An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)

Main Hydrogeological Problems and Some New Water Prevention and Controlling Technology in Northern Anhui Mining Area

Yuhua Wu, Zhongwen Duan, Benkui Sun
Wanbei Coal-Electricity Group Co., LTD., sunbenkui@126.com

Abstract Wanbei mining area belongs to the Wanbei Coal-Electricity Group, and it is located in the Huaibei coalfield, where the coals in the Carboniferous-Permian coal measure strata of North China are the main object of exploitation. The hydrogeological condition in the area is complex. There are multi factors affecting the safety of coal mining in the area to varying degrees, including the collapse column, the aquifers in the loose layer strata and of the seam roof and floor sandstone, as well as in the limestone of Taiyuan Group from coal seam floor. In recent years, based on investigation and study and the corporation with relevant research institutions, a large number of research programs have been systematically carried out: detailed exploration, S type hole grouting in surface, grouting and reinforcement on working face floor above confined water and presplit blasting on the working face roof below confined water as well as hydro-chemical monitoring and predicting in mining process. These technologies protect the continuous safety and efficient production in the mining area, and remarkable economic and social benefits have been achieved.
Keywords mine hydrogeology, wanbei mining area, new water prevention and controlling technology

Introduction

Wanbei Coal-Electricity Group Co., LTD is a large state-owned energy enterprises based on extractive industries, and supported by electrochemical coal, coal logistics and non-metallic materials. It is China's top 500 enterprises(Li and Fan 2002; Ding 2004). The coal industry is distributed in six provinces, including Anhui, Shanxi, Inner Mongolia, Shanxi, Xinjiang and Yunnan. And there are eleven coal mines located in the Anhui Province, including Renlou, Qidong, Qianyingzi, Wugou, Wolonghu, Liuyi, Hengyuan and Zhujixi coal mines, which cover the areas in the Huaibei, Suzhou and Huainan, and most of the them are located in the Huaibei coal field. In 2013, the coal production was more than 15 million tons and most of them were obtained from the strata with age between Carboniferous and Permian.

Hydrogeological conditions and problems affecting the safety of coal mining

The hydrogeological conditions in the mining area

The Huaibei coal field belongs to the Xuhuai stratigraphic small division, Luxi subdivision in north China. The basement in the area is covered by the Cenozoic loose layer, and the strata in the area from old to young include the Cambrian, Ordovician, Carboniferous, Permian, Tertiary and the Quaternary(Fu 2010; Gui and Sun 1999) (fig. 1).

The coal field is located in the southern margin of North China type coal field, and belongs to the eastern of Yu Huai depression and central southern of Xusu nappe. The area is connected with the Southern China plate by the Tanlu fault in the east, and the north is the North China subsidence. The Taikang uplift and Zhoukou depression is located west to the area, whereas the Bengbu uplift and Huainan coal field is located in the south. The area has been influenced by multi period tectonic movement, and the results include a series of E-W and NNE trending tectonic lines. More than 50 faults have displacements higher than 100m. Most of the faults have NNE and E-W trending.

Series	Symbol	Thickness (m)	Coal seam	Lithologic characteristic
Quaternary	Q 4	26	first aquifer	Near surface for 3 to 8 meters of planting soil, lower to sand and clay layer, several layers at the bottom of the film of clay.
	Q 3	65	second aquifer	The upper part is brownish yellow sandy clay containing iron and manganese nodules, the lower part is grayish - yellow, the sand layer and the bottom layer of quartz gravel development.
	Q 2	45	third aquifer	The upper part is brown-red clay, gravel and sandy clay middle of the bottom of the sand with limestone gravel.
	Q 1	65	fourth aquifer	The upper part is grey marl, cave and fracture, the lower for celadon sandy clay, for at the bottom of the clay in fine sand and gravel, sometimes with marl layer.
Tertiary	R	0~15		Upside for clay and sandy clay, topped with iron, manganese and calcium tuberculosis ; Lower for the sandy clay, gravel layer, accidentally see massive marl.
Permian	P2sh	>610		Mainly of fine sandstone and siltstone, shale and thin coal seam. The lower coal-bearing8-12 layers, local minable seam1-2 layer.
	P1x	245~326 average280		Mainly of fine sandstone and siltstone, clip 2-3 layers of oolitic marlstone. Contain special thick coal seam 8 is one of the strata in this area, about 3 m at the bottom of the aluminum mudstone.
	P1sh	102~167 average120		The main coal-bearing strata of the area, and local mineable coal layer 8 layers, with an average thickness of 20.6m. Upper part of fine sandstone, in the middle to thick-bedded fine sandstone, with thin mudstone, siltstone, including the main coal seam 10 coal; Lower for sandy mudstone and siltstone.
Carboniferous	C3t	160.9	aquifer of Taiyuan formation	10-14 limestone and four to six layer thin coal seam, 3, 4 limestone thicker, fracture water-eroded cave development, rich in water. Upper for powder sandstone with 2-3 layers, thin layers of limestone in central mainly limestone, with mudstone siltstone and thin coal seam, the lower of siltstone sandstone with thin-layer limestone and thin coal seam.
	C2b	14.34		Mudstone, aluminum mudstone and siltstone interbed
Ordovician	O1+2	133.47	aquifer of Ordovician	Dark gray thick layered cryptocrystalline, fine crystal and dolomitic limestone, and fracture water-eroded cave development, water is rich.

