2005).

Also there were vertical passageways in coal field of North China. The vertical passageways included fault zones, fissures and Karst subsidence columns. They were complicated and unusual hydrogeological bodies. They destroyed multi-layer aquicludes, and thus the water inrush occurred under high groundwater pressure. Using the above mentioned exploration technologies and methods, researching scope transformed gradually from coal field to mining area and from surface to ground, the passageway could be determined, the water inrush could be predicted and forecast.

3 Technology of Prediction and Forecast of Water Inrush

3.1 Mechanism of Coal Floor Water Inrush

The mechanism of water inrush was the basis of the technology of prediction and forecast. The research method could be divided into three categories: in situ analytic approach, numerical simulation and physical simulation. Up to the present, the founded theories of coal floor water inrush included "water inrush coefficient theory", "down three zones theory", "plate model theory", "key strata theory", "rock-groundwater interaction theory", "progressive intrusion theory" etc.(e.g., Baiying 1999; Longqing and Jin 2004; Weiyue 2005; Tianhong et al. 2007; Yunlai 2008; Shangxian and Weiyue 2008).

3.2 Technology of Prediction and Forecast of Coal Floor Water Inrush

Each theory of water inrush had respective methods of prediction and forecast. According to the researchers at home and abroad, it was gradually acknowledged that the water pressure of the Karst aquifer and intensity of protective layer were the main factors that affected water inrush. So the research focused on the coupling of ground pressure, groundwater pressure and the mechanical property and deformation of faults and fissures. Rock-groundwater interaction theory and progressive intrusion theory were typical theories of water inrush. The technology of prediction and forecast of water inrush corresponding to above two theories was called multi-parameters monitoring system. This system was made up of water inrush precursor detector and corresponding computer software and hardware, and KTJ-A type of water inrush precursor detector mainly consisted of central station on the ground, substation in the mine, and corresponding software (e.g., Weiyue 2005). This system has already been used in production, and got good results.

Water inrush coefficient theory was put forward in the 1960's. In the 1970's and 1980's, considering the influence of ground pressure and the rock formation, water inrush coefficient was modified two times. Now, water inrush coefficient can be expressed as Eq. 1.

$$T_s = \frac{P}{M - C_p} \tag{1}$$

where

Ts = water inrush coefficient, MPa/m; P = Karst water pressure on coal floor, MPa; M = thickness of aquicludes, m; Cp = broken depth of ground pressure, m.

Empirical values of water inrush coefficient in some coal fields were listed in Table 1.

The values of water inrush coefficient were critical. If real value of water inrush coefficient was lower than critical value, the coal mining was safe. Otherwise the coal mining was not safe.

Table 1 Empirical values of water inrush coefficient in some coal fields (unit: MPa/m)

Coal field	Fengfeng (Hebei province)	Jiaozuo (Henan province)	Zibo (Shandong province)	Jingxing (Hebei province)
Ts	0.066–0.076	0.06–0.10	0.06–0.10	0.06–0.15

In early 1990's, safety coefficient concept was put forward. Safety coefficient was based on in situ hydraulic fracturing tests. It could be described as Eq. 2.

$$z = \frac{p_b}{R} \tag{2}$$

where

Z = safety coefficient, MPa/m; P_b = rock mass hydraulic fracturing pressure, MPa; R = fissure extension radius, m.

The above two coefficients formed pair of coefficients theory. In addition, along with the introduction of information theory, system theory, quantity theory, some new methods already were posed and came into operation, such as water inrush information analytic approach, quantity prediction and neural network prediction etc. Also, the expert system to predict and forecast water inrush hazards has already been come into operation.

4 Technology of Mining Under Safe Water Pressure

When coal floor aquiclude bore higher Karst water pressure, under the condition of Karst water was not drained, the coal mining was called mining under safe water pressure (e.g., Jinkai 1991). If coal mining was not safe, there would be corresponding countermeasures such as pre-grouting in working face.

