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Study of Operation Subsurface Flow Wetland in Batch Flow System for Municipal Wastewater Treatment

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Experimental results from a pilot-scale constructed wetland treatment plant have been described. The study was conducted at two different systems: continuous and batch. The pilot plant consists of two serially connected settled up with subsurface flow wetlands. One bed and pre-treatment unit were selected at witness unit. Wastewater with 26 m^3/day flowrate and average amount of BOD_5 = 250 mg/L, TSS = 320 mg/L, TKN = 35 mg/L, TP = 12 mg/L was selected from municipal network in sabzevar wastewater treatment plant and the pilot was studied for one year from December 2006 to December 2007. Biweekly water samples at the inlet and outlet of each component of the combined system were analyzed for biochemical oxygen demand (BOD_5), total suspended solid (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP). The average removal efficiency of BOD_5, TSS, TKN and TP in continuous flow for witness unit was 77.2, 90, 85, 81 % and in batch flow for research unit was 92, 95, 94 and 92 %, respectively.

Key Words: Constructed wetland, Anaerobic pond, Continuous flow, Batch flow.

INTRODUCTION

Wetlands are considered as low-cost alternatives for treating municipal, industrial and agricultural effluents. Constructed wetlands are preferred because they have more engineered systems and they are easier to control. They may be classified as surface flow marshes, vegetated subsurface flow beds, submerged aquatic beds and floating leaved aquatics[1]. This new developing technology may offer a low cost and maintenance to domestic wastewater treatment, which is especially suitable for developing countries[1-4]. Considering the uncontrolled expansion of big cities of Iran (*e.g.*, Sabzevar, Mashhad), constructed wetland technologies might be a good solution due to the following advantages: (a) No need to establish the sewerage system for single houses or small communities. (b) Lowering the initial costs by using cheap materials and allowing self-construction. (c) Developing a pathogenically safe, as well as aesthetic treatment unit that combines water treatment with hobby garden activities and reuse possibilities.

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One of the disadvantages of such systems may be the requirement of a large area. Area requirements for different configurations and different purposes (BOD removal, nitrification, *etc*.) have been given in the range of 1.3-10.3 m^2/person (1 m^2/person for BOD removal and 2 m^2/person for BOD removal and nitrification)[5]. The plant growing in wetlands are adapted for growing in water-saturated soils. The wetland plants have many functions related to the treatment of wastewater in constructed wetland. In small systems the aesthetic value of the macrophytes may be more important. It is possible to select nice-looking wetland plants like the yellow flag (pseudacorus) or cannas-lilies and this way makes sewage treatment systems aesthetically pleasing[6]. Although the plants are the most obvious components of wetland ecosystem, wastewater treatment is accomplished through an integrated combination of biological, physical and chemical interactions among the plants, the substrate and the inherent microbial community. The role of the macrophytes in treatment wetlands is well-documented by several authors[7-10]. The plants were often claimed to provide adequate oxygen *via* their root zones to degrade the organics and nitrogen compounds present in the wastewater. But it was demonstrated that the amount of oxygen being released by the plants to the immediate environment around the roots is limited[7,9]. The limited aeration around the roots ensures the anaerobic conditions will predominate, unless the organic load to the wetland is low and wetland is shallow.

EXPERIMENTAL

Site description: This research project was done for Sabzevar wastewater treatment plant for optimization combined system of waste stabilization pond and constructed wetland for direct discharge to surface water and agricultural consumption.

Pretreatment units: Two anaerobic ponds with flow rate of 26 m^3/day, 2 day detention time, 6 m long, 2 m wide and 4.4 m deep were built. The average BOD loading rate of ponds were 165 g BOD/m^3.day. One bent pipe was located in an outlet pipe in order to prevent the oil and grease from surface ponds.

Wetland cell units: Two subsurface flow wetland cells were built with 2 day hydraulic detention time, 20 m long, 6.6 m wide and 0.6 m deep, respectively. The first (bed I) with one pretreatment (pond I) unit were selected as the witness unit and the second (bed II) with other pretreatment unit (pond II) were selected as the research unit that operated in continuous and batch flow, respectively. The plant used in wetland beds was bulrush and the basins were charged with sand with 5 mm effective size and 1.5 uniformity coefficient and 35 % porosity. The organic loading in beds was 78 kg BOD/m^3.day. Because of equal detention times of pretreatment units and wetland beds the time of batch flow for systems were selected 48 h.

Sampling and analysis: Water samples were collected twice a week from December 2006 to December 2007 at the inflows and outflows of ponds and wetland beds. The samples from pilot were analyzed for biochemical oxygen demand (BOD_5), total suspended solid (TSS), total kjeldahl nitrogen (TKN) and total phosphorus

(TP) (Tables 1 and 2). The analysis of the water samples was done in our laboratory of wastewater treatment plant. All the experimental analytical methods follow the methodology outlined in standard methods[11].

