Safety Management of Producing Coalmines Adjacent to Closed Coalmines: Case Study of a Coalmine Closure in Xuzhou Mining Area, China

Zhimin Xu, Yajun Sun, Mengfei Zhang

School of Resources and Geosciences, China University of Mining and Technology, Xuzhou 221116, China

Abstract

This paper selects Pangzhuang Coalmine in Xuzhou mining district as a case study, and carries out two detailed technical measures: the post-closure safety evaluation and the safety management measures. The safety evaluation includes: the volume calculation of the mining goaf, the prediction of water levels rising, the prediction of local groundwater level recovery and the assessment of adjacent coalmines' boundary coal pillars stability. On the other hand, the safety management measures include: the monitoring of water level ascending in the goaf, the monitoring of local groundwater level recovery, the construction of the water-block wall in connected mining lanes and the pre-closure drainage in surrounding coalmines.

The research and practice results show that, the local groundwater level will recover to its initial state after 9 years by the predicting and the water level rising in the mining goaf after the mine closure by the real time monitoring, it is very important for the adjacent coalmines to take the initiative safety management and measures to prevent and control the goaf water.

The results of the paper has proved the evaluation and management measures as the most cost-effective approach for post-closure safety, and also bring sustainable benefits to the mining stage before the mine closure. The practical experience obtained in this paper is of great significance for China's coalmine to prevent and control the goaf water after closing a large number of adjacent coalmines.

Keywords: mine closure, goaf water, water level recovery, monitoring, mine drainage

Introduction

In recent years, due to the increasing depletion of coal resources in eastern China, the macro-economic control of the country's energy policy and implementation of capacity reduction policies, a large number of coalmines in China's eastern region have gradually closed. Xuzhou mining area has 140 years of mining history, and all coalmines has been closed by the end of 2016. The coalmines in Xuzhou mining area were mainly distributed around the urban areas, and most of the coalmines were located adjacent to each other. During the closure of each coalmine, a series of problems related to hydrogeology and environmental effects arose, the resulting rising water levels affected the deeper producing coalmines. Rising groundwater level in the closed coalmines flowed into the neighboring coalmine in production through some fractures or other water-conducting passages, including breaking through boundary pillars.

Nowadays, the developed countries have begun to research the ecological problems to solve the series of hydrogeological and environmental effects after mine closure since the last century. Dogaru et al. (2009) studied the balance of mining and the environmental risks caused by mining from the perspective of socio-economic and environmental. Lghoul et al. (2014) investigated the characteristics and evolution of mine water and its impact on regional water resources. Khalil et al. (2013) performed the ecological impact and acid toxicity study of acid mine water. With the large number of coalmines closed in China, Huang et al. (2017) proposed the technical system framework of mine closure, Wu and Li et al. (2018) analyzed the positive and negative eco-environmental effects of closed coalmines and proposed corresponding countermeasures. For the safety problem after mine closed, Xiao et al. (2014) conducted experimental research and analysis on the stability of the boundary pillars, Zhou et al. (2010, 2013) analyzed the environmental and safety hazards caused by rising water level of abandoned mine, Li (2014) studied the risk assessment of underground water pollution in abandoned mines, Chen et al. (2015) studied the technical approaches to the geologic environment treatment in closed mines. Although a large amount of basic work was done on the problem of closed mines, there was still a lack of relevant, systematic research.

In this paper, using the example of the threat caused to the Jiahe Coalmine after the closure of the adjacent Pangzhuang Coalmine, the safety management of producing coalmines adjacent to closed coalmines was studied.

Hydrogeological conditions of the study area

The Pangzhuang Coalmine is located in the Jiuli District of Xuzhou , 13 km from the city's center. Formally commissioned on May 1, 1965, the originally designed production capacity of the mine was 450,000 t/a, but after transformation, the approved production capacity was increased to 1.4 million t/a. The main mining coal seams in Pangzhuang Coalmine are No. 7 and No. 9 coal seams, and there are four production levels at–370m,–520m,–620m,and–850m. Due to the exhaustion of the resource, the Pangzhuang Coalmine closed in August, 2013.

The Jiahe Coalmine is located in the southwest of the Pangzhuang Coalmine and the production level is lower than the goaf of the Pangzhuang Coalmine. With the groundwater level rose continuously after the closure of Pangzhuang Coalmine, the groundwater flow transferred from the original mine drainage to a weak section along the coal pillars, faults, and other channels into the Jiahe Coalmine. The Shitun Coalmine is located in a shallow area of Pangzhuang Coalmine and connected by a roadway at the −370m level to the Pangzhuang Coalmine. When the recovering groundwater level rising at —262m, the groundwater of Pangzhuang Coalmine will drain through the connecting roadway and threaten safe production at the Shitun Coalmine. The Wangzhuang Coalmine is also located in a shallow area of the Pangzhuang Coalmine, but there is a natural water-resistant boundary and no hydraulic connection between the two coalmines.

