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Purification and reclamation of wastewater by an integrated biological pond system

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Abstract — The feasibility of an inexpensive wastewater treatment system is evaluated in this study. The experiment was conducted in 3 phases with different treatment combinations for testing their purification efficiencies. The pond system was divided into 3 functional regions: influent purification, effluent upgrading and multi-utilization. Various kinds of aquatic organisms, were effectively cooperated in this system. The system attained high reduction of BOD_5, COD, TSS, TN, TP and other pollutants. The mutagenic effect and numbers of bacteria and virus significantly declined during the process of purification. After the wastewater flowed through the upgrading zone, the concentrations of pollutants and algae evidently decreased. Plant harvesting did not yield dramatic effects on reductions of the main pollutants, through it did affect remarkably the biomass productivity of the macrophytes. The wastewater was reclaimed for various purposes.

Keywords: integrated biological pond system; macrophyte; wastewater treatment; ecological upgrading; wastewater reuse.

1 Introduction

Wastewater stabilization pond is one of the most inexpensive methods for treating domestic wastewater in small communities (Oswald, 1963). Research has been conducted for more than two decades on the use of macrophytes for treating wastewater (Dinges, 1978). However, very few researches have been conducted on the coordination of various kinds of purifying organisms in wastewater treatment processes. Researches reported in this paper were conducted to explore the feasibity of an integrated biological pond system for treating wastewater from a medium-sized Chinese city.

2 Material and methods

The pond system was situated on the suburbs of Huangzhou City with a population of 120000 people, Hubei Province, China. The research was conducted in 3 phases.

Ponds: Pond 1 (concrete) had an area of 234 m^2, 3.5m depth and a volume of 819 m^3. Ponds 2, 3 and 4 had the same dimensions, each having an area of 390m^2 and a volume of 543m^3. Pond 5 had an area of 450 m^2 and a volume of 607 m^3.

Phase I: The pond system was operated in series. Pond 1 was furnished with the soft staff, the fibre fill 150 cm in length and 20 × 20 cm^2 surface area for each. Water hyacinths (*Eichhornia crassipes* solms) and large duckweed (*Spirodela polyrhiza* L. Schleid) covered on the water surface. In pond 2, macrophyte zones of water lettuces (*Pistia stratiotes* L.). Water peanuts (*Alternanthera philoxeroides* Griseb) and water hyacinths were arranged in series. Algae naturally grow in pond 3. Some aquatic plants and animals were cultured in pond 4 and pond 5. The hydraulic loading was 150 m^3/d.

Phase II: Pond 1 was no longer used. An upgrading zone of macrophytes, mainly water hyacinths, water peanuts and water lettuces, was set in the last quarter of pond 3. The other conditions were the same as to phase I.

Phase III: Pond 2 and pond 3 were run in parallel, each of them received equal influent and both effluents flowed into pond 4. Pond 2 was divided into 4 equal parts, i.e. water peanut zone, open water zone, water hyacinth zone and a second open water zone, separated by big bamboos. The last quarter of pond 3 was the hyacinth upgrading zone, which was equally divided into 2 parallel subzones separated by layers of plastic film which extended from the bottom to the water surface. Hyacinths in one subzone were harvested every other day to keep their standing biomass in the range of 10±2 kg/m^2. No harvest was made in the other subzone. The hydraulic loading for the whole system was 250 m^3/d. The experiment lasted one year.

Test methods: Chemical parameters were tested twice a week. Some parameters were tested daily. Biological parameters were tested twice a month. All tests were conducted according to the "Standard Methods for Examination of Water and Wastewater" (Chinese National EPA, 1983).

3 Results

The whole system was divided into 3 functional regions: influent purification region, effluent upgrading region and multi-utilization region.

3.1 Influent purification region

The levels of COD, BOD_5, TSS, N, P in the influent varied and sometimes were very high. After being purified in pond 2 or pond 3, the pollutants in the effluents of the ponds greatly decreased. The levels of BOD_5 and TSS in the effluent were much lower than the effluent standards. COD content in effluents of pond 2 and pond 3 were much lower than 60 mg/L. In phase III BOD_5 reductions of pond 2 and pond 3 were 85.67% and 81.4% respectively (Table 1). The nitrogen and phosphorus contents in the influent were gradually decreased by the pond system. The conductivity, alkalinity, pH, etc. were also improved to some extents. The water quality parameters in the influent changed dramatically from time to time, however, they were relatively stable in the effluents of the ponds (Fig.1 and Fig.2).