RESULTS AND DISCUSSION

The average influent and effluent concentration are shown in Tables 1 and 2 and the removal of pollutants is summarized for all of the treatment stage in Table-3 from December 2006 to December 2007. During the hot and cold seasons the average temperature in ponds 30.5 ± 8.5 ºC, 12 ± 6.5 ºC and in the wetland cells the average temperature were 25.7 ± 6.7 ºC and 10.5 ± 4.8 ºC, respectively.

TABLE-1
AVERAGE INFLUENT AND EFFLUENT CONCENTRATIONS IN THE CONTINUOUS SYSTEM

Parameter	Pond I		Bed I	
	Inflow	Outflow	Inflow	Outflow
BOD_5 (mg/L)	250	150.00	150.00	57.00
TSS (mg/L)	320	102.50	102.50	25.50
TKN (mg/L)	35	22.00	22.00	3.06
TP (mg/L)	12	9.96	9.96	1.30

TABLE-2
AVERAGE INFLUENT AND EFFLUENT CONCENTRATIONS IN THE BATCH SYSTEM

Parameter	Pond I		Bed I	
	Inflow	Outflow	Inflow	Outflow
BOD_5 (mg/L)	240	100.00	100.00	22.00
TSS (mg/L)	320	57.60	57.60	11.52
TKN (mg/L)	35	16.80	16.80	0.85
TP (mg/L)	12	8.75	8.75	0.34

TABLE-3
REMOVAL POLLUTANTS EFFICIENCY IN CONTINUOUS AND BATCH FLOW SYSTEMS

Parameter	Continuous flow			Batch flow		
	Pond I	Bed I	Total	Pond II	Bed II	Total
BOD_5 (%)	40	62	77.5	65	78	92.0
TSS (%)	68	75	92.0	80	82	96.5
TKN (%)	37	86	91.2	52	95	97.5
TP (%)	17	87	89.0	27	96	97.0

In 1-2 day detention time and the temperature of 22 ºC the removal efficiency in anaerobic ponds are 40 %[12] or 40-60 %[13]. The average influent concentration of BOD_5 in pond I was 250 mg/L. This concentration was reduced to 150 mg/L and 100 mg/L in effluent (Tables 1 and 2). The mean BOD_5 removal efficiency in pond I was 40 % and in pond II was 65 %.

BOD_5 removal in SFS wetlands depend on hydraulic detention time, temperature and kind of plants. Cooper[5] reported that in SFS wetland with 6 day hydraulic detention time and three Bulrush, Reed and Cattail plants, the BOD_5 removal efficiency were 95, 81 and 74 %, respectively. The influent concentration of BOD_5 in bed I and bed II was 150 and 100 mg/L, respectively (Tables 1 and 2). These concentrations were reduced to 57 mg/L by bed I and 22 mg/L by bed II (Tables 1 and 2). The mean BOD_5 removal efficiency in bed I was 62 % and in bed II was 78 % that was 16 % higher than that of cell I (Table-3). This different removal efficiency in wetland beds depends on the creation of batch flow and then the increase of detention time in bed II.

The average influent concentration of TSS in both ponds was 320 mg/L. This concentration was reduced to a 102.5 mg/L by pond I, 57.6 mg/L by pond II (Tables 1 and 2). The mean TSS removal efficiency in pond I was 68 % and in pond II was 82 %.

The influent concentration of TSS to bed I was 102.5 mg/L and in bed II was 57.6 mg/L. These concentrations were reduced to a 25.5 mg/L by bed II and 11.54 mg/L by bed II (Tables 1 and 2). The mean TSS removal efficiency in bed I was 75 % and in bed II was 80 % that was 5 % higher than bed I (Table-3).

The average influent concentration of TKN in both ponds was 35.37 mg/L. This concentration was reduced to a 22 mg/L by pond I and 16.8 mg/L by pond II (Tables 1 and 2). The mean TKN removal efficiency in pond I and pond II was 37 and 52 %, respectively (Table-3).

The average influent concentrations of TP in both ponds were 12 mg/L. This concentration was reduced to a 9.96 mg/L by pond I, 8.75 mg/L by pond II (Tables 1 and 2). The mean TP removal efficiency in pond I and pond II was 17 and 27 %, respectively. Arceivala[14] reported that the removal of nitrogen and phosphorus in waste stabilization ponds are taken place by biosorption, precipitation, dinitrification and percolation. In this research the algae did not exist so the anaerobic condition was the cause of the removal of both TP and TKN. The mean TKN and TP removal efficiency in pond II were 52 and 27 % that were higher than the TKN and TP in pond I, respectively.

The TP and TKN removal efficiency in wetland beds was high. The influent concentration of TKN in bed I was 22 mg/L and in bed II was 16.58 mg/L. These concentrations were reduced to mean 3.06 mg/L by bed II and 0.85 mg/L by bed II. The influent concentration of TP in bed I was 9.96 mg/L and in bed II was 8.75 mg/L (Tables 1 and 2). These concentrations were reduced to mean 1.3 mg/L by bed I and 0.34 mg/L by bed II (Table-3). The nitrogen removal in SFS wetlands depends on the kind of plant, sand diameter, hydraulic detention time and ambient conditions[8]. In this research two wetland cells were similar, but the mean TKN removal efficiency in bed II was 9 % higher than that of bed I (Table-3). It seemed that in addition to these parameters the clogging phenomenon in cell I was an important factor in TKN removal. The nitrogen removal in wetland beds is done by nitrification and denitrification. In bed I because of clogging and fading of plants, the rate of oxygen transfer by plants and penetration by soil surface was reduced so the nitrification of ammonia was less than bed II.

