

Project Description of Ecological Reconstruction of Soda Residue Dump in Tianjin, China

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Abstract: Soda residue dump is a special type of urban industrial wasteland which brings bad damage to ecological environment and waste of land resources, the specialized research on ecological restoration of soda residue dump is lack in China and other countries. The main compositions of soda residue which produced in the producing process of alkali are calcium chloride and calcium carbonate, which have serious influence on surface water and soil quality. As a solid which is very tiny and big interspaces granule, the soda residue turn into dusts and fly with the wind very easily. That causes severity atmosphere environment pollution and is hard to manage. Soda residue dump located in Tanggu district in Tianjin is formed by producing alkali used ammonia-alkali process in recent 80 years. More than 16,000,000m³ soda residues in total were turned into engineering soil that is mixed with soda residue and fly ash added calcium from 1996 to 2001 in the project. 7 hills building up with engineering soil are reconstructed into a park named Ziyun Park and the program is a successful ecological restoration attempt. Peak height of the dump is 32 m. The surface of hill-body is covered with 0.8-1.2 meters deep planting soil and then vegetation planted on it. More than 40,000 flowers and plants, 160,000 m² lawn and almost 300,000 arbors and shrubs with more than 100 plant species of variety are cultivated in this project. After five-year restoration, the effect of ecological restoration is satisfactory. Furthermore the experience of ecological restoration of soda residue dump can offer reference for ecological restoration of other similar projects.

Key Words: ecological restoration; reconstruction; soda residue dump; industrial wastelands; China

1. Introduction

Land is one of the most important resources on which humans depend. With economic development, industrial expansion, acceleration of urbanization and growth of population, China is experiencing a rapid decline in its total cultivated land area. Furthermore, industrial wastelands in city not only occupy a mass of lands but also bring local environment pollution. Thus, it is an urgent and important task to restore industrial wasteland in China.

Industrial wastelands are anthropogenic landforms that consciously achieved by human activities include dumps, railway embankments and excavations. These industrial wastelands have had important function in history that they were the witness of city's economic and social development. However, once these industrial wastelands are abandoned, they will bring serious damage to environment and is difficult for restoration. The aim of this paper is to document Caustic Sludge dump wastelands landforms, which, being significant morpho-

logical features and complicated composition are frequently positively perceived and accepted by local community, who detect in them usable and aesthetic values.

Ecological restoration practice of industrial wastelands in America and Europe started in the late 1950's and a great number of ecological restoration projects were fulfilled in recent half century, which, much experience was obtained in engineering technology, base rebuild, vegetation restoration and project management^[1]. Furthermore, some countries successfully reconstructed industrial wastelands into park landscape e.g. U.S.A., Australia and Germany. An early example is that Buttes-Chaumont park, a place long known for its mixed uses, the park was the site served as a gypsum quarry and then dumping grounds for refuse and "night soils" from surrounding neighborhoods for 300 years. In the 1860s, Napoleon III transformed the area into a park^[2]. With the decline of traditional industry and strengthening of environmental consciousness, meanwhile, development

of science and technology provides enough supports, restoration and reconstruction programs of industrial wastelands become popular after 1970's. A good example is Gas Works Park, in Seattle, Washington, which is located on the site of a coal and oil gasification plant that ceased operation in 1956. During operation, many types of wastes, including coal, tar, and oil, accumulated on-site. It is a leading card reconstructed from industrial wastelands into park landscape with landscape design method in U.S.A. in 1972^[3]. After that, more programs with landscape design methods restoring industrial wastelands that destroyed local environment although once had important function in history appeared to improve environmental condition and promote the development of economy and society. These practices fulfill successfully reconstruction and restoration of industrial wastelands.

As discarded waste material dump, soda residue dump in Tianjin city have many characteristics like lower density, complicated chemistry compositions, tiny granule and easy collapse. The program not only resolves the problem of soda residue pollution but also reconstructs local ecological environment. The aim of this paper was to describe the background and the process of ecological engineering and natural vegetation reconstruction on abandoned soda residue dump in Tianjin as well as to provide valuable experiences for ecological restoration of other type caustic sludge dumps.

2. Methods

2.1 Background

In the year 1917, YongLi Alkali Plant (Tianjin Alkali Plant) founded by the famous businessman FanXudong and soon became the cradle of China's chemical industry. From then on the plant forged a close tie with Tianjin, where the plant built on. In the past 80 years from the foundation of the plant, Tianjin Alkali Plant adopted the ammonia-alkali process to produce alkali. Each ton of alkali could produce 0.3 ton soda residue which produced in the producing process of alkali.