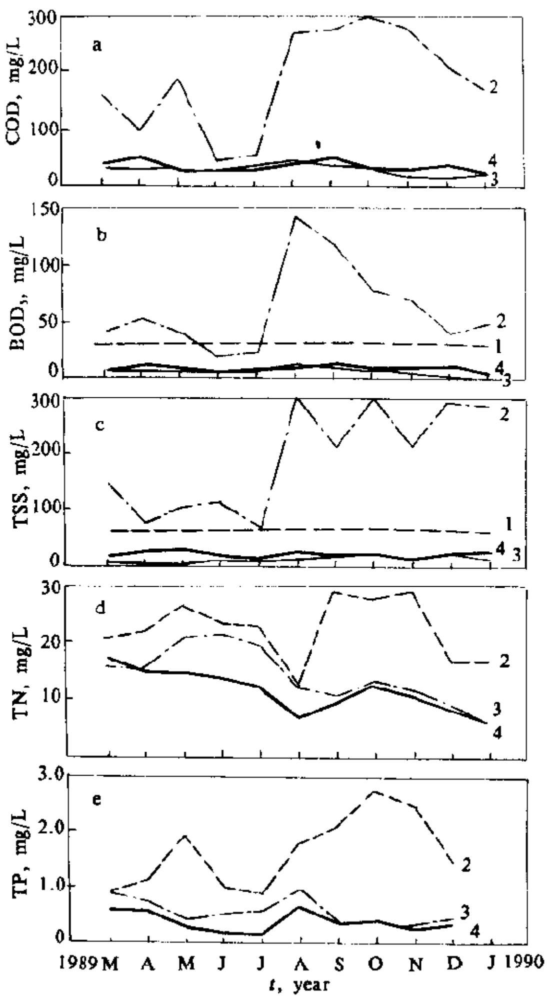

Fig. 1 Main pollutant content changes in influents and effluents of pond 2 and pond 3 under 4.3 d detention time
1. Effluent standard; 2. influent; 3. effluent of pond 2; 4. Effluent of pond 3

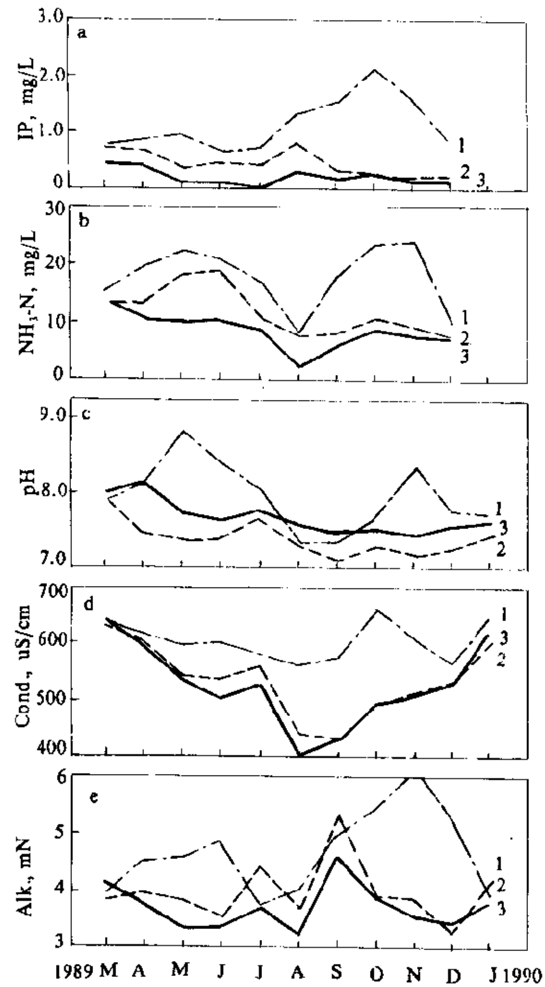

Fig.2 Some pollution parameter changes in influents and effluents of pond 2 and pond 3 under 4.3 d detention time
1. Influent; 2. Effluent of pond 2; 3. Effluent of pond 3