The mean TP removal efficiency in bed II was 9 % higher than that of bed I (Table-3). Richardson[15] reported that the phosphor removal in wetland beds depends on clay soil at the floor of bed, precipitation and plant absorption. In these two wetland cells constructed with compressed clay soil at the floor of beds and the plants were bulrushes, the reduction removal in bed I was related to plant absorption and short circuiting.

In wetland beds the removal efficiency according to distance from entrance was shown in Figs. 1-4. It is reported that by one bench scale wetland bed with 1.7 m long, 0.5 m wide and 0.36 m deep and constant COD = 200 mg L^{-1} the most removal efficiency took place in one third of the entrance with amount of 65-70 % and hydraulic load by increasing this per cent decreased. As shown in Fig. 1 in bed I the influent BOD_5 was reduced from 157 mg/L to 90 mg/L in the first 5 m from entrance and in bed II it was reduced from 82 to 60 mg/L, *i.e.* 42 and 26 % in one fourth from entrance, respectively. The hydraulic load was equal in both beds but the organic load in bed I was higher than that of bed II, thus with decrease of organic load this percent was decreased.

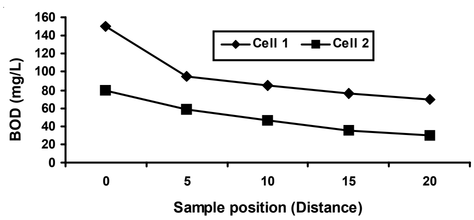

Fig. 1. BOD removal in subsurface flow wetlands

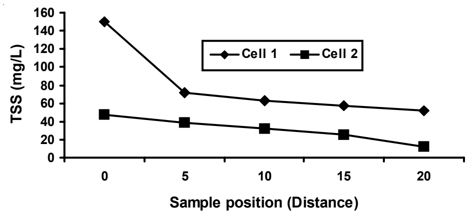

Fig. 2. TSS removal in subsurface flow wetlands

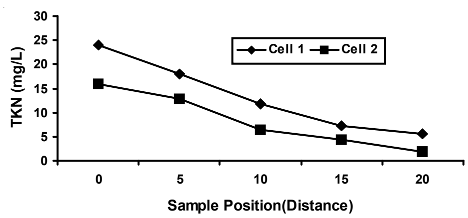

Fig. 3. TKN removal in subsurface flow wetlands

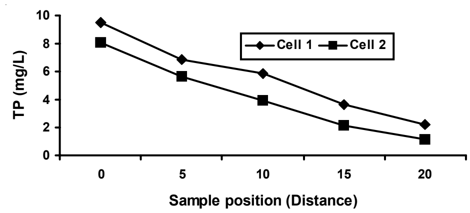

Fig. 4. TP removal in subsurface flow wetlands

As shown in Fig. 2 the mean TSS removal efficiency is one fourth from entrance in bed I was 68 % and in bed II was 31 %. The mean TKN removal efficiency in one fourth of bed I was 25 % and in bed II was 20 % (Fig. 3). The mean TP removal efficiency in one fourth from entrance in bed I was 28 % and in bed II was 30 % (Fig. 4). From Figs. 1-4, it was resulted that the removal efficiency in wetland beds varies in different length of beds. The per cent and the place of removal efficiency from entrance and the kind of concentration in wetland beds were not constant for every wetland bed and depend on the pretreatment, kind of plant, current, hydraulic and organic loads.

Conclusion

The removal efficiency in combined pond and bed II was higher than the combined pond and bed II because: (1) In bed I, the pretreatment was lower and the per cent of influent pollution load was higher when compared with bed II. Thus it causes clogging in initial bed. (2) Clogging was caused short circuiting in bed I. (3) In bed I, due to clogging in initial bed, the level of wastewater was equal or higher than the surface bed and the roots of plants were submerged in wastewater. (4) In wetland beds, the oxygen gas is transferred from plants and soils into roots. The phenomenon of clogging would hinder oxygen transfer and therefore oxygen level drops in bed I. As a result nitrification will be reduced and the TKN removal efficiency stands at lower level than bed II.

In general, waste stabilization ponds will enjoy high ability in wastewater treatment if they are designed in proper methods. One of the most effective methods for optimization ponds is the application of batch flow systems. In this manner the efficiency removal increases and the treatment area decreases. In this research it was shown that the short circuiting decreased in batch flow system with increasing detention time and more plug flow conditions. The result of operation and maintenance of wetland beds showed that if the pretreatment is not sufficient, clogging and short circuiting will take place and ultimately the removal efficiency will decrease.

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