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Article

Ecological Restoration of Abandoned Mine Land in China

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Abstract: Mining activities produced a lot of abandoned mine land. This paper introduced the theoretical and technical progress of ecological restoration of surface coal mines, mining subsidence land and coal waste piles in China and discussed some key problems for research in the future. Ecological restoration of abandoned mine land was related to many disciplines, and multi-disciplinary theories might make great contributes to it. Some practical techniques of ecological restoration of abandoned mine land and their demonstration bases in China were introduced. Ecosystem succession process and mechanism, structure optimization of land use and new technologies of ecological restoration of abandoned mine land should be focused on in research activities.

Key words: abandoned mine land; ecological restoration; surface coal mine; mining subsidence land; coal waste piles

1 Introduction

Mineral resources are essential materials of industrial and agricultural production and socio-economic development. More than 95% of primary energy, 80% of industrial raw materials, 70% of agricultural production materials are from mining industry, which has become important basic industry of the national economy in China (Wu *et al*. 2009). The exploitation of mineral resources not only provided the energy and raw materials for the development of the national economy, but also caused the destruction of land and ecological environment such as land subsidence, solid waste and geological disasters; in the western ecological fragile area, coal mining also resulted in the intensifies of soil erosion and depletion of groundwater resources; the toxic gases produced by the spontaneous combustion of the coal gangue and the harmful substance leached from the coal gangue jointly polluted the air, water and soil in the mining area, bringing serious harm to the industrial and agricultural production and people's lives (Peng 2009).

The problems of land and ecological environment in mining area are related to the sustainable development of mining and society, and are also closely related to the pressing issues named "agriculture, rural areas and farmers" and "mining, mine, miners, mining town". Land reclamation and ecological restoration is an effective way to use land resources economically and achieve harmony between people and land in mining area. In our country, large-scale and organized ecological restoration in mining area began in the 1980s. So far, significant progress has been achieved in the ecological restoration of mining subsidence land, excavated land and occupied land and other fields, providing a theoretical basis for the government to formulate and implement environment protection strategy in mining area. At the same time, also providing technical countermeasures for coal enterprises to implement the ecological restoration of abandoned mine land. The theoretical and technical progress of ecological restoration of surface coal mines, mining subsidence land and coal waste piles in China are reviewed and key problems in the future are preliminarily prospected in this paper.

2 Theoretical progress of ecological restoration of abandoned mine land

Abandoned mine land referred to the land that were destroyed in the mining process and could not be used without restoration or the land use function declined, including the open pit, waste dump, tailings pond, subsidence land and the land that lost economic value in use caused by heavy-metal contamination (Xian *et al*. 2009).

The ecological restoration of abandoned mine land was a complex system engineering problem, which was related

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to many disciplines, such as ecology, geology, mining, soil, crop cultivation, forestry, environment, aesthetics, agronomy, geography, land and so on. The domestic early research of land reclamation laid emphasis on engineering design and relatively lacked of research in the theories. Hu (1997a) believed the comprehensiveness of the basic theories of the related disciplines should be the basic theory of land reclamation, including soil and botany theory, ecological theory, mining subsidence theory, as well as soil reconstruction theory (Hu *et al*. 2008). Bai *et al*. (1999) regarded restoration ecology as the theoretical foundation of the ecological reconstruction in mining area. Hu *et al*. (2008) stated the connotation and relationship between land reclamation and ecological reconstruction on the basis of analyzing the definition of land reclamation, understanding the reclamation goals in the foreign countries and introducing foreign reclamation regulations, the contents and history of land reclamation, thinking that "reclamation" itself contained many ecological reconstruction (restoration) contents, the core contents and English name of them had no difference, and there were certain problems of the translation of "reclamation" in our country. Long (1997) proposed five principles of ecological reconstruction of abandoned mine land from the perspectives of landscape ecology: imitation natural prototype principle, the principle of spots-gallery-base relations, the principle of diversity and heterogeneity, the principle of combination of external conditions and man and nature biological control symbiosis theory. Zhang and Zhang (1999) discussed the basic theoretical issues of land reclamation systematically, such as the concept, objects, nature, disciplinary affiliation, research space and its theoretical framework, believing that the basic theories of land reclamation should include: land failure mechanism and land loss theory, the basic principles and laws of land reclamation, and the theory of sustainable and efficient use of reclaimed land. Bian (2005) considered that ecological succession theory provided a good theoretical basis for vegetation recovery and the establishment of a reasonable population pattern of land reclamation and ecological reconstruction in coal mining area, the principles of landscape ecology can be used for the planning of ecological reconstruction and choice of land-use direction. Meng and Zong (2010) regarded ecological succession theory as the principles of ecological restoration in coal mining area, and many other ecological theories were used in the recovery process, including: limiting factor principle, the laws of thermodynamics, population density constraints and distribution pattern principle, ecological adaptability theory, niche principle, succession theory, plant invasion theory, biodiversity principle, the patch-corridor-base theory and so on. The ecological restoration of abandoned mine land was a multidisciplinary research area, not only should it learn from the ecological theories and principles, but it also should draw lessons from other discipline theories, to build its own unique basic theory system.