Fig.1 *Strata colume in the area.*

The coalfield is concealed with covering by the Cenozoic loose layer strata. As to the geomorphic unit, it is a part of the North China Plain. Except for the exposed bedrock with erosion, small hills and valleys in the Suixi, Xiaoxian and the area between northern Suzhou and Xuzhou, the rest area is the alluvial plain of the Yellow and Huaihe rivers. The surface flows in the area are rich and most of them are belonging to the Huaihe river system. Moreover, because of the distribution of large number of faults in the area, the recharge, runoff and discharge of groundwater in the area have been limited, and the groundwater system in the area is a semi closed system. The water in the tunnel can be recharged from top and down, including the groundwater in the loose layer aquifer, coal bearing sandstone aquifer, the Carboniferous and Ordovician limestone aquifer, the water related to fault, Karst collapse column and goaf.

The main hydrogeological problems in the mining areas

(1) The fourth aquifer which at the bottom of Cenozoic loose beds develops well and the ancient gully whose water abundance is rich occupies partly, which threatens the upper bound mining activities a lot.

(2) The fracture water in the sandstone on the roof of coal seams (fault) develops well,

especially on the faces of initial minery in new coal mines, which influences the normal production in mines seriously.
(3) The water bursting coefficient of limestone water under high pressure on the floor of No.10 coal is beyond critical value, and that threatens the safety mining of No.10 coal.
(4) Hidden karstic collapse column grows fine in the mining area, which threatens safety mining all the time.
(5) The reclaimed waters likes goaf water and water of boreholes are also the potential hidden troubles in old mines of the mining area.

Several new water hazards controlling technologies

Detailed surface exploration

According to the law of geological prospecting, carrying out searching, general prospecting, detailed prospecting and precise prospecting. Especially, we should pay attention to special hydrogeological supplement exploration which focuses on the object of mining engineering and the demand of geology and hydrogeology. Comprehensively applying all kinds of methods of exploration according to local circumstances. Using new technologies of geophysics such as high precision 3-D seismic method on the ground, transient electromagnetic methods and organically combining with geological drilling and hydrogeological supplement exploration. Carrying out drainage experiment, geophysical prospecting, geochemical exploration, drilling and implementing detailed prospecting in mines, as well as finding out the geological and hydrogeological conditions in them. We spend more than 30 million yuan on the coal exploration every year.

By means of pre-stack migration of 3-D seismic data on the ground in mines, we can expand fine interpretation of 3-D seismic data. Each mine has installed dynamic management system of 3-D seismic data on the ground in mines which would be close to the production of mines.

Underground comprehensive advanced detection

The principle that detection should be taken if there is any doubt should be obeyed. Using geophysical prospecting, drilling and geochemical exploration to find out the hydrogeological conditions in front of working faces. Efficient water controlling measures need to be taken to make sure of the safety production of working faces. The objects of advanced detection in mining faces include the following aspects:
(1) Approaching the roadways, old goafs or nearby mines where may be flooded or be pondings;
(2) Approaching aquifer, water-conductive fault, underground river, karst cave and water-conductive collapse column;
(3) Opening water preventing coal (rock) pillars before blow-off;
(4) Approaching the fault fracture zones which may be connected with rivers, lakes, reservoirs and wells;
(5) Approaching the boreholes which may spray water;
(6) Excavating water preventing coal which is influenced by confined aquifers or water-bearing structures or lies in coal seams and aquifers may lead to water inrush if the thickness is not got clearly;
(7) Approaching the grouted area where may be ponding;
(8) Approaching and enter the abnormal areas of ground prospecting;
(9) Mines whose hydrogeological conditions are complex or very complex and we can’t find out the hydrogeological conditions and water-filling factors clearly on the ground;
(10) There appears water inrush on mining faces. The quality and temperature of water is abnormal;

(11) Karst collapse columns have been found or the mines that are predicted to grow collapse columns. During the roadway driving of new areas (exploit excavating area of preparatory working and the coal seam mining area of low group or middle-low group)and before excavating on working faces;
(12) Before the extraction of first mining face in new mines or areas;
(13) Approaching the area under threat of water disaster or other regions where the water inrush would happen in mines.

