

Resourceful ecological treatment of wastewater in urban ecosystem

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Abstract— The treatment amount of wastewater is restricted to a small percentage in China. One of the reasons for that is the shortage of funds. Therefore, developing the technology of cost-effective, low energy-consuming and high efficiency is one of the important way to speed up the steps of wastewater treatment. This paper elucidated the principal and characteristics of the resourceful ecological treatment of wastewater. A successful example of resourceful ecological land treatment of wastewater was given. The key points and the relative policies concerning the further development of resourceful ecological treatment of wastewater as a sets of technologies have been suggested.

Keywords: ecological treatment; water resources; wastewater; pollution.

1 Introduction

At present, water pollution and shortage are the great problems in many countries around the world, especially in the developing countries. Environmental pollution has brought a great threaten to the human healths and the quality of ecological environment on which the people rely for their very existence.

In China, the discharge amount of wastewater is accompanied with the development of the economic construction at the tremendous speed. Statistics show that the total amount of wastewater deposited, nowadays, is about 36 billion tons. The percentage of treatment was only 24 % for the industrial wastewater and 4 % for the domestic wastewater, respectively. The directly discharge of wastewater has caused the heavy pollution of the aqueous environment. It is clear that wastewater treatment is an urgency of important problem to be solved.

There are a number of techniques available for the treatment of wastewater, which include the primary physical treatment; the traditional biological secondary treatment and the advanced tertiary treatment. Among them, the biological secondary treatment is general recognized as the more efficiency and has been widely used in the developed countries. However, concerned with the total amount of the wastewater mentioned above, the cost for setting up the secondary treatment plants in all of the cities of China are still considered very expensive.

The resourceful ecological treatment of wastewater is a cost-effective, low energy-

consuming and high efficient technology. The organic components in the wastewater can be degraded by the soil microbes through the processes of physics, chemistry and biology. And the nutrient contained in the wastewater can be used by plants. At the end, the planned goals of harmless and resourceful use of wastewater can be reached. In this paper, the necessity and possibility of developing the technology of resourceful ecological treatment of wastewater based on the status of shortage and serious pollution of water resources in China has been aimed, together with the example of resourceful ecological treatment of wastewater. Suggestions concerned with the future development of the resourceful ecological treatment of wastewater have been made.

2 The principal and concepts of resourceful ecological treatment

Resourceful ecological treatment of wastewater is defined as the controlled application of wastewater onto the surface to achieve a designed degree of treatment through natural physical, chemical and biological processes within the soil-plant-water matrix (USEPA, 1981). It should be regarded as an ecological engineering which combines ecological principals with engineering methods. The main principals in it include integral optimization, recycling of materials and geographic diversity (Ma, 1990).

2.1 Integral optimization

Each biosystem level has emergent properties and reduced variance as well as a summation of attributes of its subsystem components. The old folk wisdom about the forest being more than just a collection of trees is indeed a first working principal of ecology (Odum, 1983). Resourceful ecological treatment of wastewater is a systematic engineering including control of discharging sources, pretreatment, transportation and land distribution of wastewater, cultivation of selected plants and collection of renovated water. Thus, a comprehensive design should be integrally optimized for the ecological treatment system to maximize its functions of ecological purifying the applied wastewater and reusing the nutrients and water resources in the wastewater.

2.2 Recycling of materials

The rational underlying resourceful ecological treatment systems derives from general and specific needs in the utilities of the earth's soil mantle and the suitable plants in an engineering system for wastewater disposal. Utilization of the soil as a "living filter" has been acclaimed as the most ecologically appropriate treatment technique because recycling of materials is a built-in reality. However, the recycling of processes are very complex because of the large number of interacting variables involved. The fate of wastewater materials in the multi-compartment plant-soil system is determined by a great number of processes, including physical retention adsorption on solid surfaces, plant and microbial uptake, microbial, mineralization, volatilization, leaching, chemical

breakdown and precipitation (Sanks, 1976). Theoretically, the ecological system is the regenerated resources itself. It can be renovated continuously and developed according to the substitution regulation of the ecological system. However, rational management and control of the assimilation capacity of the heavy metals and priority organic pollutants must be enhanced in order to prolong the life of the system.

2.3 Geographic diversity

Among all sites available for land disposal, one differs from another on such aspects as land use, soils, climate, topography and geohydrology. So that, preceding any design of resourceful ecological treatment system, extensive site investigation and adequate planning should be made to collect necessary information and to ensure rational designation of engineering and the management of the operation of resourceful ecological treatment system that are feasible for local conditions.