Table 1 Accumulated hydraulic retention time and purification parameters in the ponds

Item	Phase	Influent	Ponds			
			1	2	3	4
Hydraulic retention time, d	I		5.5	9.1	12.7	16.3
	II			3.6	7.2	10.8
	III			4.3	4.3	6.5
BOD_5 content, mg/L	I	66.0*	20.6	12.7	13.0	12.8
		(16.7–14.17)	(7.0–28.5)	(6.3–30.2)	(6.6–30.0)	(5.3–
	II	60.8		6.9	6.6	9.4
		(26.6–99.6)		(3.6–12.3)	(1.2–11.1)	(5.3–
	III	62.0		9.0	11.3	
		(12.0–332.8)	·	(2.7–21.8)	(3.4–19.1)	(2.1–
BOD_5 reduction, %	I		66.6	76.9	79.2	80.5
	II			87.7	88.5	83.8
	III			85.6	81.5	77.4
Purification loading, g BOD_5 m^{-2} D^{-1}	I		29.1	12.8	7.9	6.6
	II			20.7	1.04	6.6
	III			17.7	17.0	10.8

*phase mean (min. –max.)

The algal cell densities in pond 2 and pond 3 were 6.5 and 16.4×10^7 ind./L, algal biomass was 17.6 and 32.3 mg/L, respectively. The numbers of protozoa, rotatoria, cladocera and copepoda were 5000, 1300, 13 and 60 ind./L in pond 2 and 8000, 1800, 7 and 300 ind./L in pond 3, respectively. The plankton in pond 3 were slightly abundanter than those in pond 2. The numbers of total bacteria in the influents, effluents of pond 2 and pond 3 were 700, 19.9 and 2.7×10^5 ind./ml, total coliform bacteria were 130, 32 and 13 100MPN/100ml, fecal coliform bacteria were 87, 17 and 7.5 100MPN/100ml, respectively. The intestines virus were 1.32, 0.84 and 0.32 PFU/L, phage of E. coli. were 1200, 5.50 and 3.00 PFU/L, respectively. The mutagenic effect also declined gradually from the influent to the effluents of this system. The above results showed that the biological parameters related to the public health were evidently improved by means of this system.

3.2 Effluent upgrading region

After the wastewater flowed through the macrophyte upgrading zone, levels of BOD_5, COD and TSS were reduced by 32.2%, 21.3% and 25.8% and TN, TP contents by 11.4% and 15.8%, respectively. The algal cells and biomass were reduced by 20%–70%. The algal reduction was the highest in summer and lowest in winter, with an annual mean of 42.4%.

The field and laboratory researches showed that apart from the competitions for light, nutrient and space between the macrophytes and algae, the mechanism of the inhibitory effect on algae was mainly due to the excretion of some organic substances from the rhizosphere of the water hyacinth, water peanut, water lettuce, duckweed and so on. When the algae were treated with cultured water of the macrophytes, the algal cell density and photosynthetic rate were significantly declined, the algal cells were damaged and subjected to coagulate and, in most cases, sink to the bottom.

The hyacinth standing biomass in the harvested subzone was relatively stable in the range of 10 ± 2 kg/m^2, and the plant grew at its maximum growth rate. However, the standing biomass in the nonharvested subzone accumulated in most time except in cold months. It was more than 30 kg/m^2 in most time and more than 40 kg/m^2 in several months. The annual biomass production in the harvested subzone was as high as 3 times that of the nonharvested subzone. However, poor correlations were observed between the plant productivity and the pollutant removal. The main pollutant reductions did not show significant difference between the two subzones.

3.3 Multi-utilization region

Levels of COD, BOD_5 and TSS in the effluent of pond 4 and pond 5 increased slightly, but still could meet the standards. The content of N, P and so on decreased continuously. It suggested that some of nutrients in the wastewater were turned into cultured biomass. Dissolved oxygen, which was especially beneficial to aquaculture, increased remarkably in this region.

4 Discusion

4.1 Coordination of various kinds of purifying organisms

Macrophytes took an important role in this system. Apart from the water hyacinth, some other macrophytes, such as water peanut, water lettuce, reed (*Phragmites communis Trin.*), large duckweed, water fern (*Saluinia natans* L. All.), lotus (*Nelumbo nucifera Gaertn.*) and so on were also planted in the ponds. Each of them contributed its special function and cooperated in the purification processes.