3 Ecological restoration of abandoned mine land caused by surface mining

3.1 Impact mechanism of surface mining to the ecological environment

The destruction to land caused by surface mining was most direct and obvious because surface mining needed to strip the topsoil and rock above the coal seam (Hu 1996). Surface coal mine can be divided into several parts, such as the stope, waste dump, tailing pond and industrial site, so its land destruction types included excavation, occupation and pollution, of which excavation and occupation were most direct (Hu 1995b). In fact, in addition to the land damaged directly by mining, the destruction of soil erosion and regional ecological environment caused by mining far went beyond the boundaries of the mine areas. Although there were only a few of surface coal mines, and all located in the western and northern of China where population density was low, but most of these areas were arid or semi-arid ecological environment fragile area. Not only did the development of surface coal mines directly damage large area of land, but it also caused a wider range of soil erosion and land desertification which were more serious.

3.2 Ecological restoration of the waste dump of surface coal mine

The waste dump was often a mixture of rock and soil, and there was more rock than soil in the waste materials. Therefore, the waste dump was mainly reclaimed to forestry land, and it also could be used as agricultural land or other purposes. The ecological restoration of the waste dump of surface coal mine included three major parts: landform reshaping, soil reconstruction and vegetation recovery.

3.2.1 Reshaping of the waste dump of surface coal mine

The landform reshaping system of the waste dump of surface coal mine included the base construct, main part construct, platform construct and slope construct. A large number of practices proved that the precautions of ecological restoration of the waste dump were as follows: (i) the combination of mining process and ecological restoration process; (ii) the stripping and storage of topsoil; (iii) the abandon of gangue and ground leveling; (iv) topsoil covering and formation engineering; and (v) the construction of basic water conservancy projects (Wei et al. 2004).

3.2.2 Soil reconstruction of the waste dump of surface coal mine

The key measure of soil reconstruction was that how to make soil order remain basically unchanged or more suitable for crop growth after the ecological restoration. Wei *et al*. (2001) described the concept of the soil reconstruction method of outer waste dump platform, and further studied the erosion control mechanism through hydrological analysis calculation. A large number of practices



Fig. 1 Ecological restoration effect of the waste dump of Pingshuo surface coal mine in Shanxi Province.

have proved that the internal dumping with mining-reclamation integration was a cost-effective method of soil reconstruction. Hu (1997b) proposed the soil reconstruction method named "layered peeling, staggered backfill", whose characteristics could be summarized as follows: (i) stripping topsoil and stockpiling in the mining channel; (ii) dividing the overburden into several layers (such as the top soil layer and bottom rock mass) and stripping respectively; and (iii) staggered backfilling the rock (soil) layer. Staggered backfill was the core principle of soil reconstruction theory (Hu 1997b).

3.2.3 Vegetation recovery of the waste dump

Because of the mixed piled material, the waste dump usually needed to be stacked for 4 to 6 years before stability. Generally speaking, the waste dump was not convenient for ecological restoration before stability. The mode that reasonable configuration of grass, forestry and agriculture and the combination of short-term and long-term benefits could be used as well as the mode called "grass first" and "grass main" in the ecological restoration of the waste dump. Wei *et al*. (2004) analyzed the effect of reducing stream and sediment of different vegetations and their configuration modes of south waste dump in Antaibao surface coal mine and proposed suitable vegetation improvement measures. Tai *et al*. (2002) found that sea-buckthorn was the ideal reclamation plant of the waste dump of surface coal mine in grassland area, which could form the dense artificial sea-buckthorn shrubs in a short period of time, their effect of soil fertilization and water and soil conservation was remarkable and the salinization degree of the lower slope pasture had been slowed down significantly by them.

The ecological restoration effect of the waste dump of Pingshuo surface coal mine in Shanxi Province was shown in Fig. 1.

