Harmony of large-scale underground mining and surface ecological environment protection in desert district - a case study in Shendong mining area, northwest of China

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Abstract

Large-scale exploitation in Shendong mining area will encounter the puzzle of preserving the frail ecological environment in desert area. The interactive relationship between underground mining suiting for surface ecological environment protection and surface ecological environment prevention adapting to mining disturbance is the research and development core of this technique. There are three actions involved in controlling ecological environment, to dispose before exploitation, to protect surface ecological environment during the exploitation and to repair and build up after exploitation. Based on the law of overburden movement in shallow coal seam, the law of surface subsidence and the law of vegetation growth in subsidence area, an integrated controlling technique, including the key techniques of aquifer-protection mining, mine water filtration and purification through goaf, fire prevention and extinguishment in shallow seam, non-rockroadway layout with underground waste disposal, pre-mining eco-function circle construction and post-mining ecological recycling system building, has been developed by methodologies of theoretical analysis, laboratory simulation, numerical calculation, industrial practice, etc.

Keywords: desert area; large-scale exploitation; aquifer-protection mining; eco-function circle; ecological environment protection

1. Introduction

It is all along hard to make a choice between resource exploitation and ecological environment protection. How to resolve the contradiction has become the difficulty and hot spot of theoretical study and engineering practice. Now the solution is mainly from two aspects, one is source control, the other is post-mining disposal\textsuperscript{[1-3]}. Shendong mining area, located on the edge of Mu-Us desert, is the first ten-million-ton modernized mining area of China. Under traditional mode of environment protection, which is an environment treatment after mining, the...
fragile ecological environment will get worse.

For the sake of boosting up ecological environment’s ability of resisting mining disturbance in advance, following the law of surface subsidence and the law of vegetation growth in the mine area subsidence, the interactive control techniques between ground and underground must be adopted before large-scale exploitation. The protective techniques in underground mining should minimize the negative influence on surface ecological environment, and furthermore, the local ecological environment affected by mining should be repaired and optimized in right time after exploitation. By these two ways, the frail ecological environment in the mining area should have been improved and reinforced evidently.

2. Topographic features and coal-bearing conditions

Shendong Mining Area, a part of huge Ordos Coal Basin, extends 38 km to 90 km from west to east and 35 km to 55 km from north to south, where is about 3489 km² with a proved reserves of 35.6 billion tons.

The surface of this area is covered by travelling dunes and semi-fixed dunes, and the maximum thickness may reach from 20 m to 50 m. The area of desertification and latent desertification accounts for 85 percent of gross area. The mean altitude is around 1200m. It holds typical continental climate character of semiarid and semidesert[4].

This area gives priority to monocline with simple geologic structure, few fault, and non-developed cranny. The primary exploitive coal seam includes the coal beds coded as 1-2, 2-2, 3-1, 4-2 and 5-2. The typical features of occurrence of coal seam are stated as follows:

1. Shallow depth: the depth of coal seam ranges from 60 m to 400 m, mostly around 100 m.
2. Thin bedrock: the minimum thickness of overlying bedrock is about 1.4 m, and the aeolian sand layer above bedrock ranges from 10m to 60m in thickness.
3. Abundant phreatic water bearing: There is 10 m high groundwater bearing in the unconsolidated formation. Immediate roof and floor of coal seam in this area belong to fine sand, siltstone, and sandy mudstone.

3. Features of overburden movement in shallow seam and its influence on vegetation in subsidence area

3.1. Features of overburden movement and surface subsidence in shallow seam

So far as the different thickness of bedrock was concerned, this paper analyzed synthetically the subsidence character of overburden strata by means of physical simulation and numerical calculation along with practice data[5-6].

1. The characteristics of overburden movement and surface subsidence are correlative to the thickness of bedrock. The overburden strata may holistically collapse during shallow coal seam mining with holistic surface subsidence, consequently, by which the surface soil and plants are destroyed slightly.
2. Along with the movement of working face, the bedding cranny could be re-compacted basically which is beneficial to the water-protection and fire prevention. The degree of re-compacted will be better and the density of surface crack will be smaller with a bigger area and a faster advance.

3.2. Influence of surface subsidence on vegetation

The influence of subsidence caused by underground mining on vegetation[7-8] could be presented as follows:
1. The subsidence caused by coal mining has little evident effect on the composition of plant community, species diversity, and vegetation coverage. Two years after subsidence, the vegetation tends to be generally stable.
2. In most cases, that the species in subsidence area increase is because the subsidence cracks give the chance of surviving to the seeds germinated only under illumination.
3. Subsidence caused by mining has a negative influence on large broad-leaved arbors, however, no obvious influence on the trees with developed branch roots, such as Salix psammophila, caragana korshinskii, etc. The breakage of part of the root system dues to subsidence will not make the whole plant dead.