The resourceful ecological treatment of wastewater, in point of engineering, is main including three aspects as follows: First, systematic design aimed at a specific situation; second, rigorous engineering construction of the systems; and last, the proper operation and rational management. It should be remained that although resourceful ecological treatment of wastewater is derived from traditional direct irrigation with untreated sewage, the modern concept of resourceful ecological treatment has been developed into an integral technology and differs from irrigation farming mainly at 4 aspects as follows:

(a) The direction of the utilization

The traditional irrigation of wastewater was an hydraulic engineering for farmland. Its principal purpose is to utilize the wastewater as a resources to increase the production of vegetation without considering the continuous operation of the systems. On the contrary, resourceful ecological treatment of wastewater emphasizes wastewater treatability, design of storage pond, water balance, distribution methods, hydraulic loading rates and selection or combination of covering plants to ensure continuous operation and obtain the optimum treatment of wastewater.

(b) Control of the pollutants loading

Wastewater from industries and municipalities are considered as resources with traditional irrigation rather than waters. With sewage irrigation, there is only one important concept of the quality of wastewater. However, resourceful ecological treatment places much emphasis on the pollutants loading per unit area and the calculation of environmental assimilated capacity to obtain from several limited conditions, the lowest limited constituents (LLCs) as the basis of determining the parameters of hydraulic loads.

(c) Ecological structure

Resourceful ecological treatment system use the varieties ecological structure rather than the monoecological form from the traditional irrigation of wastewater to adjust the

demand of hydraulic and pollutants loading at the different cases for the aims of continuous and optimum operation of the systems.

(d) Engineering design and management

An ecological treatment system should be elaborately designed to achieve planned goals. The selection of type of ecological treatment systems is depended on the site conditions, climate and regulatory requirements. The major design variables such as plants and hydraulic loading rate. Land area and storage requirements and application methods would be determined. When selecting the type of distribution system, the designer must consider the terrain, plant, soil and operation/maintenance costs. The wastewater must be passed through the filtration of the soil and rhizosphere. Overflow usually occurred in the traditional irrigation must be controlled.

3 The functions of resourceful ecological treatment systems

The resourceful ecological treatment of wastewater is a multi-functions and multi-objectives ecological engineering system that stimulated the principal of natural ecosystem. It applied the modern technology to establish the positive cycling and multi-utilization of wastes from the wastewater treatment processes and realized the harmlessness of wastewater at the high efficiency and lowest energy-consuming. Resourceful ecological treatment system mainly use the regulation, cycling functions of natural ecosystem under the control conditions for the harmless treatment and utilization of wastewater.

3.1 Production

Resourceful ecological treatment is aimed at the special economic activities. Its functions are growing vegetations and at the same time to treat wastewater. As known that traditional secondary biotreatment was not efficiency to remove the nitrogen and phosphorous from wastewater so that causing the eutrophication of receiving water bodies at various degree. In opposite, the nitrogen and phosphorous from wastewater can be as the resources to be used in the resourceful ecological treatment system. The contents of nitrogen in the municipal wastewater is usually at the level of 20—30 mg/L. Which is sufficient for the crop and plant growing in the whole growth seasons.

3.2 Purification

In the resourceful ecological treatment systems, soil-plant-water matrix is the principal medium in which treatment and removal of pollutants take place. The mechanisms responsible to the purification of wastewater consist of : uptake, transformation and breakdown by plant roots and leaves; degradation, transformation and adsorption by soil microbes such as fungi, actinomycete and bacteria; absorption, complexing and precipitation by soil organic matters or inorganic colloids; ion exchange and physical retention. In 1987, a pilot scale ecological land treatment system was set up in Shenyang,

China, which was designed to dispose of wastewater from the city where various industries were located. The wastewater was characterized by high COD and TOC and low BOD₅, nitrogen and phosphorus. The system operation has got a great success (Ou, 1992). Operation results indicated that the average removal rates for BOD₅ was 95.7, for COD was 84.4, for TOC was 83.1, for TN was 72.8, for TP was 90.5, for SS was 79.3, respectively (Table 1).

