REVIEW OF ECOLOGICAL RESTORATION TECHNOLOGY FOR MINE TAILINGS IN CHINA

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ARTICLE INFO

***Article history*:**
Received: 11.11.2014.
Received in revised form: 4.2.2015.
Accepted: 6.2.2015.
Keywords:
Ecological restoration
Rehabilitation
Revegetation
Phytoremediation
Reclamation

Abstract:

The disposal of mine tailings is identified as one source of an environmental impact finally resulting in a typically degraded ecosystem. It can easily cause air and water pollution and is a source of man-made mudslides with high-potential socio-economic-energy impacts. Pollution control and ecological restoration technologies of mine tailings have become the burning question in China. In this paper restoration technologies for mine tailings in China are reviewed, by pointing out problems and deficiencies of physical remediation, chemical remediation, bioremediation and phytoremediation. On this basis, the existing problem and the future development of ecological restoration technology for mine tailings in China were discussed and some suggestions proposed. The utilization of comprehensive restoration technologies is a trend for future development. Management systems should be improved in order to promote the sustainable development of mining in China.

1 Introduction

Mineral resources belong to the basic human survival needs. Globally, 80% of industrial raw materials and 90% of the energy comes from mineral resources. In recent decades, with the rapid development of China’s economy and rising people's living standards, mining has become one of the basic industries of China's national development. However, byproducts generated during mining and smelting processes have been increased year by year [1, 2]. More and more environmental and ecological issues loom up as a result of mining development. The ecology and the health of people surrounding the mining area is a serious threat. Research shows that for each ton metal extracted from the ores, approximately 2-12 tons of ore raw materials are lost as tailings [3]. Approximately 300 million hectares land was affected by Chinese mining. The desolate wasteland caused by mining now amounts to about 33000 hectares per year [4]. Among them, waste land as a result of the mining activity itself totally accounted for 59%, dump accounted for 20%, mine tailings for 13%, the goaf for 3% and waste rock piles accounted for 5% [5]. China is a country of relatively low per capita arable land area. The large wasteland of mining areas represents not only the destruction of the ecological environment, but also a waste of land resources. Wasteland formation

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created after mining can be divided into three types:
- tailings wasteland is created where mined ores are processed into concentrates, usually stacked in mine tailings disposal;
- waste land formed by goaf;
- dump waste land formed by waste rock and stripping topsoil.

The disposal of mine tailings results in a typical degraded ecosystem. Tailings sand is completely different from traditional soil due to lower water conservation, extreme poor nutrition, pH and so on. Therefore, the tailings are generally not suitable for plant growth. The mine tailings can lead to the surrounding atmospheric and water pollution [6]. As there is no vegetation cover on the surface, soil erosion can be easily caused. Since mine tailings generally have a greater slope, a man-made danger is posed by high potential mudslides. Once the tailings dam has collapsed, people's lives in this area face a huge threat. Because of these characteristics, pollution control and ecological restoration of mine tailings has attracted more attention and has now become a worldwide problem.

2 Development of mine tailings ecological restoration in China

At the end of 2012, there were 12273 mine tailings in China, of which 6633 mine tailings are in use, 1234 mine tailings are being built and 2193 mine tailings are closed. These tailings are mainly distributed in northern, northeast and central China. By the end of 1994, about 13% of mine tailings had been ecologically restored in China, but mine tailings reclamation activity rates were relatively low compared with 75% ecological restoration rate of mine tailings in developed countries [2, 7].

Therefore, China is still confronted with a severe challenge on issues of mine tailings pollution control and ecological restoration. In recent years, the comprehensive utilization and ecological restoration of mine tailings have made some progress in China. There has been prosperity of ecological restoration technology of mine tailings. However, it is still at the initial stage and the further development should be promoted.

3 Ecological restoration technologies of mine tailings in China

Ecological restoration is a comprehensive technology to pollution controlling and ecological rehabilitating. It is based on bioremediation and ecological principles, combined with physical and chemical engineering technologies to achieve the best results at the lowest cost [8]. Ecological restoration technology is the core of ecological restoration. The essence of ecological restoration technologies is to recover and rebuild damaged ecosystems through appropriate manual guidance and self-regulating ability of ecosystems. Due to special natural conditions of mine tailings, the repair process requires three stages, including the improvement of the tailing sands, vegetation restoration and landscape restoration. The three stages are complementary to each other. The improvement of the tailing sands is the basic premise. Restoration of vegetation is a key step in the process. Landscape restoration is the ultimate goal.