The comprehensive methods or ways that geophysical prospecting goes ahead of the rest , drilling is set to test the results, hydrological observation and hydrogeochemical survey and the combination of geophysical prospecting, geochemical exploration, drilling are in advanced detection. There are some advanced geophysical prospecting methods in mining faces such as:
(1) Mine transient electromagnetic method;
(2) Direct current electric method in mine;
(3) Audio perspective method in mine;
(4) Network parallel electrical method in mine;
(5) Radio wave penetration method on working face;
(6) Rayleigh wave method;
(7) Underground seismic prediction;
(8) Geological radar method, etc.

Among these methods, (1), (2), (3), (4) are resistivity methods and the first two methods are mainly used to detect the water abundance circumstance of all kinds of geologic bodies. Ordinarily, one to two kinds of methods are selected to do the detection. The latter two methods are mainly applied to detect the water abundance circumstance in the mining faces and the floors. Items (5), (6), (7), (8) are radio wave methods and seismic prediction methods and they are used to the detect geological structures in working faces or front.

Hydrological observation and hydrogeochemical survey include outlet form, water quantity, temperature observation, chemical examination, analysis and prediction on the quality of samples, and all of these belong to the daily water disaster controlling and monitoring on the underground mining faces.

Drilling is generally used to find out the water circumstance in the reliable goafs or boreholes in front of roadways or used to test points where are abnormal by geophysical prospecting and geochemical exploration, getting the water abundance of faults, collapse columns and aquifers in front of the roadways or in mining faces. In addition, drilling is also applied to treat other objects that must be given advanced detection. Drilling is necessary to select drilling rigs according to the situations in working points. Detecting-outlet holes should be anchored, tested and constructed according to provisions for mine water prevention and control strictly.

The safety distance should be settled on the basis of real situations and provisions for mine water prevention and control.

We also spend more than 30 million yuan on the underground advanced detection each year.

The grouting of S hole on ground

When we do the grouting of S hole, we set boreholes in the certain areas beside wellheads. The diameter gets to be larger because of giving up wellhead. However, the grouting area doesn’t need to be so great. The track of borehole is curve or slash from the side view. Given

that the reason of drilling technology and construction and to achieve the goal, we design the track to be S.

The grouting of S hole on ground doesn't influence the shaft freezing construction, construction of everlasting headframe and driving workings.

The new CL-C clay-water mud is used to grout and it consists of clay, cement and sodium silicate. Among these materials, the main material is clay. The new CL-C clay-water mud is cheap and easy to get and it could save more than 70 percent of cement compared with cement slurry. Its suppressible stability is well and it's not easy to subside and diluted by water. It has good rheological property that it wouldn't curdle during the transportation and it would get plastic strength quickly after the flow. It wouldn't crack after explosion or the movement of rocks, which overcomes that single fluid mud has only strength but bad earthquake resistance. What's more, the new CL-C clay-water mud has good earthquake resistance as well as good water resisting property and durability, and that would work well on preventing new cracks from the blasting in the process of shaft digging and sealing overdue water. Since we can impose higher grouting pressure on clay-water mud, the filling ratio in cracks could reach more than 90 percent, which would improve the quality of engineering and play a positive role in cutting construction period.

According to the grouting process, aquifer characteristic, lithology, grouting equipment, the variety of grouting materials and other factors, the section needed grouting can be divided scientifically. The type of S hole ground grouting for rockshaft was carried out economically and reasonable based on the hydrogeological characteristics, grouting pressure, diffusion radius and the end standard of the grouting.

Grouting reinforcement of coal floor above the confined aquifer

The technology of coal floor grouting and aquifer reform is one of the prevention and control technologies which are used widely and fast-growing. This technology takes advantage of the exit roadways, geophysical prospecting and drilling to explore the degree of water abundance under the coal floor. The coal floor is reinforced and part of the aquifer is reformed by grouting to enhance the water resisting ability of the coal floor. Ground grouting station is built and used for transporting the slurry to the underground. The grouting system is simplified and the grouting ability can be proved providing the effective means for reforming the geological conditions. The grouting cost was reduced by using the materials such as fly ash, clay, ordinary Portland cement paste. This technology has been used in Liuqiao coal mine, Hengyuan coal mine and Wugou coal mine.