According to this law, the whole ecological environment of mine area will get stable and strong after repairing and optimizing the affected vegetation community in local area of eco-functional system.
3.3. Interactional requirements between surface environment treatment and underground mining

(1) Requirements of underground mining in consideration of surface environment protection
   ① To reduce pollution sources and emissions;
   ② To design the longwall face in great size and increase the advance rate;
   ③ To prevent the coal away from spontaneous combustion and the underground water from loss.

(2) Requirements of surface environment treatment with respect to underground mining
   ① To Plant the spices with abundant horizontal roots to resist the horizontal displacement of ground surface;
   ② To change the stand structure from “arbor mainly with shrub partly” into “grass mainly with shrub partly”;
   ③ To take different corresponding treatments to the features of underground mining in different periods.

4. The key of integrated control techniques of ecological environment

It is an active ecological environment protection mode including large-scale integrated treatment and localized desertification control with the core techniques of pre-mining eco-function circle construction, underground protective mining and post-mining ecological recycling system building.[9]

4.1. The construction of pre-mining eco-function circle

In accordance to the ecologic fundamental principle and the theory of eco-function regionalization construction, taking Shendong Mine Area as concerned on the natural characteristics of ecological environment and the features of the surface subsidence caused by underground mining, the technique includes three constructions as follows:

(1) The construction of periphery defensive circle
   This technology includes large traveling dune control, the revegetation on semi-fixed dune, and the sand-damage prevention for railway and public road, etc.

(2) The construction of periphery evergreen circle
   It includes water and soil conservation, the technique of mixed forestation with conifer and frutex, the technique of synthetically controlling and disposing in localized area.

(3) The construction of center decorating circle and landscaping
   To create a graceful space for production and living, this technology forms a whole ecological function in conjunction with Perimeter defense circle and Periphery evergreen circle.

4.2. Underground protective mining

To minimize the disturbance and destruction of ecological environment caused by large-scale exploitation, such as water loss and pollution, coal waste stacking and coal spontaneous combustion, this paper develops a technology of mining with suitable protection for surface ecological environment.

4.2.1. Aquifer-protection mining

Based on the characteristic of hydrological geology in Shendong Mine Area, this paper analyzed the breakage and movement law of overburden strata by simulation and other methods, and proposed the basic conditions and the classification of applicable conditions for aquifer-protection mining.

(1) The mechanism of aquifer-protection mining
   There are two cases involved in the mechanism. The first is that the severely weathered formation ranging in thickness from 5 m to 10m at the bottom of shallow water-bearing strata and the top of thin bedrock, acts as an aquiclude with high clay content which gets argillization when encountering water. The second is that the developed degree and form of water cranny within overburden strata has a direct effect on the leaking degree and amount of
water resource. Moreover, it could be controlled by the lithology, the structure of key stratum, and the spatial characteristic and stable degree of the "setting girder".

When the advancement speeds up, the working face could pass the area with abundant water before the cranny in overburden strata have been fully developed, and the aquifer-protection mining can be used, vice versa [10-11].

(2) The basic conditions of aquifer-protection mining

Through the physical simulation and numeric analysis, the integral broken roof might articulate, press each other, quickly close and have the action of water resistance in the rapid advance face. In addition, through the measures of localized injection and filling into the four corners of roof where the water can flow into the face easily, make the aquifer-protection mining feasible. Its basic conditions are as follows:

① Rapid advance
Dependent on the assorting of high reliable equipments and the technologies of quick-crossing fault, quick-shift-moving and so on, the large-scale working face could move forward quickly.

② Reasonable selection of hydraulic support
The reasonable support-resistance could be defined by the optimization of logical hypotactic model support and adjacent rock. Then according to different applicable conditions, the face support could be selected.

③ Localized disposal
It mainly means the processing technique in the area, includes filling, reducing the mining height and injecting, etc.

(3) The classification of applicable conditions for aquifer-protection mining

This paper classifies the applicable conditions for aquifer-protective mining technique in Shendong Mine Area through comprehensive analysis according to the result of simulation, fractured zone height, and caved zone height, and so on.

The classification can be seen from Table 1.

<table>
<thead>
<tr>
<th>Sort</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock thickness (m) &lt;20</td>
<td>20-35</td>
<td>35-60</td>
<td>60-85</td>
<td>&gt;85</td>
<td></td>
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<tr>
<td>Containing water character</td>
<td>Wealthy or middle containing water</td>
<td></td>
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<tr>
<td>Rate (m/d)</td>
<td>&lt;20</td>
<td>&gt;20</td>
<td>&lt;15</td>
<td>&gt;15</td>
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<tr>
<td>Mining method</td>
<td>Room pillar mining and Ribbon mining</td>
<td>Long-wall-face</td>
<td>Part treat</td>
<td>Part disposal</td>
<td>Part disposal</td>
</tr>
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4.2.2. The technique of filtration and purification of mine water through goaf

Filtration and purification of mine water through goaf depends on mine water quality and characteristic of goaf fillings. It has physical and chemical process including filtration, deposition, adsorption, ion exchange, generation of authigenic mineral and so on. The aim of mine water used as resource could be achieved through self-purification. See Fig.1.