4 Ecological restoration of abandoned mine land caused by underground mining

4.1 Mechanism and process of ecological changes of mining subsidence land

The rock masses without being mined which were in natural stress equilibrium were bound by all directions forces in the earth's crust. Taking the mining of nearly horizontal coal seam for example, downward movement and bending of the direct roof of goaf would be generated after the underground mining of coal seam. The direct roof was first fractured, then crushed, and successively fallen when the internal tensile stress exceeded the tensile strength limit of rock stratum. The strata range affected by mining was expanding with the moving forward of working face and the earth's surface would be affected by rock strata movement when the mining area was large enough, and eventually causing the formation of subsidence land, which was regarded as "mining subsidence land". According to the physical characteristics of subsidence damage, damage degree of soil productivity, adequacy degree of mining and ownership of subsidence land, Hu (1996) systematically classified the mining subsidence land. Gu *et al*. (1998a) revealed the spatial difference, stage law, productivity change mechanism of mining subsidence land on basis of testing the soil characteristics and crop yield for three consecutive years and using fuzzy mathematics method to evaluate the productivity quantitatively. His research further proved that soil physical properties such as soil bulk density and porosity, were obviously affected by mining subsidence, but the chemical properties were not except the conductivity. The impact on microbial biomass was mainly concentrated in a period of time before and after the stability of subsidence land, soil microbial biomass was gradually restored along with the subsidence time going (Gu *et al*. 1998b). Besides a direct impact on the quantity and quality of land, mining subsidence also had a negative impact on the landscape, regional water environment, survival and growth of wildlife (Hu *et al*. 2008).

4.2 Ecological restoration technology of mining subsidence land

4.2.1 Planning technology

The improvement plan of mining subsidence land belonged to the special plan in the land-use planning system, and earlier research began in the 1990s (Hu *et al*. 1994). Its basic contents included survey and analysis of damaged land status, quasi-damaged land forecast, determination

of reclamation methods and ecological restoration targets, reclamation measures, timing sequence and spatial arrangement of reclamation work, investment and fee arrangement of reclamation project, reclamation benefit evaluation and so on. Besides the traditional planning techniques, the principles and methods of landscape ecological planning were also applied in the reclamation planning process of mining subsidence land. Xia *et al*. (2007) discussed the comprehensive effect and technical means of landscape strategy in the improvement planning process of mining subsidence land, and proposed the landscape restoration approach of composite ecosystem in mining subsidence area with examples. Wang and Han (1999) proposed that only if we complied with the principles of landscape ecology, designed reasonable landscape pattern at the macro level, created suitable ecological conditions at the micro level, could we achieve the goals of ecological reconstruction.

4.2.2 Reclamation engineering technology

After more than 20 years of research and practice, the engineering technology system of ecological restoration of mining subsidence land in China has been initially formed, including the land reclamation technology with the mud pump, towed scraper and excavator, land leveling, dredging and draining method, filling reclamation with the coal gangue, fly ash, lake mud and so on (Hu *et al*. 2008). Comparing with the coal gangue, fly ash and construction waste, river sludge contained higher organic matter content, and the reclaimed land could get more fertile soil. There has been a successful application case reclaimed with lake mud in Yaoqiao coal mine, which located in the west bank of Weishanhu Lake (Zou *et al*. 2009). The disadvantages of the technology were that the silt layer was thick, the time of drainage consolidation was long and the reclaimed land needed two or three years to recover before cultivating (Xue 2006).

Due to the situation that the subsidence of cultivated land was serious in plain mining area and the sediment siltation of Yellow River was also serious,filling reclamation with Yellow River sediments, which was a huge project, became a new way of ecological restoration of mining subsidence land. Although some useful practices have been made by part of the mine enterprises, its key technologies still needed to be further studied, such as the optimization of taking sand position and taking sand pump with long distance, high lift and large flow; optimization of diameter, pipe and flow velocity of sediment transport pipeline; optimization of sediment solid-liquid ratio; assembly technology of pipeline and relay pressurized station; automation control technology; technology of filling with sand, drainage of silt, and recultivation.

4.2.3 Ecological agricultural reclamation technology

According to the principles of ecology, ecological economics, systems engineering and the basic properties and requirements of land ecological economic system, the ecological agricultural reclamation technology referred to transform the subsidence land to an integrated agricultural production system with multi-level, multi-structure, multi-function through engineering and ecological measures, achieving multistage stratified utilization of material and energy, and improving the cycle transformation efficiency and overall function of the system. There were many types of ecological agricultural reclamation technologies, material recycling type of amphibious exchange and complementary was the most typical one, which achieved comprehensive operation of agriculture-fisheries-poultry-livestock by taking full advantage of the characteristics of “deep area” and “shallow area”, and complying with the life patterns of fish, poultry and other living beings, as well as niche, and rational combination with using of the principle of ecological food chain.