Table 1 Purification functions of ecological land treatment system of Shenyang (means of 4 years operation from 1987-1990)

Samples	pH	DO, mg/L	BOD ₅ , mg/L	COD, mg/L	TOC, mg/L	TN, mg/L	TP, mg/L	SS, mg/L	Cd, μg/L
Influent	6.6	0.23	99.8	228.5	68.0	20.6	2.1	92	3.9
Effluent	6.8	4.13	4.3	35.7	11.5	5.6	0.2	19	1.3
Average removal rates, %			95.7	84.4	83.1	72.8	90.5	79.3	66.7

3.3 Regulation

Resourceful ecological treatment system is an artificial ecological engineering system and can be regulated according to the quality of wastewater, the types of system and the demand of the renovated water. The main procedures are: (1) Trends analysis of wastewater quality and quantity by the monitoring of water, soil and plants samples to define the treatability of wastewater; (2) definition of the limited parameters by hydraulic loading; (3) selection of plant species for optimum the ecological structure of the system.

In addition, an integrate management/operation system are necessary. The optimum parameters should be set up and regulated in time such as the distribution rate, distribution amount, dry and wet ratio and so on to optimize the treatment efficiency of wastewater.

4 The characteristics of resourceful ecological treatment system

As mentioned above, resourceful ecological treatment of wastewater is a multi-objectives ecological engineering system. The benefits of economy, society and ecology were jointly considered as a whole. The characteristics of the systems are as follows:

4.1 Economic benefits

Resourceful ecological treatment of wastewater is a cost-effective, low energy-consuming and easy management techniques. For example, the cost for the wastewater

treatment at all in the traditional secondary treatment plants is about 1000–1200 RMB Yuan/m³. However, in the same case, the cost in the resourceful ecological treatment systems is only 130–400 RMB Yuan/m³. By comparison, the cost for construction in the resourceful ecological treatment systems is only 1/2 or 1/3 of that in the secondary treatment plants. And the cost for operation is only 1/5 to 1/10 of that in the secondary treatment plants, respectively. In addition, in the processes of ecological treatment, the resources of water and fertilizer from wastewater can be utilized by plants for raising the products. The benefits obtained from the ecological treatment of wastewater should also be considered. Table 2 shows the values of economic benefits of ecological land treatment system of Shenyang. The system employed paddy rice in the main system and willow (*Salix Babylonica* L.), amorpha (*Amorpha frulicosa* L.), spiraea (*Spiraea salifolia* L.) and sorghum in the supplemental system as vegetations for the purposes of municipal wastewater treatment to produce effluent of an equal or better quality than that from conventional biological treatment and to utilize water and fertilizer components in wastewater as resources for crop growth. Results indicated that the annual benefits of economy obtained from the utilization of water and fertilizer in the wastewater were about 114.7 RMB Yuan/a, mu* in the case of hydraulic loading rate as 1 meter.

Table 2 The statistics values of the economic benefits obtained from resourceful ecological treatment of wastewater in Shenyang, China (1987–1990)

Hydraulic loading, m/a	Irrigation amount m/a, mu	Price, Yuan/mu	Nitrogen, kg/mu	Price, Yuan/mu	Phosphorus, kg/mu	Price, Yuan/mu	Sum
1	666.7	56.7	83.4	41.7	23.4	6.30	114.7
2	1334.0	133.0	166.7	83.3	46.7	12.6	229.3
3	2000.0	200.0	250.0	125.0	70.0	19.0	344.0

Notes: 1 ha=15 mu; Yuan means RMB Yuan

4.2 Utilization of renovated water

The amount of the renovated water depended on the types of ecological treatment of wastewater. The recovery of renovate water is about 30%–40% for the slow-rate infiltration ecological land treatment system, 70%–80% for the rapid infiltration ecological land treatment system. If the ecological treatment systems are enlarged to the middle cities and town of China in a scale of 3 millions tons/d, the renovated water is expected to be 50%, then, 1.5 millions tons of renovated water will be produced each day, which will compensated 12% water shortage of the cities for the industries because 80% of wa-

* mu is unit of area in China, one mu equals 0.067 hectares.

ter supplying in the cities is for the industries, 80% of which is used as cooling water. The quality of renovated water from the ecological treatment systems is sufficient for these purposes. In addition, the renovated water also can be used as clearing water for housing or irrigating vegetations as well.

4.3 Protection of the receiving water bodies

Resourceful ecological treatment system uses the self-regulation and buffering function of the soil-plant ecosystem to ensure the stability of the effluent and, therefore, to protect the receiving water bodies from the secondary pollution. However, in the traditional secondary treatment, when the pollutants loading in the influent increase, the sludge trends to expand and the water quality became inferior. Researches indicated that ecological treatment systems can produce an excellent quality of renovated water. Table 3 shows the results of ecological land treatment systems in Shenyang, China from 1987—1990. 21 indices were monitored and reached the national standards of surface water quality, 11 of which reached the first grade standard, 4 of which attained the second standard, 3 of which achieved the third standard, 2 of which got the fourth standard and 1 of which acquired the fifth standard, respectively.

