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Discussion on Hydrogeological Factors of Waste Backfilling in Abandoned Coal Mines

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Abstract Waste backfilling is a widely used method in oil industry to deal with pollution or dusts and redevelop underground spaces. It provides a new way for abandoned coal mines to treat waste rocks, remediate environment and lower costs. Referred to mechanic theory and previous experiences, hydrogeological factors and their criteria for site selection were listed. Then, an analysis about related features has been carried out in abandoned coal mines. For discussing application possibility of backfilling, site selection criteria were compared with related features in closed mines. And the results showed that it seems feasibly to apply waste backfilling in abandoned coal mines for waste treatment and land remediation. Environmental risks and society influences caused by backfilling projects were the last factors for application analysis. Using backfilling for waste treatments and environmental protection will offer a high level of advanced technique, and it is also beneficial for society.
Keywords feasibility analysis, waste backfilling, abandoned coal mines, hydrogeological conditions

Introduction

Waste backfilling is an advanced way to deal with waste in oil industry. And it reduces cost, decreases pollution and benefits land reclamation. It had been done successfully in 330 sites in Canada, US and India in last decades (Veil et al. 2003). It probably provides a new way for waste treatment in abandoned coal mines. In China, a large number of coal mines had been closed, and problems caused by abandoned mines have gotten worse by time, especially pollution (Hu et al. 2000, Hu et al. 2002). Hence, a newly and advanced method for waste treatment is urgently needed.

Many factors are considered for waste backfilling projects on technique, operation and afterwards management. In operation procession, target strata is one of most important and fundamental factors. So hydrogeological factors for target strata have been chosen to discuss application feasibility of waste backfilling in abandoned coal mines.

Hydrogeological aspect for Waste Backfilling

Referred to mechanic analysis and experiences from previous projects, and considering safety issues and environmental protection, target strata for backfilling projects have been chosen by a series of hydrogeological factors (Muhammad Nadeem et al. 2007).

Hydrogeological Factors

Details about mainly hydrogeological factors described as follows.

Depth: indicating vertical location and overburden thickness of target formation. Proper depth ensured wastes keeping stable in target stratum and did not leek to surface, and operated pressure would not grow too high to operate.

Thickness: thick strata have enough spaces for wastes storage, and it is valuable and operational for one site storing a large volume of wastes.

Lateral extent: ideally, target formation should be infinite at lateral extent because waste slurry spread both in horizontal and vertical ways. Due to the effect of water flow in fractures, waste slurry reached more far along strata surfaces than in perpendicular way.

Hydrogeological parameters: mainly features of a stratum influenced operation of backfilling include permeability and porosity. High permeability indicated that waste slurry dissipated fast from boreholes and decreased high bottom pressure which might cause damages on well walls. A stratum with large porosity provided big amount of spaces for waste flow and storage.

Cover Formation: specifically means the strata between closest aquifers and target formation. Cover formation must be impermeable and thick enough to be a barrier for keeping waste down in appropriate station.

Tectonic structure: best areas for backfilling are plains without faults and large fractures. Faults and fractures are flow paths connecting many aquifers in different buried depth, and slurry could flow up and down through them. So complicated tectonic structure makes high risks to fresh water and project safety of waste injection.

Aspects listed above are factors should be considered for site selection. Suitable hydrogeological conditions of target strata ensure security of projects to keep away from some environmental issues and hazards.

Factor Assessment Method

For site selection of waste backfilling, an assessment method had been developed in 2007 (Muhammad Nadeem et al) which was consisted of two phases. One step is called decision tree and next step is to rank and weight factors passing first step.

Tab 1 shows the chosen hydrogeological characteristics and their values. Depending on data showed in tab 1, preliminary analysis of site selection could be finished. In step two, factors have been ranked as numbers based on their values, quality and importance. Each parameter was given a numerical value to calculate evaluated scores for every site.