The macrophytes used for BOD_5 removal seemed to function as fixed film reactors, with the submerged plant structures acting as a substrate for bacteria (DeBusk, 1987). Some macrophytes can transport atmospheric O_2 from the foliage into the root (DeBusk, 1987). Oxygen not required for root respiration may diffuse into the wastewater and be utilized by bacteria for the oxidation of BOD_5. Our experiments showed that species and individuals of microorganisms in the rhizosphere were significantly abundanter than those in the open water. BOD_5 was evidently decreased after the wastewater flowed through the macrophyte zones.

The traditional algae-bacteria unit also took an important role in this system, especially in providing oxygen for activities of bacteria. The macrophyte zone and algae-bacteria zone were distributed alternately so as to make full use of their advantages.

Various kinds of aquatic plants and animals cultured in the ponds turned large amount of nutrients from the wastewater into useful biomass. There existed multiple food chain-web systems composed of various kinds of microorganisms, algae, zooplankton, macrophytes, fishes and so on. Because of the biological diversity of the system, various kinds of pollutants were degraded by means of different biological or biochemical processes in series. The integrated biological pond system could attain higher purification efficiencies than most traditional oxidation ponds or unique macrophyte-based ponds (Oswald, 1963; Cornwell, 1977; Wolverton, 1979; Duffer, 1982; Wu, 1987a, b).

Some cold resistant macrophytes, such as water peanut, water fern, duckweed, in addition to the fibre fill, could grow in the ponds with some protection and partially take the place of water hyacinths, water lettuces, and so on in the colder months. The water quality of the effluent from the system was relatively stable all over the year.

4.2 Effluent upgrading

Since algae were among the most important purifying organisms in the oxidation ponds, there often existed high BOD_5 and TSS levels in the effluent of these ponds (Wolverton, 1979). Direct harvesting of algae is a costly and complicated procedure. To date, there have been no satisfied methods for mechanical removal of algae, feasible for small communities (Wolverton, 1979; Duffer, 1982; DeBusk, 1989). Introduction of macrophytes was considered as one of the means of reducing the amount of algae in the pond effluent. The experiments also showed that besides the competition for light, nutrients and space between the macrophytos and algae, the mechanism of the inhibitory effect of macrophytes on algae was mainly due to an excretion of some organic substances from rhizosphere of the macrophytes which injured and killed the algae cells. The results of the upgrading experiments showed that the macrophytes upgrading zone efficiently removed pollutants as well as algae.

4.3 Effect of plant harvest

Though plant harvesting frequency greatly affected the biomass production, it did not have significant effects on the purification efficiencies for the main pollutants. The result is much similar to that reported by DeBusk (DeBusk, 1989). This result suggested that frequent plants harvest, a strategy that maximizes biomass production, may not be necessary for achieving high reduction of the main pollutants in the wastewater treatment.

4.4 Wastewater reuse

As the water quality was greatly improved, effluent from the system could be used for irrigation and aquaculture. Good fishery harvest (fishes, pearl oster, crab and so on) was got in pond 4 and pond 5 as well as in the other ponds receiving the effluent from the system. Comparative studies showed rice grown in the experiment field receiving the effluent from the system was yielded better harvest than that in ordinary field. Large amount of macrophyte biomass was harvested from the ponds during the experimental period and was utilized for food, fodder, fertilizer, fuel and some other uses. The wastewater was becoming a new resource in various kinds of usages.

4.5 Comparison of purification efficiencies among the treatment combinations

Since there were a number of water quality parameters tested in the experiments, briefly, only BOD_5 was taken as an example for the illustrations.

The mean BOD_5 in the influents among the 3 phases were in the similar level. After being purified by pond 2 and/or pond 3, BOD_5 in effluents were lower than 15 mg/L, in some months lower than 8 mg/L, BOD_5 reduction was above 75%.

If the effluent of pond 4 was considered to be the effluent of the system, the purification loadings of phase I and phase II were similar. If the effluent of pond 3 was considered to be the effluent of the system, the purification loading of phase II was higher than that of phase I. The purification loading of phase III was the highest among the 3 phases.

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