A WATER RESOURCES PROTECTION METHOD AND ITS APPLICATION TO ARID AND SEMI-ARID MINING AREAS

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ABSTRACT

The Shendong coal mine, located in mid-western China, has specific hydrogeological and mining conditions from which a water resources protection method has been developed. It is proposed that this method can be applied to other arid and semi-arid mining areas. Based on analysis of the hydrogeological structure, the characteristics of groundwater-producing fracture zones in overburden rocks, the stability of the key aquiclude, the hydrogeological structure of Shendong coal mine area can be classified into five types. Field measurements show that the unconsolidated sand aquifer above the coal seam is an aquifer with abundant groundwater. The key aquiclude between this aquifer and the coal seam has permeable fracture zones that will be disrupted by mining. To protect the water resources in the aquifer, we developed a protection method by pre-draining the water before mining, then transferring and storing it in a sandstone confined aquifer underlying the coal seam. The water can then be utilized by pumped it out from the confined sandstone aquifer. The paper describes hydrogeological conditions, drainage and storage engineering layout and the design of the abstraction and injection wells.

Key words：water resource protection；hydrogeological structure；mine water; pre-drainage; water transfer and storage, managed aquifer recharge

1. INTRODUCTION

The coal plays a very important role in the energy structure in China. It will not change, at least in the next 50 years. Shendong coal mine is one of the 13 large coal industry bases, located in the area of Shaanxi, Shanxi, Ningxia and Inner Mongolia in western China. Its coal production had reached 1.2×10^8 tons in 2007. In such an arid and semi-arid area, the long term average precipitation is only 436 mm. However, the annual evaporation reaches 1791 mm, and the infiltration is less than 15% of average rainfall due to the topography and geomorphology. Therefore there is a serious shortage of water resources and a fragile ecological environment.

The Salawusu group of Quaternary age (Q_{3s}) is the only aquifer in the Shendong coal mine area. It supplies the water resources for local industry, agriculture and the local population, but it lies above the coal seam. The thickness of the coal seam is 3.2-5.8 m, and it lies 70-120 m below the ground surface. The distance from the aquifer to the coal seam is only 30-50 m. The aquitard will be disrupted by the underlying mine development, draining the aquifer and allowing the groundwater to flow into the mine through the water flowing fractured zones (WFFZ) which are formed after coal is excavated (Qian, 2006).

Generally, there are two ways to protect the groundwater resources in the coal mine area. In some cases, the mining thickness of the coal seam is limited, to control the development of water-conducting fracture zones. The approach preserves the aquiclude, which can prevent groundwater loss from the aquifer into the mine (Hickcox, 1980. MIAO, 2007). If there is no aquiclude or the aquiclude is too close to the coal seam, mining will be forbidden (Plotkin, 1979), which prevents utilization of much of the coal resource.

In other cases, mine water treatment and re-use are applied instead of protecting the aquifer by limiting the mining (Thomas, 1976). The aquifer is destroyed in these cases, and the groundwater drains into the coal mine and then is treated or purified to be re-used.

In the Shendong coal mine area, it is very difficult to preserve the aquifer because the coal seam is too close to the ground surface, so we developed a new method of water transfer and storage. The groundwater in the Salawusu aquifer is transferred to and stored in a sandstone confined aquifer that underlies the coal seam before mining. Then the water can be utilized by pumped it out from the sandstone aquifer.

2. THE HYDROGEOLOGICAL STRUCTURE IN THE SHENDONG COAL MINE AREA

There are many different hydrogeological structures in different parts of the Shendong coal mine area. In some of them, there is at least one aquiclude which can be preserved during coal mining by controlling the development height of water flowing fractured zone. In this situation, the groundwater in the Salawusu aquifer will not be lost and can be used as normal. However, there are also some areas in which the aquiclude is in the range of water conducted fractured zone because it is so close to the coal seam. In this situation, the groundwater will drain into the coal mine without the protection of the aquiclude.

The Hydrogeological Structure System in Coal Mine Area

The approach that has been taken is first to divide the Shendong coal mine area into many different sub-areas, then the hydrogeological structure is classified into five types in the water-resisting strata regions according to the aquiclude layers and their spatial locations (see Fig.1). This classification is achieved through:

- the analysis of the distribution of the aquifer and aquicludes,
- the characteristics of groundwater occurrence,
- the recharge, runoff and discharge characteristics of the groundwater system,
- the positions of runoff channels,
- the hydrogeological unit structure and the boundary conditions,
- the relationship of the main water abundant region and the primary coal seam, and
- the structural characteristics of the roof,

For TypeⅠand II, there is at least one aquifuge and it is not within the range of development of water flowing fractured zones, so the aquifer will not be affected by mining. For Type IV, the valley intersects both the aquifer and the aquiclude, so the groundwater will be lost before coal mining. For Types Ⅲ and V, the aquifuge will be broken while mining or there is no aquifuge, so we have to take effective action to protect the groundwater in the aquifer. For this case, we developed and used the pre-drainage method.