Table 1 *Hydrogeological factors and their values*

Parameters	Values (m)	description
Depth	200~3000	Suitable and economical
Thickness	>2	Suitable
Permeability	10~10000 (m/d)	Suitable and economical
Overburden	>8	Suitable
Tectonic structure	Intermediate or simple	Suitable

Referred from Muhammad Nadeem, 2007.

According to professional experiences, total score of a ranking system is 125. Project sites with more than 100 scores are best ones for backfilling.

Hydrogeological features of abandoned coal mines in China

Some waste backfilling projects had been done in abandoned coal mines in decades ago (Jeffrey S. Walker 1993). Therefore, feasibility analysis of waste backfilling application was reasonable to be discussed in abandoned coal mines in China.

Typical coal mines in China

China has four coal fields divided by different coal forming time and deposit region.

North China Coal Field is located in central region of China. Roofs of coal seams include sandstone and large thickness of unconsolidated formations. Floorsare consisted of limestone with high content of water. In this region, coal seams buried very deep commonly. South China Coal Field is located in south of China. Coal seams in this area mainly deposit in Later Permian. Roofs are composed of mudstones and sandstones. Floor strata are thick limestone.

Coal seams in North-west Coal Field deposits in Jurassic strata system mainly. In this area, precipitation is less than other regions. Strata are sandstones with low permeability and unconsolidated aquifers are exposed widely. Coal seams in North-east Coal Fields mainly deposit in Cretaceous series, and have high water content. Roof and floor strata are sandstones and unconsolidated formation.

Hence, each coal field has its' typical natural hydrogeological conditions which would be first factors for site selection of backfilling.

Special features in abandoned coal mines

Abandoned coal mines have different features from unmining area because of mining activities. Naturally, coal mine areas have their hydrogeological conditions. While underground mining happened, coal seams have been dug out which created large voids in the strata. Then formation stress was changed in surrounding rock and caused strata damage in different ways. In the immediate roofs, rock collapsed completely into blocks and piled up in goaf. Above it, fractures created along and perpendicular strata face (Zhou et al. 2011).

Furthermore, Mining systems were composed of tunnels, roadways and working faces. After mines closed, part of mining systems had been left in the ground (Zhou et al. 2011) (fig.1).

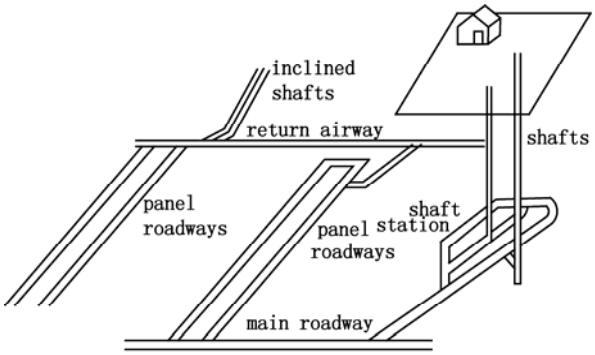

Fig. 1 *Section sketch of roadways network in abandoned mines*

Spaces created by mining activities increased formation permeability, porosity and thickness. And they also determined groundwater flow speed and direction when water flew through those areas. So special hydrogeological features formed in the abandoned coal mines..

Discussion of abandoned coal mines for waste injection

Factors assessment in abandoned coal mines

All hydrogeological factors listed formerly for site selection should be also discussed in abandoned coal mines to analyze the operation feasibility of waste backfilling. Description and analysis of all factors in abandoned coal mines showed in table 2.

Comparison between criteria in decision tree and data in table 2 were discussed by using assessment method mentioned formerly, and results showed that abandoned coal mines in some areas could be used for waste backfilling. Next step is using rank and weighting values to calculate scores for chosen sites, and it has to be done in specific places. Therefore, first step of factor assessment was discussed only in this paper for feasible study on wastes backfilling in abandoned coal mines.