Therefore, vegetation restoration of tailing sands with improved technology is the only way to ecological restoration of tailings. At present, ecological restoration technologies for mine tailings are being used, including physical remediation, chemical remediation, bioremediation and phytoremediation in China.

3.1 Physical remediation

Physical remediation uses physical methods to restore fertility of the tailings in order to make them suitable for vegetation growth, including covering with other soil for melioration, electro-remediation technology, heat treatment, and so on. The removal rate of the heavy metals (lead, zinc and copper) can reach 66%-81% by using electro-remediation technology [9]. The study showed that by increasing the voltage and addition of EDTA, the removal rate of copper from the copper mine tailings can be elevated [10].

One of the most commonly used physical remediation means is employing other soil for melioration and the growth of plants in China. The method of covering the ground with the new soil has achieved desirable results in Anshan city and Chengde city of China [11]. So, this ecological method is generally used for restoring iron ore tailings.

Although the physical approach has achieved some success in tailings restoration, it is very costly and requires high consumptions of energy. After remediation of sand tailings by covering with other soil, they can attain the quality of agricultural soils of the standard. However, this requires not only a lot of manpower, but also a lot of new soil to be covered. Ecological destruction and disturbance can be caused in new soil collection area, which restricted the widespread application of the method. Then again, there is a certain slope on tailings. In the precipitation process, the rain will penetrate the soil on the slope and cause a destructive effect on the layer of covering new soil. Therefore, heavy rain or inappropriate irrigation could cause the erosion of the newly covered soil, and even tailings dam collapse. Research has shown that the stability of the new soil layer is closely related to the precipitation characteristics, slope gradient, slope characteristics and the thickness of the covered soil [12].

In addition, the iron tailings often contain relatively high level of minerals, such as nitrogen, phosphorus, and potassium. Therefore, the method of covering semi-new soil should be adopted. This method consists not only in mixing a certain proportion of new soil and tailings sand but also in covering the tailings surface. On the one hand, it will improve the physical and chemical properties of the soil. On the other hand, it will reduce the costs of using a lot of new soil. Simultaneously, it will reduce the ecological destruction and disturbance in new soil collection area. The study indicated that biological diversity and uniformity index are higher by covering semi-new soil (new soil: tailings sand=1:1) [13]. The method of covering semi-new soil is worth promoting due to the fact that ecological restoration techniques improve the effect and reduce the costs.

3.2 Chemical remediation

Chemical remediation uses chemical methods to achieve pollution control and tailings sand improvement, it includes leaching, addition organic fertilizer, chelating agents, and fixing agents. The removal rate of 60% for lead and cadmium is achieved by adopting the chemical leaching methods [14]. Complexant EDTA added can stimulate the assimilation of heavy metals by plants [15]. Additionally, the study showed that application of limestone was able not only to change the pH value of tailings sand, but also to reduce heavy metals concentration in tailings [16, 17].

In addition, tailings sand is devoid of the necessary nutrients of plant growth, such as nitrogen, phosphorus and potassium. For this reason, improvement of tailings sand fertility is a key step in the ecological restoration of mine tailings. Studies have shown that adding organic waste can enhance their fertility, such as sludge, animal manure, straw, etc., and can effectively improve the plants biomass and reduce the bioavailability of heavy metals [17, 18]. Also, biosolids contain lots of organic matter, plant nutrients, total nitrogen and total phosphorus contents in it, which are significantly higher than in animal manure, so that it is a natural organic fertilizer [19, 20]. However, unlike composting animal manure, biosolids contain parasites, bacteria, as well as some toxic and hazardous substances. Therefore, before being applied, biosolids should be treated innocuously to make them safe and reliable for further use.