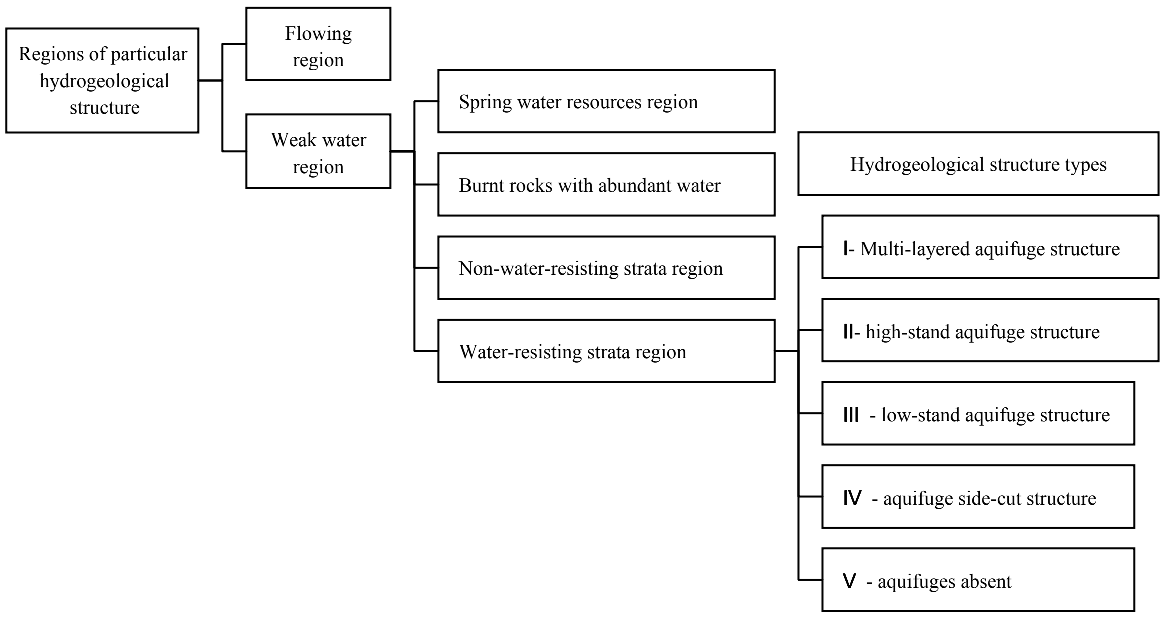

Fig.1. The classification of hydrogeological structure types in the Shendong coal mine area

The Corresponding Strategies for Different Groundwater Resource Types

We propose particular countermeasures to protect important groundwater resources whilst carrying out conventional mining near poor aquifers in fissured bedrock. The countermeasures take account of the characteristics of occurrence of the hydrogeological structures in the mine area to protect the aquifer of Salawusu Group and the burnt rock zone aquifers (see Table 1).

Table 1. Water resources occurrence and protective technical countermeasure in Shendong coal mine area

Water Resources Type	Occurrence Conditions	Water Abundance	Methods and Key Technologies in Water-Preserved Mining
Surface water and water source	Valley and Quaternary aquifer	strong	Limited mining in the range of reserves
Cavity water in burnt rock	Cavity aquifer in burnt rock zone	strong	Lateral water-preserved pillar
Quaternary phreatic water	Salawusu aquifer	weak-strong	The key aquiclude protection, water transferring and storage etc.
Bedrock fissure phreatic water	Zhiluo sandstone fracture aquifer	weak	Conventional mining
Bedrock fissure confined water	Yanan sandstone fracture aquifer	weak	Conventional mining

3. THE DEVELOPMENT OF WATER FLOWING FRACTURED ZONES IN OVERBURDEN ROCK

The evolution of mining-induced fractures, the development of preferred seepage channels and seepage law can be analyzed by using numerical simulations and field testing, which is the basis of the analysis of stability of the key strata that resist groundwater flow in the mining rock mass. Understanding the stability of the key aquiclude is the theoretical basis for mining in a way that preserves groundwater.