For decades, caustic sludge had spread from the plant to the seaside, forming huge soda residue hills with

an area of 3.99 km², the height between 15-26 meters. The total volume of the hills reaches to 16,000,000m³. With rapid development of TangGu District, Tianjin Economic- Technological Development Area (TEDA), Tianjin harbor and Tianjin tax-protected zone, soda residue hills seem more and more like a tumor of the city. Soda residue contains lots of water, with poor stability. It is easy to collapse once encounters with earthquakes. On sunny days, the dust which is the essential element of the soda would float in the air. When the rain occurs, sewage flows everywhere. So the existence of the soda residue hills seriously pollutes the air quality.

Using of alkali results in large quantities of soda residue which requires proper disposal. Disposal of soda residue has adverse impacts on terrestrial and aquatic ecosystems due to leaching of chemical substances from soda residue into soil and groundwater, as well as reduction in plant establishment and growth. The chloride contained in the liquid soda residue is much higher than the criteria. It makes the physical and chemical index of surface water quality decline and increases the content of chloride, salinity, suspended matter of the river and coastal waters of the Bohai Sea, which seriously polluted the water quality. Since the essential component of the soda residue is solid particles particularly small particles with large pores, so it is easy to fly on windy days. In addition, the wind is prevailing in Tianjin, this place suffered a lot from caustic sludge dust. Monitoring data show that even the average wind speed is 4.6 m/s, the dust will also affect air quality of about 20 km² around the hills. This brought great threat and harm to the health of people and their living environment. Moreover, unlike other industrial dust pollution, soda residue dust is more difficult to control, making the pollution even more serious.

In this context, one of the best and eco-friendly alternative management would be to plant vegetation in the dump area which will serve the purpose of both stabilization of soda residue dump and providing a pleasing landscape^[4-6]. Hence it is necessary to restore the soda residue dump site following suitable scientific approach.

September 1996, soda residue dump treatment project in Tanggu district of Tianjin city started. On the ef-

fort of workers and experts, more than 16,000,000m³ soda residue was turned into engineering soil in 2001. After filling the pond with an area of 9,750,000m², about 230,000m² lands were available again. Residual soda residue about 7,000,000m³ (occupy about 0.96km² lands) we called it The 3rd Road Soda Residue Dump will be reconstructed into park named Ziyun Park landscape in this program.

2.2 Study Area

Tanggu district (lat39°N, long117.6°E) is located in the east of Tianjin city of China. The study site is located in the east of Tanggu district and the total area is 0.96km²(Fig. 1), and it is the derelict land formed from the river-sea interaction, the soil formed no more than 600 years. According to statistics data, the biggest solar radiation intensity of the whole year is 5652.18 MJ/m² and sunshine duration of the whole year is 2891.8 hours. The climate is characterized by cold dry winters and warm moist summers. The mean annual temperature is 12.4°C, and the mean monthly temperature is 26.2°C in July and -4°C in January. Annual precipitation in the mining area is 550–680mm, 60% of which is concentrated as rainfall between July and September. Spring is characterized by drier conditions and the annual evaporation is 3–4 times as much as annual precipitation. The soil type is saline-alkaline soil which has bad effect on plant growth. The main difficulties of planting trees in this area were mainly due to soil conditions, which had (1) low levels of organic matter(1.02-1.41%), (2) industrial debris and inert materials, (3) high levels of total salt content(about 3%), (4) high pH, usually above 8. The difficulties of the project in soda residue were mainly due to characters of physics, which had (1) very tiny granule, (2) big interspaces granule, (3) high levels of water content. These natural conditions make the ecological restoration of soda residue dump more difficult, thus it is necessary to cover planting soil to improve soil quality.

Three major themes that currently are used to develop statements of restoration goals: restoration of species, restoration of whole ecosystems or landscapes, and the restoration of ecosystem services^[7]. We decided to

select the restoration of landscapes according to the demand of the local government and citizen.

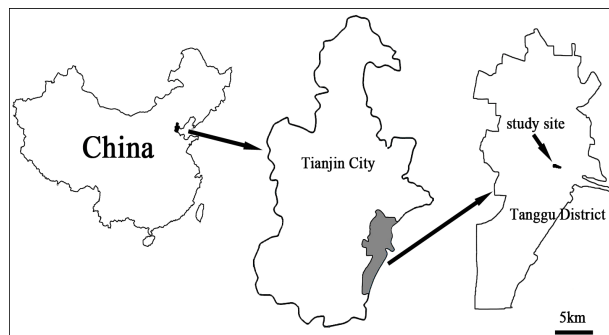


Fig.1- Map showing the location of study area, Tianjin, China

2.3 Decision making

The decision maker for the restoration program included the working staff and consultants responsible for the restoration, local government regulators, environmental groups and the local public. They all had valid but often conflicting concerns. The working staff was interested in constructing a successful dump restoration project that satisfied all regulatory requirements. The regulators were interested in restoring dump as landscape for repairing ecological damage. Environmental groups were interested in ecological outcomes. The local public had concerns about the change of air quality. All of these concerns needed to be identified and addressed early in the process to avoid conflict.