4.2.3. The technology of fire prevention and extinguishment in shallow seam

The principle of pressure-sharing aeration could be applied to the whole mine. The passive traditional fire disposal should be transferred into the active prevention and from the system to cell. Then the aim of no fire in the mining area could be achieved through the technologies of reducing the pressure to prevent the fire, speeding up to control the fire and filling the sand to extinguish the fire.

(1) The technique of fire prevention by reducing the pressure
Under the precondition of production capacity, this technique will dispense ventilation resistance reasonably. The ventilation system with large cross-section, low wind pressure and large air input actualizes the lower pressure ventilation in the whole mine.

(2) The technique of fire control by the rapid advance
With the rapid advance, quick-shift-moving of working face and quick-closing of goaf, not only the high-yielding and high-effectiveness could be achieved but also the passive fire disposal could be translated into the active fire prevention. Consequently, it reduces effectively the recombination time of coal and oxygen, which creates a very beneficial condition for spontaneous combustion prevention in goaf.

(3) The technique of fire extinguishment by sand filling
Aiming at the special circumstances of Shan-Meng Mine Area, through filling sand into goaf, one kind of float-sand additive agent with non-sedimentation and non-choking has been developed to prevent the spontaneous combustion of coal seam.

**Fig. 1. Mine water purification and its mechanism**

4.2.4. *The technology of non-rock roadway layout and underground waste disposal*

To minimize the waste discharge from headstream, the layout methods of non-rock roadway have been developed along with the technique of underground waste disposal, such as abandoned roadway filling, waste storage chamber filling, and so on.

(1) The technique of non-rock roadway layout
Layout in each coal seam: canceling the central layout, and forming the independent productive system of each coal seam.
Level crossing disposal instead of grade separation: grade crossing layout needs to dig out rock roadway about 100 m long, with about 2000 m³ waste.
Non-rock passing through the fault: developing roadways in advance on both sides of the fault in order to pass the fault quickly[2].

(2) Underground waste disposal
Abandoned roadway filling: treating the abandoned roadways and goaf as the space for filling waste.
Waste-storage chamber filling: digging waste-storage chamber in permanent rib in order to substitute the waste for the coal.
Resource utilization: using the waste as the filler, gunite stone, explosion-prevention rock/dust, and so on.

4.3. *Post-mining system for the construction of the ecological cycle*

According to the law of ecological balance and water resource balance, in conjunction with the characteristics of
surface subsidence caused by underground mining and the reclamation in strip mining area, a new ecosystem were constructed to achieve the ecological cycle.

(1) The technique of ecosystem optimization and recycling in the mine area subsidence
It mainly means the large-scale artificial supplementary seeding and reclamation of farm field in the subsidence mine area.

(2) The technique of reclamation of farm field
By the comprehensive measure of engineering reclamation and biological reclamation, ecological conditions of the package of optimization techniques in subsidence area will be formed. And after three stages, sequencing as monitoring and managing and repairing, the fertility has been increased and renewed.

(3) The technique of reclamation and ecological rebuilding in strip mining area
This technique mainly includes improving soil quality by the use of clay, diverting flooded land and fertilizing organic matter, and so on.

5. The effect of engineering practice

(1) Economic benefit
Every year, 12.3 billion yuan can be acquired. The benefit is from two aspects. One is the protection of ecological environment in underground mining, and the other is the treatment of the ground ecological environment for reducing the mining damage.

(2) Ecological benefit
Steady ecosystem in the mining area has been built. The vegetation coverage has increased from 3 percent to 59.4 percent. The considerable ecological benefit of 1.788 billion yuan each year has been acquired.

(3) Social benefit
Based on the solution of self-sustainable development, this mining area contributes much to building the local and national ecological environment.

After disposed, the land structure tends to be optimized and become the basis of eliminating poverty and becomes prosperous for local farmers.

6. Conclusions

(1) Only if both preserving ground ecological environment and underground protective mining are interactive in coal exploitation, can harmonious development be achieved in the west large coal field of China.

(2) The aquifer-protection mining technique is the key to develop water recycling system in the mining area.

(3) Engineering practice indicates that this technique could achieve good economic benefit, ecological benefit and social benefit. Consequently, it will become a typical guide to building the mining area in similar conditions.

Acknowledgements

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