To estimate the thickness of the water-producing, mining-induced fractured zones, we chose 4 working faces in Shendong coal mine area. Five methods were used to observe the overburden rock.

1) Electrical method detection and analysis, used in 12610 working face of Daliuta coal mine and 31401 working face of Bulianta coal mine.
2) Drilling observation and analysis, used in 12401, 12201 and 31401 working face
3) Detecting and analysis of elastic wave logging method, used in 12201 working face
4) Detecting and analysis of shallow seismic exploration method, used in 12201 working face
5) Ground penetrating radar detecting and analysis, used in 12201 working face

For the different methods outlined above, the results of estimates of the thickness of the mining-induced fractured zones (which allow groundwater inflows from overburden rock) are summarized in Table 2.

Table 2. Thickness of mining water flowing fractured zone in overburden rock

Serial number	Number of working face	Height of the caving zone (m)	Thickness of overlying bedrock (m)	Estimated thickness of mining-induced fractured zone (m)
1	12610	4.8	40-45	40-45
2	31401	5.3	120-190	105-153.9
3	12404	3.4	31-36.84	30.82-36.52
4	12201	4.0	40-50	40.45-49.1

The results shown in Table 2 demonstrate that the mining-induced fracture zones will penetrate much of the overlying bedrock, even reaching the surface, under normal mining conditions. So it is inevitable that the mining will damage the overlying aquifer in these situations.

4. AQUIFER PRE-DRAINING, TRANSFERRING AND STORAGE PROJECT

Most of the area of interest at the Shendong coal mine has a shallow burial depth. As discussed above, the research has shown that, with normal mining conditions, the mining-induced fracturing will penetrate overlying bedrock, allowing groundwater inflows that will damage the overlying aquifer.

The proposed approach is to transfer water, before mining, to storage in an aquifer which will not be affected and from which it can be recovered. This aquifer may be the same one as that which overlies the coal seam but in a different area or the goaf before the aquifer is damaged. Then the water can be utilized if needed, so as to realize water resources protection.

This process is called aquifer transferring and storage. This method adjusts the temporal and spatial distribution of groundwater resources in this area by taking appropriate measures and achieving sustainable utilization of those groundwater resources.

Based on analysis and research of the system of hydrogeological structure in Shendong coal mine, the Bulianta coal mine, Shigetai coal mine, Halagou coal mine and Wulanmulun coal mine, it has been shown that all of them possess appropriate characteristics for pre-draining, transferring and storage of the groundwater resources. It is proposed that the water resources protection method of aquifer pre-draining, transferring and storage includes both:

- underlying aquifer transferring-storage and
- goaf transferring-storage.

Underlying Aquifer Transferring and Storage Method

The fractured and confined aquifer beneath the coals seam can be divided into six slices. The third slice, which is between coal seam 2-2 and coal seam 3, is a moderately coarse sandstone with a thickness of 20 m. It provides a favorable storage into which to transfer groundwater.

Boundary conditions: the northeast condition is a first terrace of the Wulanmulun River, and the surface of which is nearly parallel to the river bed. It is consisted of medium-fine sand and fine sand. The river infiltrates and recharges the confined aquifer, that is forms a recharge boundary. The southwest boundary is impervious. Roof and floor confined aquifers which are consisted of sandy mudstone and mud are used as upper and lower boundaries. Both of them are 20 m-thick.

Water head: the water head of the (upper) aquifer from which the groundwater is to be transferred is 30~100 m higher than the receiving aquifer below the coal seam. So the transfer of groundwater from the shallow aquifer to the deep, receiving aquifer can be achieved using that head difference.

The transferring and storage project includes the structural design of dewatering hole and observation hole and the project layout (see Fig. 2-4).

Storage capacity calculation of receiving aquifer: the largest storage capacity is $1.287\times10^7 m^3$, the least storage capacity is $5.15\times10^6 m^3$, and the regulation and storage capacity is $7.72\times10^6 m^3$.

The Technology of Water Transferring and Storage in Goaf

The groundwater from overlying aquifers will be deliberately transferred and stored in the goaf before mining, then re-used after purification. According to the statistical results, the goaf area in Shendong coal mine reached 136,080 m^2, while the available storage space reached 570 million m^3.