The key to integrate decision makers' concerns is communication. Contact with the regulatory community should come first and should begin with individuals from or familiar with the dump area, so that if the objectives of regulators and restorers do not coincide, there is an opportunity to resolve differences. Existing site conditions need to be well understood so that the restoration as designed will be physically and biologically achievable.

2.4 Chemical characteristics of soda residue

Composite soda residue samples were collected in the month of January 1996 and were analyzed for different parameters. The chemical parameters were analyzed as per the standard methods^[8]. According to the test, the main compositions of soda residue are CaCO₃, CaCl₂,

and CaO etc (Table 1).

Table 1. The chemical composition of soda residue (%)

Comp.	CaCO ₃	CaSO ₄	CaCl ₂	CaO	NaCl	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	Mg(OH) ₂
Content	45.6	3.9	10.5	10.3	2.7	3.0	0.7	7.8	9.0

2.5 Reconstruction Steps

Reconstruction was accomplished in three steps: (1) making engineering soil used soda residue and fly ash added calcium, (2) heaping the hill-body using engineering soil, (3) covering the hill with planting soil, and (4) planting vegetation.

2.5.1 Make Engineering Soil

From table 1, we can find that main compositions of soda residue are insoluble salt include CaCO₃, CaSO₄, Al₂O₃, Fe₂O₃ and SiO₂ etc and which all can become important composition of engineering soil. Other composition like CaCl₂ and NaCl₂ etc are soluble and will be reduced with leaching. Toxic substances can not be eluviated from soda residue. Hence, soda residue neither has damage to the plant growth nor has adverse impacts on groundwater. However, it is necessary to improve structure of soda residue so as to increase the dry unit weight and strength. Making engineering soil using soda residue needs to decrease water contents and pore of soda residue first. As soda residue granules have very good hydrophilicity, it is difficult to separate the water from soda residue naturally.

Fly ash added calcium is another residue producing with the produce process of alkali (Table 2). So we can mix fly ash added calcium into soda residue in suitable proportion to decrease water contents. The admixture of soda residue and fly ash added calcium is used in the ecological restoration project of soda residue dump and so is called engineering soil. Physical character of engineering soil is tested by experiment and found the best performance is in the proportion 8:2 which the content of soda residue is 80% and the content of fly ash added calcium is 20% (Table 3).

Table 2 The chemical composition of fly ash added calcium (%)

Composition	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	Mg	Loss on ignition
Content	35	22	15	6	2	20

Table 3 The physical character of engineering soil

Parameter	gravity	Water content	Plastic	Liquid	Soluble salt content
value	2.35	70%	62.1%	80.2%	10%

Moisture expansion and collapsible deformation of soil are hazardous factors to the project and the ground stability^[9]. Moisture expansion and collapsible deformation of engineering soil are tested and the experiment results show that engineering soil had no hazard to safety of project.

After the test of physical and chemical character of engineering soil, the project committee decided to initiate engineering soil making project which is the most important part of the restoration program in September 1996.

From September 1996 to March 2001, 460 million dollars are spent and more than 16,000,000m³ soda residue was turned into engineering soil which can be used in the project. From now the preparation of ecological restoration of soda residue dump in Tanggu district of Tianjin is completed.

2.5.2 Building the Hill-body Using Engineering Soil

In the second step of reconstruction, it was decided to develop this site for recreation purposes and to set up a park with varied topography. Therefore, the engineering soil was used to build five hills. Using the natural shape of the soda residue dump, as well as erecting earthworks, the project which heaping the hill-body using engineering soil is started in April 2001. To reclaim this area, i.e. to level and construct the hills, 7,000,000m³ was used, i.e. 44 percent of the mass of soda residue produced in the past 80 years. Although the stability of the engineering soil is proved by experiment, we have no experience in real practice. It will bring economic loss and safety accidents if hill-body collapsed. So it is necessary to monitor the stability of hill-body with the constructing process. We can take effective and secure measures to prevent accident when dangerous signal appeared. Monitor result indicates that the hill-body is basically stable in heaping process. Suitable strengthening measures were taken when settlement velocity of hill-body exceeded design criteria and the project is completed successfully in No-

vember 2001. These hills are the so-called over-level dumps. From the south to the north their relative heights are as follows: 28 m, 18.5 m, 19.5 m, 16 m, 24 m, 27 m and 32 m. They have the shape of flat-topped cones. The slopes are divided into terraces to resist soil erosion which runs spirally around two of seven hills from its foot to the top.