3.3 Bioremediation

Bioremediation employing microbial technology is one of technologies for removing or neutralizing tailings pollutants with microbial life metabolic activities. Meanwhile, microorganisms can change the physical and chemical properties of tailings sand and promote vegetation growth. Research displayed that mushroom compost as tailings sand improvement can be beneficial to reducing heavy metals and increasing the content of organic matter and nutrients [21]. Arbuscular mycorrhizal fungi were able to stimulate acid phosphatase of rhizosphere soil and increase biomass [22]. With additions of microbial remediation agents, the microbial activity and microbial community diversity can significantly be increased in gold tailings [23].

3.4 Phytoremediation

Phytoremediation relies on planting native species and green plants as a means for removing polluting substances in mine tailings. During this procedure, phytoextraction, phytostabilization and rhizofiltration effects of vegetation were utilized in order to achieve ecological restoration. However, the tailings sand is very poor, so plant selection is very important. The plants used for phytoremediation should be characterized by fast growth, high adaptability, strong anti-adversity, sufficient roots proliferation and large biomass. In addition, Hyperaccumulator plants can remove heavy metals. Nitrogen-fixing plant can increase nitrogen content of tailings sand. Currently, the plants used for ecological restoration of mine tailings in China are showed in Table1. As can be seen from the table 1, plants of poaceae and leguminosae family are most commonly used in ecological restoration of mine tailings.

Shi et al. researched into the accumulation of Lead (Pb) and Zinc (Zn) by 15 plants in the Pb-Zn tailings [24]. The result showed that *Cercis Canadensis* had the highest concentrations of Pb and Zn in roots. The highest concentrations of Pb and Zn were in stems and leaves of *Rhus chinensis* and *Salix matsudana*, respectively.

Table 1. Plant used in ecological restoration of mine tailings in China. Note: Greenhouse studies (G), field studies (F), and (P) plant surveys

Latin name of plant	Plant family	Comments
Hippophae rhamnoides Linn.	Elaeagnaceae	(F) iron mine tailings [25]
Amorpha fruticosa Linn.	Leguminosae	(F) iron mine tailings [26]
Vetiveria zizanioides (L.) Nash	Poaceae	(G) lead-zinc mine tailings [27] (P) copper mine tailings [28]
Paspalum natatu	Poaceae	(G) lead-zinc mine tailings [27]
Festuca arundinacea L.	Poaceae	(G) lead-zinc mine tailings [29]
Poa pratensis L.	Poaceae	(G) lead-zinc mine tailings [29]
Lolium perenne Linn.	Poaceae	(G) lead-zinc mine tailings [29]
Medicago Sativa L.	Fabaceae	(G) lead-zinc mine tailings [29] (G) iron mine tailings [30]
Magnolia grandiflora	Magnoliaceae	(F) manganese mine tailings [31]
Pittosporum tobira	Pittosporaceae	(F) manganese mine tailings [31]
Euonymus japonicus L.	Celastraceae	(F) manganese mine tailings [31]
Ligustrum quihoui Carr.	Oleaceae	*(F)* manganese mine tailings [31]
Trachycarpus fortunei (Hook.) H. Wendl	Palmea	(F) manganese mine tailings [31]
Juncus effusus	Juncaceae	(G) lead-zinc mine tailings [29]
Imperata cylindrica	Poaceae	(P) lead-zinc mine tailings [32]
Erigeron annuus	Compositae	(P) lead-zinc mine tailings [32]
Lysimachia clethroides	Myrsinaceae	(P) lead-zinc mine tailings [32]
Argyreia seguinii (Levl.)	Convolvuloideae	(P) lead-zinc mine tailings [32]
Equisetum ramosissimum	Equisetaceae	(P) lead-zinc mine tailings [32]
Miscanthus floridulus	Poaceae	(P) lead-zinc mine tailings [32]
Phytolacca Americana L.	Phytolaccaceae	(G) manganese mine tailings [33] (P) uranium mine tailings [34]
Agave sisalana	Amaryllidaceae	(G) iron mine tailings [35]
Pinus massoniana Lamb.	Pinaceae	(P) wolfram mine tailings [36]
Pteris vittata L.	Pteridaceae	(P) uranium mine tailings [34]
Xanthium sibiricum	Compositae	(P) uranium mine tailings [34]
Cassia tora Linn.	Leguminosae	(G) copper mine tailings [37]
Sesbania cannabina	Leguminosae	(G) copper mine tailings [37]
Crotalaria juncea Linn.	Leguminosae	(G) copper mine tailings [37]

4 The prospects of mine tailings ecological restoration technology

In recent years, the ecological restoration technology has gradually attracted attention in China so that the study of ecological restoration technology of mine tailings could be improved. For the time being, the restoration technology is the only technology present in China.