4.2.4 Biological reclamation technology

Biological reclamation technology referred to restore the soil fertility and biological production capacity. The application of biological reclamation technology could effectively improve the structure of reclaimed soil and restore the fertility of reclaimed land. Therefore, biological reclamation which included soil improvement and vegetation recovery was also considered as the continuation of engineering reclamation and an integral part of the land reclamation process. The amelioration of mycorrhizal and other microorganism on reclaimed soil achieved more and more concern, which could effectively promote vegetation recovery and played an important role in maintaining the stability of ecosystems. But the application of mycorrhizal technology in ecological restoration was still in the stage of indoor experimental study in China, and most of the study areas located in the traditional coal mining areas, such as Shanxi, Shaanxi and Hebei provinces, and Inner Mongolia.

The ecological restoration effect of mining subsidence land of Tangshan coal mine in Hebei Province was shown in Fig. 2.

5 Ecological restoration of coal waste piles

The ecological restoration of coal waste piles mainly included three key stages: analysis and evaluation of site conditions of coal waste piles, reshaping and soil preparation and vegetation recovery.

5.1 Analysis and evaluation of site conditions of coal waste piles

Site conditions were the comprehensiveness of the environmental factors related to the growth and development of vegetation, including climate, terrain conditions and the properties of the surface composition substance. Coal waste pile was a special site type, which was different from the general site type of soil. Numerous studies showed that the coal waste pile had coarse particle, large porosity, high permeability coefficient, barren nutrient



Fig. 2 Ecological restoration effect of mining subsidence land of Tangshan coal mine in Hebei Province.

content (Hu 1995a; Duan *et al*. 1999; Wang *et al*. 2008), low field capacity, low wilting coefficient and low cumulative evaporation (Duan *et al*. 1999; Wang *et al*. 2008) and other features. Duan and Zhao (1998) studied the salt condition of the surface weathered material of coal waste piles and the results indicated that the salt content of the weathered material was high and the pH value was low with the spontaneous combustion of coal gangue, which was difficult to meet the site conditions for plant growth; the weathered material contained minimum salinity when there was no spontaneous combustion of coal gangue, and the pH value tends to be neutral, which was suitable for normal growth and development of plants. The main limiting factors of the ecological restoration of coal waste piles were texture, moisture, nutrients, pH, salinity, surface temperature, heavy metals in turn (Wei and Wang 2009). Cheng *et al*. (2009) revealed the physical and chemical properties of coal gangue in Huainan area: limited weathering degree; high pH value, strong alkalinity; the nutritional element contents were relatively insufficient except the organic matter, especially the available nutrient; the heavy metal content was much lower than the secondary standard value of soil environmental quality, which demonstrated that there was no heavy metal pollution.

5.2 Reshaping and soil preparation of coal waste piles

Generally, the coal waste piles had steep slopes and loose, poor site conditions. In order to meet the requirements of the planting projects and soil and water conservation of ecological restoration of coal waste piles, the measures of reshaping and soil preparation must be taken. The selection of reshaping form of coal waste piles and design of mountain roads, drainage systems and erosion-resistant slopes were introduced in detail by Zhang and Bian (1997). The soil preparation way of coal waste piles contained overall soil preparation and local soil preparation; soil preparation depth varied from different vegetations; soil preparation width should not be too large, so as not to exacerbate soil erosion; soil preparation time should be at least ahead of a rainy season (Li *et al*. 2006a; Hu *et al*. 2006). Based on the ecological restoration practice of coal waste piles, the cave-shaped site preparation and terracing land preparation were used more often in our country (Hu 1995c).

5.3 Vegetation recovery of coal waste piles

Due to the limiting factors for the growth of many plants, matrix improvement, selection of greening species, vegetation recovery planting and scientific tending management should be implemented on the basis of analysis and evaluation of site conditions and reshaping and soil preparation of coal waste piles.