2.5.3 Cover the Hill with Planting Soil

It is not suitable for plant growth because of the complicated chemical compositions of the engineering soil. In order to improve landscape and environmental quality of soda residue dump completely, extra plants are necessary in the future. The method covering planting soil on the surface of hill-body to meet the requirements of plant growth is selected after study and analysis. Covering with planting soil is simple and effective; however thickness should be considered first. The characters of soil have effects on plant growth. Taking the soil erosion by wind and rain into account, the hill-body is covered with planting soil with the thickness between 0.8-1.2 m. The planting soil comes from a farmland which will become another industrial area according to the plan. This task is accomplished in great effort until April 2002.

2.5.4 Plant vegetation

The plant species selected for bioremediation of soda residue dump were based on their adaptation to climate conditions, resistant to pH and salinity. Native plant species were selected on the basis of their commercial availability.

Fieldwork was started in the month of June 2002 and completed in October 2002, more than 40,000 flowers, 160,000 m² lawns and a total of 0.3 million trees and bushes were planted (mainly dragon juniper, purple barberry, London planetree, Chinese hawthorn, peach, silk tree and Chinese pagoda-tree). At present more than 100 species of plant species grow in the park. The basic den-droflora of the park is created by 15 native species of arbor and bush. The vegetation that has developed here in a variety of ecological conditions makes a permanent test area for research on landscape and vegetation reconstruction of devastated areas. The park constitutes a specific enclave, both of landscape and nature. Here it is possible to find juniper, purple barberry, London plane-

tree, Chinese hawthorn, peach, silk tree and Chinese pagoda-tree, indigobush amorpha, tree of heaven ailanthus, Chinese box, staghorn sumac, common jujubetree, Adam's needle etc. The verdant plants have attracted dozens of kinds of birds coming to perch. Local dweller's dream of 50 years that turn soda residue dump into beautiful landscape has come true. The landscape is called Ziyun Park which means luck and happiness.

3. Results and discussion

3.1 Results

In this paper we have described the ecological reconstruction process. According to the short-term (2003-2007) observation, mostly plants have a good growth. Observation can provide initial information on the success of the reconstruction, but extrapolations and conclusions from the observation have to be made with caution as the restored ecosystems have not yet reached equilibrium. During the initial phase biotic elements and morphology will exhibit large spatial and temporal variation as the restored ecosystems slowly mature^[10-12]. After 4 years' cultivation, the vegetation growth has been flourished in spatial form.

After 4 years the project completed, due to the developed root system of slope herbage and its good network properties and high mechanic strength, it possessed a strong capability of soil-conservation and slope-protection. After slope management, the amount of soil erosion decreased by as much as 60%, so soil erosion was controlled effectively.

From this project, we obtain valuable experiences on dump wasteland reconstruction that is a special anthropogenic convex landform type. In fact, as landscape material, the project not only solve pollution problem of soda residue but also create beautiful anthropogenic landscape. To a large city, such reconstruction can meet citizen's demand of good environmental quality.

3.2 Discussion

A whole set of engineering and ecological restoration approaches were applied to the reconstruction of soda residue dump. So far, the whole landscape is satisfactory. On the basis of experience of the project, con-

sidering its application, and, I hope, strengthening research in:

(1) Covering planting soil on the surface of dump is a simple and effective method; however the cost is high and often destroys cropland and other places. So other methods should be researched.

(2) A primary shortcoming is lack of a clearly formulated objective for what rehabilitation is to achieve. We can not estimate how long current landscape exist and whether the landscape change better or not. It is acceptable to have an objective function to minimize cost, provided this is qualified (in the style of linear programming) with 'subject to the constraints that'.

(3) Take different measures according to different chemical compositions in other types of dump in the future.

(4) It is necessary that the ecological observation and monitoring system should be established for plant growth and succession. Such monitoring system had not established and it is the main defect in our project.

4. Conclusion

Ecological reconstruction transformed the soda residue dump into park landscape. Engineering soil was made successfully by using soda residue which had complicated chemical compositions of soda residue and fly ash added calcium in suitable proportion through experiment and in the project. The approach depended upon ecological engineering in the context of experiment data construction plan that favored artificial reconstruction in a short time frame. The difficult engineering problem which builds hill-body by using soda residue was solved. This project is a great example of dump wasteland ecological reconstruction and can offer reference for ecological restoration of other similar projects.

Further studies are needed in order to assess the ecological status of plant species in the context of envi-

ronmental reconstruction project. New research initiatives and research studies are advisable to determine the long-term response of vegetation community to the soil conditions.

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