Table 2 *Estimation of hydrogeological factors for site selection in abandoned coal mines*

Parameters	Analysis	Values
Depth	Deposit depth of coal seams differs in a large range probably from 0~1000 m or more in China.	Empirical values from existed projects are 380~390 m
Thickness	Coal seams more than 1m are permitted to be extracted in China, which caused a collapsed zone with more than 4~5 times height of coal thickness.	>4 m
Permeability	Tunnels and shafts are pipes which could be used for injection well and slurry paths. Collapsed zone and part of fractured zone (closed to collapsed zone) have high permeability and porosity.	10~10000(m/d) from existed projects; 3.0~4.85(m/h) in one of abandoned coal mines
Cover formation	Usually, coal roof strata are alternating layers of sandstone, mudstone and shale. In some deep mines, there was thick cover formation with low permeability.	>8 m from existed projects; more than 50m in some abandoned coal mines.
Porosity	In collapsed zone and fractured zone, porosity of strata is high.	
Lateral extent	According to coal mine data in China, lateral extent is usually larger than 2km.	>2 km in abandoned coal mines

Consequently, hydrogeological factors in some abandoned mines can satisfy requirements of waste backfilling projects, and the injection can also benefit on environmental issues, like subsidence reduction, waste treatment and land reclamation.

Risk analysis

Based on discussion above, some abandoned coal mines can be used for waste backfilling. However, backfilling projects triggered some environmental and social risks, and they are other factors which should be discussed for site selection.

Pollution

Pollution on groundwater has three patterns. Firstly, waste slurry polluted underground water directly because of low poisonous materials inside. Chemical reaction between slurry and surrounding rocks is the second way inducing pollution. Some contaminants could be generated by those reactions, such as: acid, metal compounds and some organic materials. Thirdly, wastes left by human dissolved in water of slurry, and then strata would be polluted by slurry with new contaminants.

Liquid leakage

Liquid leakage (John A. et al. 2003) might occur on surface land or along well walls. Those accidents will cause project failure and water pollution both on surface and in underground. Especially, leaking from well walls has potential impacts on drinking water resources which cost citizens' health and safety.

Surface risks

Surface risks happened because of operated processes and equipment. Leaking is one of surface risks discussed above. Building damage is another risk caused by project operation. Waste injection induces a little amount of displacement in vertical direction after slurry consolidated (John A. et al. 2003), and buildings damaged by that uplift. Some other relevant accidents happened during project working, such as, equipment breakdowns, project failures, and traffic accidents, and etc.

Conclusion

Based on criteria of hydrogeological factors using for waste backfilling projects, typical coal mines and their geological conditions have been discussed, and space features and

hydrogeological characteristics in abandoned coal mines have been analyzed. Then factors involved in site selection were estimated by using decision tree. Results showed that it seems feasibly to use waste backfilling in abandoned coal mines. However, operation has pollution and leaking risks to environment, society and safety. When after treatments, risk levels could be decreased. Therefore, waste backfilling probably provide a new method for waste treatment in abandoned coal mines in China.

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Reference

John A. Veil, Maurice B. Dusseault (2003) International database on slurry injection of drilling wastes, Argonne National Laboratory, 1-21

Weiyue Hu, Lanying Yan (2000) Characteristics of groundwater pollution in abandoned coal mine and control technique, Coal Mine Environment Protection, 14(4): 37-38

Weiyue Hu, Zhongming Li, Chengxu Wang (2002) Abandoned mine and geological environment hazardous, Coal Geology & Exploration, 30(4): 33-35

Muhammad Nadeem, Maurice B. Dusseault (2007) Geological engineering criteria for deep solids injection, Environmental Geosciences, V.14, No.2, pp.61-77

Jeffrey S. Walker (1993) State-of-the-art techniques for backfilling abandoned mine voids, Bureau of mines, United States Department of the Interior

Jianjun Zhou, Weiyue Hu, Yingfeng Liu (2011) Analysis on water-bearing media characteristic and groundwater kinetics in abandoned mines, Coal Science and Technology, 39(01): 107-110

John A. Veil, Maurice B. Dusseault (2003) Evaluation of slurry injection technology for management of drilling wastes, Argonne National Laboratory, U.S.Department of Energy National Petroleum Technology Office