The technology of mining under safe water pressure was referred to as five maps and double coefficients. Five maps included coal floor protection layer broken depth isoline map, coal floor protection layer water pressure isoline map, coal floor aquifer water pressure isoline map, coal floor protection layer thickness isoline map, mining under safe water pressure evaluation map. Double coefficients included water inrush coefficient and safety coefficient of mining under water pressure.

5 Technology of Sealing off Groundwater by Grouting

"Pumping water and reducing water pressure" and "sealing off groundwater by grouting" were two major engineering measures that prevented coal mine water hazards in China (e.g., Jinkai 1991). For water inrush incidents, in order to do rescue and relief work, the sealing off groundwater by grouting method was used.

The detection of source of water inrush and runoff passageway was important for engineering design and implementation of sealing off groundwater by grouting. Technologies mentioned in "exploration of hydrogeological condition" had been used for this detection. Besides, statistical analytic approach, fuzzy cluster analytic approach, grey systematic theory already came into operation, and made good results.

For the detection of water inrush source and passageway, the borehole radar began to use. It could implement the measurement in single borehole or between two boreholes, confirm the size, shape, space distribution of faults, fissures and Karst caves.

In the process of sealing off groundwater by grouting, in order to increase the amount of cement slurry, controlled orientating drilling technology was applied in some special geological bodies. The special geological bodies were Karst subsidence columns, fissure zones.

In recent years, academician Qian Minggao put forward the concept of green mining and its technical framework (e.g., Jialin and Minggao 2007). This theory emphasized on alleviating the impact of coal mining mostly. The goal was to maximize the economic and social benefits. The technical framework of green mining included water—preservation in mining areas, coal mining to retard surface subsidence, simultaneous extraction of coal and coal-bed methane, reduction of rock waste, underground coal gasification, and others.

6 Conclusions

Hydrogeological conditions in coal field of North China were very complicated. Coal mining was threatened by Ordovician and Permo-Carboniferous Karst water. In order to guarantee sustainable development of China coal industry, following technologies of preventing water hazards should be taken. The technologies were exploration of hydrogeological conditions, prediction and forecast of water inrush, mining under safe water pressure, sealing off groundwater by grouting. Nearly 50 years practices in North China proved these technologies were valid.

References

Baiying L (1999) "Down three zones" in the prediction of water inrush from coal bed floor aquifer-theory, development and application. J Shandong Inst Min Technol Nat Sci 18(4):11–18

Hanhu L, Yinchao Y, Jingbo G (1999) Environmental-geological impact of Karst coal mines in North China. In: Xie H, Golosinski TS (eds) Proceedings of the international symposium on mining science and technology, Beijing, pp 195–199

Jialin X, Minggao Q (2007) Concept of green mining and its technical framework. Sci Technol Rev 25(7):61–65

Jinkai L (1990) Preventing karst water inrush in North China. Shanxi People Press, Xian, pp 150–153

Jinkai L (1991) Preventing karst water in coal mine. Coal Industry Press, Beijing, pp 77–103

Longqing S, Jin H (2004) Floor water-inrush mechanism and prediction. China University of Mining and Technology Press, Xuzhou, pp 6–12

Shangxian Y, Weiyue H (2008) Rock' water-resistance ability and natural progressive intrusion height. Coal Geol Explor 36(1):34–40

Tianhong Y, Chunan T, Zhihong T, Wancheng Z, Qiyan F (2007) State of the research of inrush models in rock mass failure and developing trend for prediction and forecast of groundwater inrush. Chin J Rock Mech Eng 26(2):268–277

Weiyue H (2005) Theory and techniques of mine water hazard prevention and cure. Coal Industry Press, Beijing, pp 174–190

Yunlai B (2008) Water inrush characteristics of mine floor confined water and research status of prevention measures. Express Inf Min Ind 472(8):10–13