Analysis of the groundwater storage space and flow route

The groundwater storage volume of Pangzhuang Coalmine

The total mine water inflow in Pangzhuang Coalmine is 93m^3/h: the −370m level is 18m^3/h, the −520m level is 26m^3/h and the −620m level is 49m^3/h. Since the mine closure, the rising groundwater formed four catchments at −850m, −620m, −520m and −370m levels (Fig. 1).

In the mine safety evaluation, the calculation of the volume of the mine water in the goaf is particularly important. This article distribute the amount of water in the mining area to each area according to the area of the Pangzhuang Coalmine . The water line is delineated every 20m according to the contour line, of which −370m catchment recharges the -520 catchments and the two catchments are unified into a single catchment area. A preliminary estimation of the volume of water storage for each catchment area was obtained by the following formula from China's

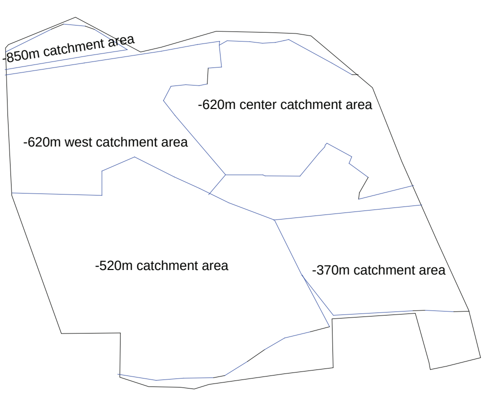

Figure 1 The four catchments of Pangzhuang Coalmine.

National Regulations on Prevention and Control of Mine Water in Coalmines:

$$Q = KMF \frac{1}{\cos a}$$

where Q is the goaf water accumulation (m3), α is the coalseam inclination (°), K is the water-filling coefficient (0.25 was used in this study), M is the mining thickness (m) and F is the horizontal projection area of the goaf water area (m^2).

By calculation, after the Pangzhuang Coalmine closed, there is a lot of mine water storage space below the level of -370m, and the amount of water that can be accommodated is 4522905m^3.

Stability analysis of the boundary coal pillar

According to the width of the coal pillars at the boundary of the Pangzhuang and Jiahe Coalmines, the gap between the pillars at each level is relatively different: the narrowest boundary of the No.7 coal seam is at the −440m level, where is only 14m; the narrowest boundary of the No.9 coal seam is at the −530m level. The deepest elevation of the No.7 coal seam goaf adjacent Jiahe Coalmine is −685m, where the width of the boundary pillar is 36m. The deepest elevation of the No.9 coal seam adjacent Jiahe Coalmine is −670m, where the width of the boundary pillar is 38m.

According to the national technonigical regulations, the following formula from China's National Regulations on Prevention and Control of Mine Water in Coalmines is derived to calculate the head pressure that the coal pillars can withstand:

$$P = \left(\frac{2L}{KM}\right)^2 \frac{K_P}{3}$$

where L is the width of coal pillar (m), K is the safety factor, generally take 2-5, M is the mining thickness (m), and P is the water head pressure (MPa), Kp is tensile strength of the coal seam(MPa).

By calculation, when the water level rises to -441m, the water pressure on the boundary coal pillars of -685m and -670m levels reach a critical value; when the water level rises to -403m, the -440m horizontal boundary pillar reaches a critical value. As the water level continues to rise, the goaf water of Pangzhuang Coalmine will inrush into the Jiahe Coalmine.

Prediction of water level rising in the goaf

As the water level in the goaf of Pangzhuang Coalmine continues to rise, the volume of water in the goaf will gradually decrease. After about 9 years, the regional groundwater level will reach a new equilibrium and the water level will recover to −370m (Fig. 2).

The goaf water control measures of Pangzhuang Coalmine

In order to achieve effective safety management of Pangzhuang Coalmine, the time required for the water level to reach the weak pillars will win time for safe production to Jiahe Coalmine. This paper proposes prevention and control measures for the goaf water hazard (Fig. 3).