5.3.1 Matrix improvement of coal waste piles

As a result of the limit of the landform and physical and chemical properties of surface soil of coal waste piles, it was difficult for the plants which were planted directly to survive, even if survival it was also difficult to maintain and manage them, so the matrix improvement of coal waste piles must be carried out. The matrix improvement technologies of coal waste piles mainly included physical, chemical and biological improvement measures. Physical improvement measures mainly contained reshaping and soil preparation and covering with new soil, and chemical improvement measures referred to the fact that the addition of chemical substances could change the acidity and alkalinity or improve the soil nutrients of coal waste piles; biological improvement measures were to use nitrogen-fixing plants, green manure crops, as well as nitrogen-fixing microbes which could endure extreme habitat conditions to improve the physical and chemical properties of surface soil of coal waste piles (Hu *et al*. 2006).

5.3.2 Selection and configuration of greening species

Generally speaking, the greening of coal waste piles should follow the principle named “Greening comes firstly, Economics comes secondly”. According to the site conditions of coal waste piles, the preferred pioneer plants with less restricted factors were first selected to make the ecological environment gradually improve, and then other plant species would be configured. The selection of pioneer plant varieties should comply with the local geographic location, climate and other natural conditions and the particularity of site conditions of coal waste piles. The good

varieties with the resistance to drought and barren, strong germination force, high survival rate, fast growth, especially the indigenous plants, would be the first choice of pioneer plants, as well as the plants with developed root systems (Hu 1995b). Before the large-scale cultivation, the multi-species cultivation experiments in small range were necessary to be implemented for optimization. According to the principle called "diversity promotes stability", the forestation of coal waste piles should be configured with the mixed forest to increase the species diversity and hierarchy of the plant ecosystem and enhance the function of improving the ecological environment. Vegetation community structure should simulate the natural vegetation structure which was stratified mixed with the trees, bushes and grass (Li *et al*. 2006b).

5.3.3 Vegetation recovery planting technology

The forestation of coal waste piles should be implemented in the season with climatic optimum, labor-saving and less investment, which should also conform to the biological characteristics of plant species, therefore, spring, summer and autumn were the best choices. For the poor site conditions of coal waste piles, it's better to use the planting holes on the next season or interval season after excavation (Li *et al*. 2006b). Vegetation planting technology of coal waste piles included covering soil planting, no covering soil planting and drought-resistant planting technology. The covering soil planting was that vegetations were planted on the surface of coal waste piles covered by a certain thickness of soil, fly ash or sludge (Li *et al*. 2006a). The no covering soil planting was that the plants were directly cultivated in the weathered materials on the surface of coal waste piles where soil preparation method was used only, and the planting holes were backfilled with the foreign soil instead of other matrix improvement technology, such as covering with new soil, sludge and so on (Li *et al*. 2006a). Because of the fact that the water shortage was always the dominant limiting factor for plant survival and growth of coal waste piles, water retention was the key measure to improve the survival rate of seedlings. There were several drought-resistance and water-retention planting technologies, such as water retention agent technology, mulching water retention technology, container seedling planting technology, ABT rooting powder technology and so on (Hu *et al*. 2006).

5.3.4 Tending and management technology of vegetation

Tending and management of vegetation was a very important technology link whose key points were soil management (irrigation, fertilization), vegetation management (flat stubble, pruning), vegetation protection (preventing plant diseases and insect pests, fire and the destruction of human and livestock on vegetation) and so on, whose purpose was to create good environment conditions for the survival, growth, reproduction and renew of plants, so that the forestation could be finished quickly; commonly, the management intensity was relatively high in the first year after the forestation of coal waste piles (such as irrigation, fertilizing, tending of vegetation), then the management intensity could be reduced year by year, lastly the plants should grow by themselves to establish a stable self-maintaining ecological system (Li *et al*. 2006a).

5.4 Ecological restoration effect of coal waste piles

Hu *et al* (2002) studied the black locust forest productivity and ecological effect of coal waste piles in Wangzhuang coal mine, and the results indicated that the focus of hydrological effect of vegetation and soil of coal waste piles was reducing the macropore (not capillary pore), increasing the capillarypore, improving soil water-retaining capacity and fertilizer-saving ability, and reducing the infiltration rate through the effect of soil improvement caused by vegetation; the locust tree could prevent the acidification of the surface material, improve the organic matter content of coal gangue, at the same time increase the amount of total nitrogen and promote the effectiveness of nitrogen. The further research showed that: after 9 years of natural succession and growth process, there were great changes in the species and quantities of plants of coal waste piles, and the artificial plant communities had been formed, including 15 arbor species, 12 shrub species and 18 herbaceous species (Hu *et al*. 2003). Wei *et al*. (2007) discussed the effect of vegetation measures on the physical and chemical properties of the gangue weathered materials in Wangzhuang coal mine, and the results indicated that shrub planting, to some extent, was helpful to raise the characteristics of the gangue weathered materials significantly, such as the permeability and retention of moisture, the content of pH, all N, available P, available K and so on, and it also could increase the weathered depth and particle composition of the weathered material.