Covering the ground with new soil is the most effective technology currently applicable in China. The technology using microorganisms is still at the laboratory study stage. Thus, ecological technology for mine tailings restoration is still not comprehensive enough, there is biodiversity monotony and it is easy to form secondary pollution.

Certainly, the degenerated mine tailings ecosystems cannot be easily and completely rehabilitated by adoption of a single method. Therefore, the utilization of comprehensive restoration technologies could be a trend in future.

In addition, lack of funds also affects the ecological restoration of tailings. The capital costs of tailings ecological restoration is huge, and it takes a long time to benefit from the tailings ecological restoration. Business owners are not willing to take actively measures to restore tailings ecosystem, so government intervention should be needed. The Chinese government proposed that the subsidies for tailing ecological restoration would be carried out [38, 39]. The mine enterprise will be given different proportions of the government subsidies according to the characteristics of enterprises and local governments to promote development of tailings ecological restoration in China. According to statistics, from 2009 to 2013 the Chinese central government has invested the Renminbi (RMB: the official currency of China) 2.73 billion special funds. The local government and the related enterprises have invested RMB 24.032 billion [40, 41].

In management, the tailings real-time supervision should be strengthened. And relevant regulations and standards should be improved. Ecological restoration and pollution control of tailings is the premise and basis for sustainable development of mining. Therefore, restoration technologies and management system should be improved in the future in order to promote the sustainable development of mining in China.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (41501514), Natural Science Foundation of Hebei Province of China (B2014501053), Doctoral Foundation of Northeastern University at Qinhuangdao (XNB201314) and Science and Technology Support Program Foundation of Qinhuangdao of China (201302A058).

References

[1] Sujova, E.: *Contamination of the working air via metalworking fluids aerosols,* Engineering Review, 32 (2012) 1, 9-15.

[2] Wang, L., Wang, X., Xu, J., Shi, Y., and Yu, J.: *Multi-influence factors prediction for water bloom based on multi-sensor system,* Engineering Review, 34 (2014) 2, 131-138.

[3] Mohanty, M., Dhal, N., Patra, P., Das, B., and Reddy, P.: *Phytoremediation: a novel approach for utilization of iron-ore wastes*, *Reviews of Environmental Contamination and Toxicology,* Springer-Verlag, New York, 2010.

[4] Miao, Z. and Marrs, R.: *Ecological restoration and land reclamation in open-cast mines in Shanxi Province, China,* Journal of Environmental Management, 59 (2000) 3, 205-215.

[5] Gao, L., *Environmental management and pollution control in mine-A case study on nonferrous metal industry of China*, Symposium of Restoration and Management of Mined Lands: Principles and Practice, Guangzhou, China, 1996.

[6] Sharma, R.S. and Al-Busaidi, T.S.: *Groundwater pollution due to a tailings dam,* Engineering Geology, 60 (2001) 1–4, 235-244.

[7] Rodarte-Morales, A.I., Feijoo, G., Moreira, M.T., and Lema, J.M.: *Degradation of selected pharmaceutical and personal care products (PPCPs) by white-rot fungi,* World Journal of Microbiology and Biotechnology, 27 (2011) 8, 1839-1846.

[8] Beretta, M., Britto, V., Tavares, T.M., da Silva, S.M., and Pletsch, A.L.: *Occurrence of pharmaceutical and personal care products (PPCPs) in marine sediments in the Todos os Santos Bay and the north coast of Salvador,*

Bahia, Brazil, Journal of Soils and Sediments, 14 (2014) 7, 1278-1286.

[9] Wang, S., Liu, Y., Li, X., Peng, L., and Xia, W.: *Removal of heavy metals from lead-zinc mine tailings by improved electrokinetic technique,* Environment Protection of Chemical Industry, 28 (2008), 4, 331-335.