The first line of deep defense

1,600 days after the Pangzhuang Coalmine closed, the water level in the goaf area rises to −441m and the boundary pillar located at −685m is damaged. At this time, the amount of water contained in the goaf area was about 3,817,149m^3. Therefore, we can use the goaf area to store water and take the real-time monitoring. After investigation, two monitoring holes were installed (Fig. 4). Monitoring hole 1 is located in the No. 7541 panel of Pangzhuang Coalmine −620m level mining area near the boundary; monitoring hole 2 is located in the No. 7433 panel of a mining area to the west of the Jiahe Coalmine near the boundary.

The second line of deep defense

If the mine water in Pangzhuang Coalmine breaks through the boundary pillars as the water level rises and drains into the Jiahe Coalmine, It can use the goaf area of the west mining area of Jiahe Coalmine to store mine water (the volume is 389,000 m^3) and building necessary water retaining walls at the main water leakage point (Fig. 5) to prevent the goaf water from draining into the deep part of the Jiahe Coalmine.

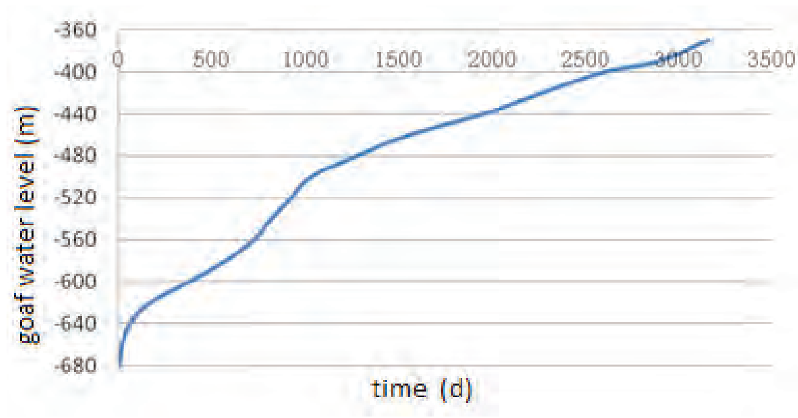

Figure2 *Water level recovery and time curve.*

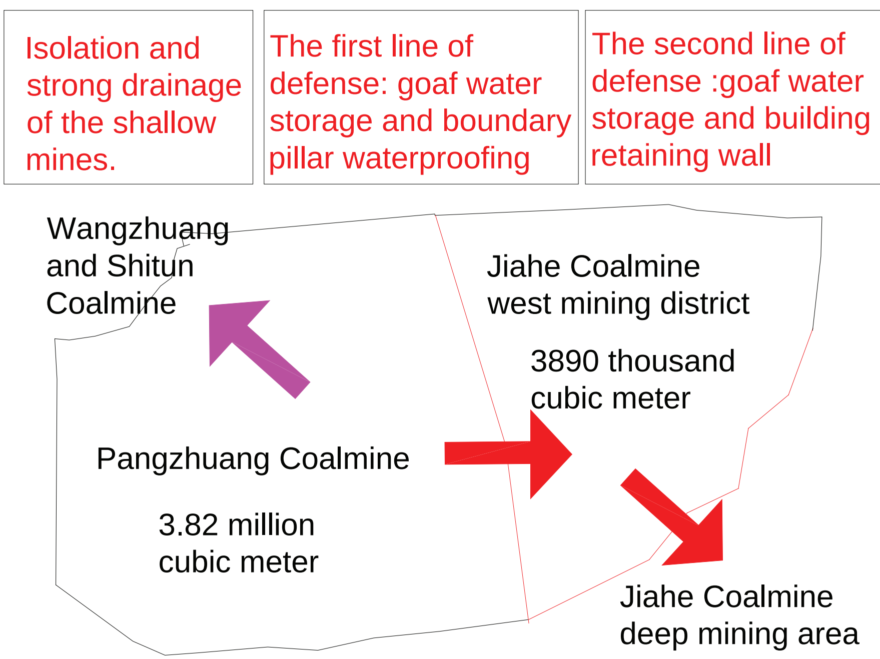

Figure 3 *Prevention and control measures for the goaf water.*

Shallow mine control measures

If the coal pillar is not broken, the goaf water of the Pangzhuang Coalmine doesn't enter the west mining area of Jiahe Coalmine and the water level will continuously rising in the Pangzhuang Coalmine, which poses a threat to the Shitun and Wangzhuang Coalmines. The Shitun Coalmine contains an artificial boundary between it and the Pangzhuang −370m level roadway and the upper exit at −262m. It is only when the Pangzhuang Coalmine goaf water level rises to over −262m that it can flow through the connecting roadway. However, water in the Shitun Coalmine can be drained using an existing drainage system.