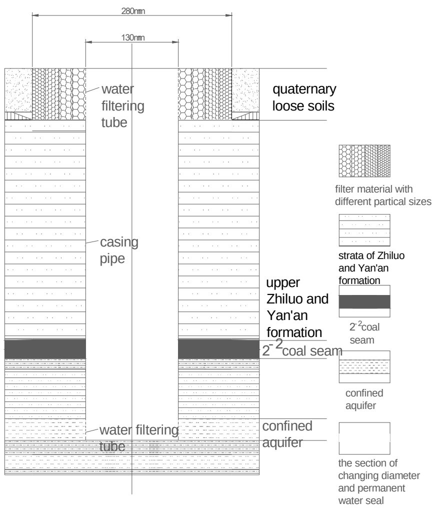

Fig.2. Sketch map of the structure of transferring and recharging hole

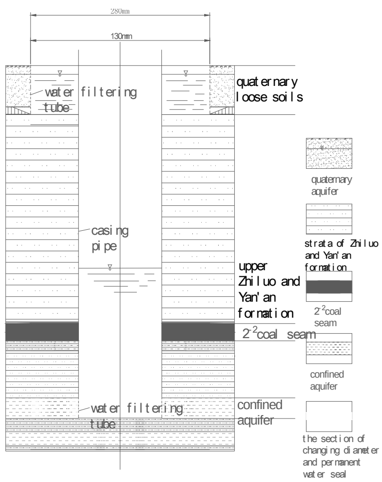

Fig.3. Sketch map of the structure of water-level observation hole

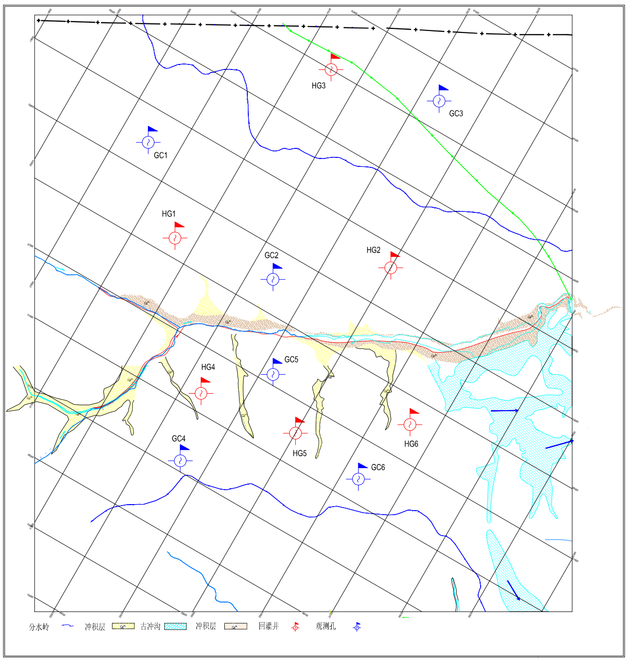

Fig.4. Layout of draining hole in Bulianta coal mine

A mass of mine water will be formed by the process of transferring from the upper aquifer and storage in goaf, and its water chemical composition will depend upon the variable effects of coal and associated minerals. Therefore, it is necessary to use the water purification technology to convert the mine water quality to that of a usable water resource.

The Chemical Characteristic of Mine Water in the Shendong Coal Mine

Based on the result of water quality analysis, taking the Grade III of environmental quality as a standard, the important parameters in mine water in the Shendong coal mine include turbidity, arsenic, petroleum, BOD_5, CODcr etc. These characteristics of the water quality basically reflect the process of groundwater entering the mine workings and then, accumulating contaminants, converting into mine water. The changes of water quality are due to pollution with underground coal dust, rock powder etc. As a whole, it shows characteristic of higher suspended matter, discoloration, CODcr.

The Test and Mechanism of Mine Water Treatment in Goaf

Mine water treatment in the goaf is a new technology of mine water treatment, including a series of complicated process of physics, chemistry, physical chemistry and biology. Mainly using pores and fractures in the goaf, mine water treatment in goaf aims to purge mine water of contamination by the actions of deposition, filtration, adsorption etc.

The treatment process flow is as follows: Taking goaf as the receiving volume (catchment) and the underground sump as the clean pool, the clean water purified in goaf enters by means of an injection hole, then the water is supplied to an underground well, causing mine waste to clean the water used as part of the process of production from the coal mine, which can meet the water demand of the underground well.

The mechanism of mine water treatment in goaf is as follows: Mine water treatment in goaf mainly uses the medium of pore and fracture of goaf. Based on real or man-made topography, mine water is purified mainly by deposition of particles held in suspension, filtration of medium, adsorption etc.

a) the action of deposition: the goaf encourages agglomeration and deposition of suspended matter because of its large storage volume, which causes a great reduction in water velocity, the complex material composition etc.
b) the action of filtration: with the medium of fracture and the various size of the mass of caved wall rock, the suspended matter and the colloidal substances in goaf can be intercepted when the water passes through the cave mass by the surface of the rocks and interior pores.
c) the action of adsorption: the residual coal stored in goaf have large surface area like active carbon, which can adsorb solid particulate and dissolved ion, in order to wipe off these impurity.