[10] Deng, C., Zhou, D., and Cang, L.: *Electrokinetic treatment affected by EDTA and applied voltage drop for Cu mine tailings,* Journal of Agro-Environment Science 24 (2005) 1, 55-59.

[11] Li, C., Bai, H., Zhang, Z., and Liu, J.: *Research on cultivating test of land reclamation in tailings reservoir,* Journal of Anhui Agricultural Science, 37 (2009) 12, 5602-5603, 5684.

[12] Wu, X., Liang, Y., and Li, S.: *Influence of rainfall on stability of carrying soil of a fforested slop,* Journal of Southwest Jiaotong University, 40 (2005) 3, 322-325.

[13] Fu, W., Wang, Y., Yu, Q., Li, J., and Li, Y.: *Effect of different improvement measures on the reclamation effect of iron tailings,* Northern Horticulture, 8 (2012), 158-163.

[14] Zhu, G., Guo, Q., Yang, J., Wei, H., Wei, R., and Wang, C.: *Research on the effect and technique of remediation for multi-metal contaminated tailing soils,* Environmental Science, 34 (2013) 9, 3690-3696.

[15] Sun, J., Tie, B., Qin, P., Yang, S., Qian, Z., and Isao, A.: *The potential of juncus effuses and eulaliopsis binata for phytoremediation of lead/zinc mine tailings contaminated soil under the adjustment of EDTA,* Research of Environmental Sciences, 19 (2006) 4, 105-110.

[16] Hu, X. and Yuan, X.: *In-situ remediation of mine tailings soil contaminated by heavy metals in Tongling city,* Resources and Environment in the Yangtze Basin, 20 (2011) 11, 1378-1382.

[17] Li, Z., Xiong, J., Ma, Q., Yan, M., and Zou, F.: *Effects of organic manure and lime on growth and heavy metals accumulation in Alfalfa grown in soil polluted by lead/zinc mine tailings,* Guangxi Agricultural Sciences, 40 (2009) 9, 1187-1191.

[18] Zhang, H., Shen, Z., Yang, G., An, Z., and Sun, Q.: *Effect of chicken manure-amended copper mine tailings on growth of three leguminous species, soil microbial biomass and enzyme activities,* Acta Ecologica Sinica, 31 (2011) 21, 6522-6531.

[19] Guo, G., Yang, J., Chen, T., Zheng, G., Gao, D., Song, B., and Du, W.: *Concentrations and variation of organic matter and nutrients in municipal sludge of China,* China Water & Wastewater, 25 (2009) 13, 120-121.

[20] Wu, Z., Gu, S., and Li, H.: *Research on the remediation with sewage sludge for the heavy metal contamination in Pb-Zn mining areas,* Safety and Environmental Engineering, 19 (2012) 4, 49-58.

[21] Zhang, X., Yang, s., Duan, C., Liu, F., and Li, F.: *Amelioration of lead-zinc tailings by spent mushroom compost: effects on growth of lolium perenne L. and physico-chemical properties of tailings,* Journal of Agro-Environment Science, 33 (2014) 3, 526-531.

[22] Xu, Y., Li, F., Zhang, J., and Han, D.: *Application of arbuscular mycorrhizal fungi in vegetation restoration of iron tailings,* Metal Mine, 411 (2010) 9, 126-129.

[23] Li, Z., Peng, A., and Qu, L.: *Effects of microbial remediation inocula on microbial community in gold-tailings soil with secondary tillage,* Hunan Agricultural Sciences, (2009) 5, 46-49.

[24] Shi, X., Chen, Y., Wang, S., and Li, J.: *Pb, Zn accumulation and nutrient uptake of 15 plant species grown in abandoned mine tailings,* Environmental Science, 33 (2012) 6, 2021-2027.

[25] Wei, F., An, G., Wang, G., An, J., and Yan, H.: *Study on the grouwth status of buckthorn in different tailings dams,* Journal of Anhui Agricultural Science, 37 (2009) 28, 13839-13841, 13855.