The forestation effect of coal waste piles of Wangzhuang coal mine in 1991 and 1994 was shown in Fig. 3.

6 Demonstration bases and promotion applications of ecological restoration of abandoned mine land

Twenty three land reclamation pilot projects had been launched by state land management department from 1989 to 1991 in Hebei, Jiangsu, Shandong, Shanxi, Shaanxi, Henan, Hubei, Hunan, Liaoning and Anhui provinces; by the end of 1992, 33 000 ha of land had already been reclaimed and three comprehensive reclamation demonstration projects had been established in Xuzhou, Huaibei and Tangshan cities in 1994, and many other reclamation demonstration projects had also been built up by many mine enterprises and local land management departments (Peng 2000). As for land reclamation of metal mines, the reclamation demonstration base of open pit stope of bauxite and red mud dump in Baise City, agricultural planting demonstration farm of copper tailings pond in Yuncheng City, soilless vegetation demonstration farm of tailings pond



Fig. 3 Forestation effect of coal wa.ste piles of Wangzhuang coal mine in 1991 and 1994.

in Tongling City, arsenic contamination remediation base in Chenzhou City had already been established by state land management department (Hu 2009).

7 Prospects

The ecological restoration of abandoned mine land is a complex system engineering problem with characteristics of systematicness, comprehensiveness and regional differences, which is related to many disciplines, such as ecology, geology, mining, soil, crop cultivation, forestry, environment, aesthetics, agronomy, geography, land and so on. Therefore, intensive research should be carried out by the ecological and environmental scientists, in conjunction with the scientific and technical personnel in mining. Judging from the current situation, the following theoretical and technical issues need to be solved:

(1) Basic theories of ecological restoration of abandoned mine land. The ecological restoration of abandoned mine land is a multidisciplinary research area, not only should it learn from the ecological theories and principles, but it also should draw lessons from other discipline theories, to build its own unique basic theoretical system.

(2) Ecosystem succession process and mechanism of abandoned mine land. According to the type of abandoned mine land and the difference of formation time, typical mine should be selected, and a long-term dynamic monitoring and modeling mechanism should be established to reveal the dynamic succession process and mechanism. The element composition and species configuration, species diversity of reconstruct ecosystems, and nutrient elements accumulation and circulation law of ecological restoration of abandoned mine land should be studied to reveal the main factors of controlling the system stability, providing a theory basis for establishing a self-sustaining ecosystem.

(3) Structure optimization of land use of abandoned mine land. Following the evolution laws of system structure and function, the optimization ways and means of the structure ratio of reclamation and utilization and the regional function structure of abandoned mine land should be discussed under the factors of different landforms (mountains, hills, plains), different land destruction types (subsidence, occupation, excavation, pollution), different economic locations and so on.

(4) Key technologies of ecological restoration of abandoned mine land, including the technologies of reclamation management and planning, reclamation engineering, tending management. Reclamation engineering technology includes matrix improvement (landform remodeling technology, topsoil protection and soil quality optimization technology) and key technologies of vegetation recovery, as well as the collaborative restoration techniques with plants, microorganisms, and animal, breaking through the common key technologies of ecological restoration in western ecological fragile region, soil conservation restoration techniques in eastern mining area with high groundwater table, as well as ecological restoration techniques of acidic coal waste piles.

(5) The establishment of ecological restoration demonstration bases. A number of ecological restoration bases of abandoned mine land with characteristics of high starting points, different minerals, different damage types and different reclamation techniques in China should be established to serve as a model in a long time and play a role in scientific research, technology extension, environmental education and other aspects.

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中国矿山迹地的生态恢复

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摘 要：矿业开发活动产生了大量的废弃地，本文综述了我国露天煤矿排土场、采煤沉陷地和煤矸石山等矿山迹地生态恢复的理论与技术进展，并对今后研究的重点问题进行了展望。采矿迹地生态恢复涉及到很多学科，需要借鉴多学科的理论，同时介绍了采矿迹地生态恢复的实用技术和示范基地建设情况，未来应重点关注矿山迹地生态系统演替过程与机理、采矿废弃地复垦利用的结构优化和采矿迹地生态恢复新技术等问题。

关键词：矿山迹地；生态恢复；露天煤矿；采煤沉陷地；煤矸石山