The Wangzhuang Coalmine and the Pangzhuang Coalmine contain natural water-repellent boundaries that cut off the hydraulic connection between the two mines. An inrush of water into the Pangzhuang Coalmine goafs poses little threat to the Wangzhuang Coalmine. However, due to the uncertainty of water passing through the goaf areas, the

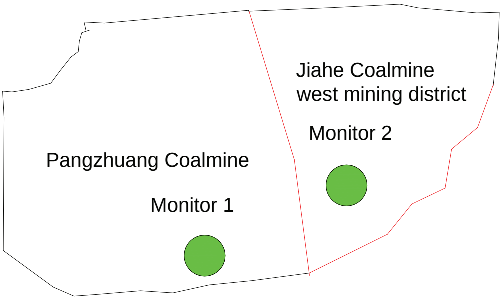

Figure 4 Position of monitoring hole

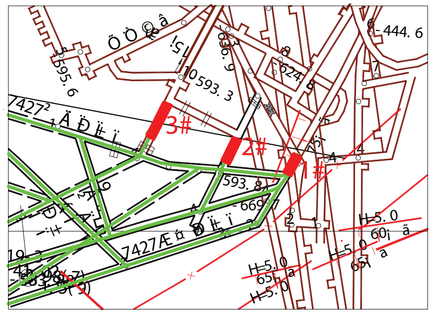

Figure 5 Position of retaining wall

Wangzhuang Coalmine needs to formulate emergency plans for protection against an inrush of water.

Conclusion

(1) In Pangzhuang Coalmine, the goaf below the −370m level can hold 4,522,905m^3 of mine water. When the water level rising to −441m, the water pressure that the boundary pillars at the −685m and −670m levels will reach a critical value; when the water level rising to −403m, the water pressure that the −440m boundary pillar can withstand will reach the critical value.

(2) As the water level in the goaf of Pangzhuang Coalmine continues to rise, the volume of water in the goaf will gradually decrease. After about 9 years, the regional groundwater level will reach a new equilibrium and the water level will recover to −370m.

(3) This paper proposed prevention and control measures for the management of the goaf water hazard created after the Pangzhuang Coalmine closure. The first line of defense at depth is goaf water storage and boundary pillar waterproofing in Pangzhuang Coalmine, and the second line of defense at depth is goaf water storage and building the retaining wall in Jiahe Coalmine.

Acknowledgements

This research was financially supported by The National Basic Research Program of China (No.2013CB227901), the National Key Research and Development Program of China (No.2017YFC0804101) and the National Natural Science Foundation of China (No. 41502282). The authors thank the editors and reviewers for their constructive suggestions.

References

Chen Yuehui, Chen Zhongsheng, et al..Technical approach to geological environmental control in closed mine area[J].Coal Science & Technology,2015(1):81-83.

Dogaru D, Zobrist J, Balteanu D, et al. Community perception of water quality in a mining-affected area: a case study for the Certej Catchment in the Apuseni Mountains in Romania.[J]. Environmental Management, 2009, 43(6): 1131-1145.

Huang B, Liu J, Nan L I, et al. Framework of the theory and technology for mine closure[J]. Journal of China University of Mining & Technology, 2017, 46(4): 715-729 and 747.

Hu Weiyue, Zhou Jianjun, et al . Analysis of environmental and safety hazards caused by rebound of water level in abandoned Mines[J]. Journal of Xian University of Science and Technology, 2010, 30(4): 436-440.

Khalil A, Hanich L, Bannari A, et al. Assessment of soil contamination around an abandoned mine in a semi-arid environment using geochemistry and geostatistics: Pre-work of geochemical process modeling with numerical models[J]. Journal of Geochemical Exploration, 2013, 125(3): 117–129.

Lghoul M, Maqsoud A, Hakkou R, et al. Hydrogeochemical behavior around the abandoned Kettara mine site, Morocco[J]. Journal of Geochemical Exploration, 2014, 144: 456-467.

Li ting. Study on Groundwater Pollution Risk Assessment of Abandoned Coal Mine[J]. Journal of China University of Mining & Technology.

Wu Qiang, Li Songying. Positive and negative environmental effects of closed mines and its countermeasures[J]. Journal of China Coal Society, 2018, 43(1): 21-32.

Xiao Hua, Yang Zhiyang, et al. Influence of water accumulation in the goaf of closed mine on the stability of waterproof coal pillar[J]. Coal Science & Technology,2014(4).

Zhou Jianjun. Risk Analysis on adjacent mine water inrush caused by groundwater rebound of abandoned coalmine[J]. Safety in Coal Mines, 2013,44(7).