[26] Wang, Y., Li, Y., Shi, J., Guo, J., and Du, J.: *Effect of different vegetation restoration measures on the species diversity and soil properties of iron tailings,* Journal of Soil and Water Conservation, 26 (2012) 3, 112-117,183.

[27] Xia, H. and Shu, W.: *Resistance to and uptake of heavy metals by vetiveria zizanioides and paspalum notatum from lead/ zinc mine tailings,* Acta Ecologica Sinica, 21 (2001) 7, 1121-1129.

[28] Yang, F., Xiao, T., Zhou, L., Ning, Z., and Jia, Y.: *Geochemical fractions of heavy metals in both vetiveria zizanioides (L.) nash and*

rhizospheric copper tailings, Earth and Environment, 38 (2010) 3, 280-285.

[29] Yuan, M., Tie, B., Tang, M., Lin, J., and Zhan, L.: *Resistance to and uptake of heavy metals by four herbaceous plants grown in the soil polluted by lead/zinc mine tailings,* Ecology and Environmental Sciences, 14 (2005) 1, 43-47.

[30] Zhang, C., Bi, Y., Yu, M., and Chen, B.: *The modified effect of arbuscular mycorrhizal fungion the Fe tailings substrate,* Metal Mine, 410 (2010) 8, 171-174.

[31] Tian, D., Yan, W., and Xiang, W.: *Adaptation of five species of resisted vegetation to differently improved models in Xiangtan Gangue,* Journal of Central South Forestry University, 26 (2006) 6, 1-5.

[32] Wang, C., Li, J., Zhao, X., Tong, H., and Gu, Q.: *Impacts of different plants on the heavy metal tolerant bacteria in mine tailings polluted by Pb and Zn,* Chinese Journal of Soil Science, 40 (2009) 1, 184-188.

[33] Xiang, Y., Feng, T., Peng, X., and Yao, G.: *Effect of phytoremediation of manganese mine tailings contaminated soils by phytolacca americana on following plants,* Journal of Ecology and Rural Environment, 25 (2009) 3, 63-68.

[34] Liu, Y., Zeng, Q., Su, W., Peng, M., Wang, C., and Liu, W.: *Studies on the character of the arthropod communities in habitats repaired by plants in uranium tailings dam,* Life Science Research, 14 (2010) 6, 516-522.

[35] Qu, Q. and Yang, A.: *Research on soil remediation with sisals in iron mine tail stock,* Journal of Anhui Agricultural Science, 37 (2009) 33, 16490-16493.

[36] Wang, Z. and Song, Q.: *Characteristics of soil heavy metals pollution in the tungsten mine tailing of Panggushan and its planting recovering,* Journal of Jiangxi University of Science and Technology, 29 (2008) 3, 34-37.

[37] Zhang, H., Shen, Z., Yang, G., An, Z., and Sun, Q.: *Effect of chicken manure-amended on inorganic nitrogen components of copper mine tailings and growing development of three leguminous species,* Journal of Agro-Environment Science, 30 (2012) 11, 2285-2293.

[38] Ministry of Finace of the People's Republic of China, *The central government's interim regulations on Non-ferrous metal mining enterprises tailings security engineering and subsidies management,* CQ 2009, 120 (2009).

[39] Peng, Y. and Lan, Z., *The management approach to special funds and project for tailings control by Hunan province,* in Zhongguo Shenji Bao 2013.

[40] State Administration of Work Safety, National Development and Reform Commission, Ministry of Industry and Information Technology of the People's Republic of China, Ministry of Finance of the People's Republic of China, Ministry of Land and Resources of the People's Republic of China, Ministry of Environmental Protection of the People's Republic of China, South-to-North Water Diversion, *The notice of the summary of national comprehensive management in 2013 and the key work arrangement in 2014,* AJZG 2014, 69 (2014).

[41] Administration of Work Safety, National Development and Reform Commission, Ministry of Industry and Information Technology of the People's Republic of China, Ministry of Finance of the People's Republic of China, Ministry of Land and Resources of the People's Republic of China, Ministry of Environmental Protection of the People's Republic of China, South-to-North Water Diversion, *The notice of the summary of national comprehensive management and the key work arrangement,* Administration of AJZG 2013, 99 (2013).