The Application of Water Treatment in Goaf in Shendong Coal Mine

Storage in goaf and water treatment to a quality that allows its use as a resource is widely used in Shendong coal mine. Daliuta is an example to explain the effect of the technology and applications.

Daliuta mine exploited 2^{-2} coal seam now, 12601 as the head working face. Because of favorable structure and storage conditions, the goaf of 2^{-2} coal seam is the best choice to act as a catchment area for mine water. The 12601 working face within the catchment must be made waterproof, firstly, to prevent flooding in goaf accidents, and secondly to ensure that the flooded goaf does not leak.

The seam floor level of 12601 working face ranges from 1130 to 1140, which is the low-lying part of the mine. The seam floor is gritty mudstone, 316 m thick, with a high content of ferrimontmorillonite, so it easily forms a clay seal concluding a certain amount of anauxite, while the bottom floor is aleurolite and is 9 m thick. Thus, the aquiclude is composed by the seam floor and the underlying rock, which become the ideal conditions for storing mine water of 12601 working face goaf (see Fig. 5).

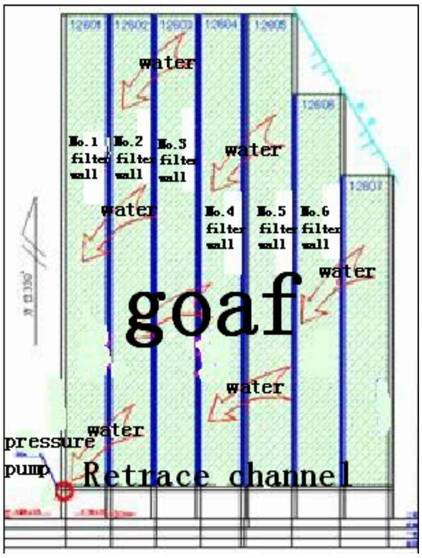

Fig.5. The filtration and purification process of goaf mine water

Purifying mine water of Daliuta in this mine goaf produced good results (see Table 3). From Table 4, it can be seen that both suspended matter and organic content reduced rapidly. The water quality was in keeping with industry and green belt irrigation and it was directly available as process water.

Table 3. Water quality comparison of Daliuta mine water

Serial number	Item	Standard ($mg.L^{-1}$)	Initial ($mg.L^{-1}$)	After purifying ($mg.L^{-1}$)
1	pH	6 ~ 9	712	6.9
2	Turbidity	—	51	3.2
3	Suspended matter	100	112	25
4	Ammonia nitrogen	15	8.64	2.6
5	Volatile phenol	0.5	None	None
6	Hexavalent chromium	0.5	0.03	0.03
7	Sulfide	110	0.15	0.15
8	Total number of bacteria	—	130 /ml	63/ml
9	Total hardness	450	7187 ~ 10107	148
10	COD	100	98	31
11	BOD5	30	40	11

5. CONCLUSIONS

For water-conservation mining research of shallow coal seams in arid and semi-arid mining areas, the following 3 important aspects can be recognized. (1) That hydrogeological structure system analysis in coal mine area is essential; (2) That the developing law analysis of mining overburden rock water flowing fractured channel is the theory basis of water disaster prevention and treatment in coal mine area and water resources protection method; (3) To research the method of water resources protection mining is research's core.

Through the research of this paper, the main conclusions are:

1) This paper proposed different hydrogeological structure types and illustrated the relations between the forming of water flowing fractured channel and water-resisting key strata, which established theory basis for choosing different water-conservation mining technologies.
2) Combining with the specific hydrogeological and mining conditions in Shendong coal mine, we proposed water resources transferring and storage technology and analyzed the feasibility of transferring and storage from the following aspects: aquifer medium characteristic, boundary conditions, head pressure difference and water storage capacity between transferred aquifers and receiving aquifers and so on.
3) This paper's research, with exploitation of the technology of water resources transferring and storage and protection mining method, established a theoretical basis to realize green mining in the mid-west of China's large-scale coal production base. This region has fragile environmental ecology conditions and coordinated development of resources and the environment. Also, it is of great significance to realize China's energy security strategy and the 21st century energy development pattern.

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