Table 3 Quality grades* of the renovated water from the ecological land treatment systems of Shenyang, China (1987—1990)

Parameter	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	CONC. (ppm)#	Grades of renovated water
BOD ₅	<3	3	4	6	10	2.76	I
COD _{C_r}	<15	<15	15	20	25	26.90	V
K-N	<0.5	0.5	1	2	2	2.80	V
NO ₃ -N	<10	10	20	20	25	1.46	I
NO ₂ -N	<0.06	0.1	0.15	1.0	1.0	0.03	I
T-P	<0.02	0.025—0.110	0.05—0.1	0.2	0.2	0.14	IV
DO	>90%	6	5	3	2	4.33	IV
CD	<0.001	0.005	0.005	0.005	0.01	0.002	II
Phenol	<0.002	0.002	0.005	0.01	0.1	0.002	I
Cyanide	<0.005	0.05	0.05—0.2	0.2	0.2	0.005	I

* National standards for the surface water quality (GB-3838-88).

Average values of 4 years.

5 Regional features and restricted conditions of resourceful ecological treatment

Resourceful ecological treatment systems have their characteristics of engineering

and strictly steps of implement. That is; plan-construction-operation-monitoring-research. The regional features and site conditions of environment are of important factors for the design of ecological treatment systems. Such as, the climate, topography, geo-hydrology, the physical chemistry properties of soil, the plant species, the quantity and quality of the wastewater and so on. Previous studies showed that the most important factors resulted in the unsuccessful operation of ecological treatment system were the unsuitable selecting of the sites. The main factors influence the development of resourceful ecological treatment of wastewater also included;

5.1 Regions and economy

As regarding to the economic reasons, the system scale is an important factor in considering the establishment of ecological treatment system. Research indicated that the most economic scale of ecological treatment of wastewater is 10–20 thousand tons/d. As a matter of fact, the discharge amount of wastewater in big cities of China was usually more than 1000 thousand tons/d. In addition, the cost of the land in the big cities is high expensive, and usually is more than 10 thousands RMB Yuan/mu. The components of wastewater in the big cities were generally complex, about 70% of which is the industrial wastewater that has high toxicity and is less easy to be treated. So, it is obviously that ecological treatment of wastewater is not suitable to develop in the big cities. In contrast, in the moderate and small cities or town, there are no such problems. The wastewater is dominated by domestic wastewater and its constituent is simple in composition and contains very little amount of toxic or non-degradable substances, which can be assimilated by soil-plant system and is feasible for ecological treatment. On the other hand, the prices of land in these cities were cheaper than that in big cities, which made it possible for the small and moderate cities to develop the technology of resourceful ecological treatment of wastewater. Generally, it was considered that the price of land for the resourceful ecological treatment should be less than 5 and 10 thousand RMB Yuan/mu in south and north regions of China, respectively. In these cases, it is suitable for development of resourceful ecological treatment of wastewater.

5.2 Natural environment

Land-based design criteria of the ecological treatment of wastewater are generally not transferable from location to location, the design of ecological treatment system needed to meet the specific conditions of site in order to performance the functions of purification of the systems. Such as, the percolated coefficient (k), the rate of hydraulic loading and so on. For example, in the slow-rate ecological land treatment system, the percolated coefficient (k) of soil should be 0.036–0.36m/d and the rate of hydraulic loading should be 0.5–6.0 m/a. In the rapid infiltration ecological system, the percolated coefficient (k) of soil should be 0.36–0.6 m/d, the rate of hydraulic loading should be 6–150 m/a, the thickness of soils must be large than 1 meter and the ground-

water table must be more than 2 meters, respectively. In the overflow ecological land treatment system, the systems were commended to set up in the areas of gentle slope (2%—5%) having a poor percolated soils.

6 Conclusion

Resourceful ecological treatment is a cost-effective, low energy-consuming and high efficient technology of wastewater treatment. As a natural treatment systems, resourceful ecological treatment of wastewater is suitable to develop in the small and middle cities of China and should be given priority in considering the selection of sewage treatment technologies in these areas. The authors have highlighted the fact that regional conditions and site information are necessary for identify the most appropriate resourceful ecological treatment schemes for a particular area. Management of the full scale resourceful ecological systems is also important to minimize the problems associated with development and application of resourceful ecological treatment of wastewater.

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