Pre-split blasting of coal roof under the confined aquifer

The coal bearing strata of Qidong coal mine are all buried under the thick Cenozoic loose bed. The bottom aquifer of the loose bed directly covered the coal bearing strata. The lithology, thickness, water rich degree and the distribution of the ancient river bed are very complex and these factors threaten to the safety of the coal mine. There were 17 times pressure frame accidents in eight mining area and fifteen times of them appeared the water inrush accidents caused by pressure frame. The 3_222 working face happened water inrush accident on November 25, 2011 and leaded to the mine flooding. The broken height of medium hard overburden rock was abnormally high based on the exited mining data. The relationship between height of overburden rock and the mining thickness was not in accordance with the mining regular of medium hard in other coal mines. The high water pressure and original high angle longitudinal fissure of the fourth aquifer lead to the abnormal broken height of the overburden rock. So, how to choose the correct type and the reasonable width of coal roof coal pillar is the key for the prevention of roof water accident. Finally, the

presplitting blasting of working face roof method was set up and the correct coal pillar type and the reasonable size were chosen. The specific practices were shown as follows:
(1) Presplitting blasting holes: The advanced presplitting blasting method was carried out at the roof of working face. The blasting parameters were adjusting continuously according to the lithology of coal roof. Reduce the periodic caving step distance and the height of up two zones. The measured height value of two zones was 43m which was lower 10m than that of the past mining method.
(2) The comprehensive physical field monitoring of the coal roof seepage flow: By the monitoring of warning drills buried in the working face, the geoelectric field parameter change regulations of coal roof deformation while the working face was advancing were achieved. It can provide the correct forecast while mining.
(3) High resistance support: The ZY10000/23.5/42 high resistance support was adopted according the lithology combination of coal roof. This support can enhance the support force of working face and prevention of roof caving. It was the first time that the support applied to the coal mine in the whole company.
(4) The ground early warning monitoring system: The water level of the fourth aquifer was monitoring by the observation hole. Based on the relationship between the water level of the fourth aquifer and the pressure cycle making sure the reasonable advancing step and avoiding the broken of bracket caused by high pressure.

Pipe roof grouting within large fault zone

Liuqiao coal mine and Qidong coal mine respectively through the Liuqiao fault and the Weimiao fault and the drops are both more than 150 m. By pipe roof grouting achieved success. The specific practices were shown as flows:
(1) Using special pipe drilling rig, mid-pressure big flow pump, D40 steel pipe, sulphoaluminate cement grouting material;
(2) Pipe hole finished the arrangement and the length of the pipe should be longer than the distance of the effective pivot. The density of pipes should be within 300mm.
(3) Put the screw thread steel which the diameter is 2.2 mm into the pipe. Fill the space and grouting to plugging the hole strengthening the rigidity of pipe.
(4) Construct some grouting holes outside the pipe and grouting with drilling to finish the pre-grouting of pipe.

Waste hole perforating the casing split grouting in surface

Wolonghu coal mine is one of the coal and gas outburst mines and the ground gas drainage holes were constructed for the reason of gas control. Because of the mining, the 1# hole was broken relating to the water inrush along the fractures of quartz sandstone above 180m of coal roof. To prevent the hole 2# appearing the similar accident, hole 2# was closed by grouting before the hole was broken caused by mining. Finally, the method of cutting the hole casing and grouting was adopted and the hole 2# was closed successfully by grouting. The specific practices were shown as flows:
(1) Using the high-power flow pressure pump matching the special drill and the cutting knife pressure bit to cut down the hole casing at the bottom of the thick sandstone where the separation may appear.
(2) Carrying out the high pressure grouting at the cutting down position up to down inside the casing and make sure the annular space outside the casing was filled.
(3) The perforating bullets of which the diameter was 89 mm were used and installed 16 each meter distributing as plum blossom piles type. Install 16 bullets in each section and all the bullets were installed in the pipe burst which was long as 4 m. After the target was served to the target horizons, the firing pin was put down from the ostiole and ignited.

Hydrological and hydro-chemical monitoring and predicting

There are many aquifers in Northern Anhui and some of them such as the Taiyuan formation limestone aquifer, the Ordovician aquifer and the bottom aquifer of loose bed in some areas are rich of water and can be threaten to the coal mines. So, how to indentify the water resource correctly and quickly is very important. By systematical research of aquifers in mining area, the water resource can be identified correctly from the aspects of water pressure, flow, water temperature and water chemistry. The suitable water prevention measures can be adopted to reduce the accident based on the possible endanger degree caused by water inrush. The 2# and 3# collapse columns in Renlou coal mine were identified successfully taking advantage of the above methods and the mining flooding accidents were avoid effectively. Meanwhile, the coal mines such as Liuqiao coal mine, Hengyuan coal mine, Wugou coal mine and Qidong coal mine also achieved the good effects.

Conclusions

(1) In terms of the hydrogeological problems, we strengthened administration of their work in water prevention and carried out technical innovation. By the series of measures, mining flooding accident and injury accident were avoided successfully ensuring the safety mining of coal mines.

(2) The coal resources buried under the aquifer of Cenozoic loose bed were excavated successfully and the output can be more than 15 m tones.

(3) The coal resources located above the confined aquifer were also excavated safety and the output can be more than 12 m tones. The benefits are obvious.