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Pollutant Removal from Municipal Sewage by Optimized Anaerobic Pond and Subsurface Flow Wetland

ABOLFAZL RAHMANI SANI[1,*], NASER MEHRDADI[2], ALIAKBAR AZIMI[2] and MAHIN DELARA[1,*]

[1]Faculty of Health, Sabzevar University of Medical Sciences, Sabzevar, Iran
[2]Faculty of Environmental Health, Tehran University, Tehran, Iran

*Corresponding authors: E-mail: rahmanisani@medsab.ac.ir; mn.delara@medsab.ac.ir

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This research project was initiated to refine the knowledge available on the treatment of municipal wastewater by combined anaerobic ponds and wetlands. To determine the treatment capacity of combined system, a pilot scale of anaerobic ponds and subsurface flow wetland was built and monitored over one treatment year. The anaerobic pond systems consisted of two ponds: a) conventional pond and b) optimized pond that are combined with two wetland cell units respectively. The conventional pond was built in common method and optimized pond in two parts *i.e.*, part one as a digestion pit with 12 h detention time and part two as an anaerobic baffled pond with 8 across baffles and 36 h detention time. The experiments were started with a tracer study to find out the hydraulic characteristics of each pond. Two subsurface flow wetlands with a two day hydraulic detention time and bulrush plant were built. Water samples at the inlet and outlet of each component of the combined system were analyzed biweekly for biochemical oxygen demand (BOD_5), total suspended solid (TSS), total kjeldalh nitrogen (TKN), total phosphorus (TP) and total coliform (TC). The average removal efficiency of conventional and optimized ponds combined with wetland cells were as follows: BOD_5 (68.5 %-88 %), TSS (82.6 %-96.3 %), TKN (83 %-93.2 %), TP (83 %-91 %) and TC (94 %-98 %) respectively.

Key Words: Constructed wetland, Anaerobic pond, Digestion pit, Across baffle.

INTRODUCTION

Industrial and domestic sewages have been subjected to various investigations[1-3]. The treatment of domestic sewage in natural systems such as waste stabilization ponds and constructed wetlands is considered as one of the most popular methods for small communities in rural and urban regions. Simplicity and low costs in construction and operation are among the most significant advantages. Conventional waste stabilization ponds require a large area and have a low efficiency[4]. On the other hand, pretreatment in wetlands is usually insufficient[5]. This has led the development of alternative wastewater treatment systems with higher efficiency and lesser area than ponds and wetlands. Among these systems, combined optimized anaerobic ponds and subsurface flow wetlands are growing as suitable substitutes[5]. There has been also considerable research on the use of digester or baffle in stabilization ponds to treat wastewater[6-8]. The fate of carbon in waste stabilization ponds represents a key diagnostic tool by which the performance and life expectancy of a system can effectively be evaluated. The transformed carbon can lead to sludge accumulation, treatment capacity lost, nuisance conditions and finally system failure. However, a pond system will continue to perform indefinitely[6]. The key to microbiological process is underlying a technology known as advanced integrated anaerobic pond systems (AIAPS). In these systems, the aim of application of baffle is to promote the waste stabilization pond practice for wastewater treatment in tropical countries. Such ponds increase nitrogen and organic carbon removal efficiency in one hand and reduce the biofilm and biomass concentration on the other hand[7,9]. There has been also a considerable research on the use of wetlands for treating wastewater[10-14]. Conventional advanced treatment of wastewater typically requires large capital investments to be built and operated. It also implies large amounts of energy[15]. Wetlands can be designed and constructed to effectively increase the capacity of a wastewater treatment system by further improving the quality of the effluent entering the receiving water[16]. In the present investigation, a pilot consisting of anaerobic ponds and subsurface flow wetland systems have been built and combined together in Sabzevar wastewater treatment plant. This paper finally reports the reduction of pollutants in municipal wastewater through this system.

EXPERIMENTAL

Site description: This research project was carried out in the wastewater treatment plant of Sabzevar, which is located in the eastern part of Iran.

Two anaerobic ponds with a flow rate of 26 m^3/day and a two day detention time were built. The first one included a conventional method with 6 m long, 2 m wide and 4.4 m deep (Fig. 1) and the second one was an optimized pond (Fig. 2). The optimized pond was divided into two parts. Part one served as a digestion pit (2 m long, 1.5 m wide, 4.4 m deep and 12 h detention time) and part two acted as a baffled pond (4.5 m long, 2 m wide, 4.4 m deep and 36 h detention time). Wastewater was entered into the digester and traveled upward. A bent pipe was placed in the outlet to prevent the outflow of the oil and grease from surface digester (Fig. 3).

Fig. 1. Conventional pond system

Fig. 2. Optimized system

The frame of a rectangular iron profile baffle was built up in 199.6 cm wide and 4.6 m long. The two frames were welded together in a distance of 37.5 cm to create stability in anaerobic pond. The frames were painted with anti ferrous oxide oil and covered with geo-membrane layer. To establish the up flow and down flow current, a rectangular plate (100 cm in length and 20 cm in width) was cut in either side (upward and downward) of the geo-membrane to let wastewater pass.

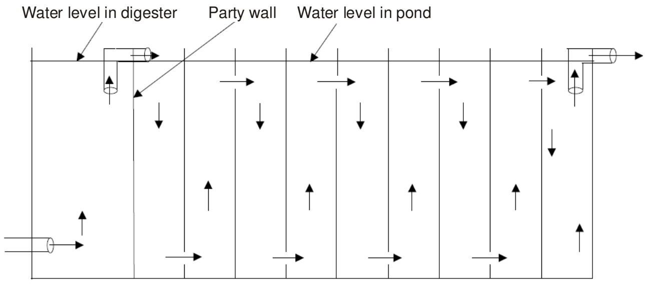

Fig. 3. Schematic diagram of the line of flow in optimized pond

Two wetland cell units were built with a two day hydraulic detention time (20 m length, 6.6 m width and 0.6 m depth, respectively). The first one (cell I) is combined with the conventional pond and the second one (cell II) is combined with the optimized pond. The plant used in wetland cells was bulrush and the basins were charged with sand (5 mm effective size, 1.5 uniformity coefficient and 35 % porosity).

Sampling and analysis: Water samples were collected twice a week from December 2010 to December 2011 at the inflows and outflows of ponds and wetland cells. The samples were analyzed for biochemical oxygen demand (BOD_5), total suspended solid, total kjeldahl nitrogen, total phosphorus and total coliform (Table-1). The analyses of the water samples were performed in labs of Sabzevar wastewater treatment plant. Analyses were also carried out in accordance with the methods outlined in standard methods[17].

RESULTS AND DISCUSSION

The concentrations and removal of pollutants from various stages of treatment are given in Table-1. During the hot and cold seasons, the average temperature in ponds were recorded respectively as 30.5 ± 8.5 ºC and 12 ± 6.5 ºC. The average temperature in the wetland cells were also 25.7 ± 6.7 ºC and 10.5 ± 4.8 ºC, respectively. Figs. 1 and 2 represent the pilot plan in Sabzevar wastewater treatment plant. Fig. 3 shows the line of flow in optimized pond. Figs. 4 and 5 depict BOD_5 and total suspended solid removal in subsurface flow of the wetland. The removal of pollutants in ponds and subsurface flow wetlands were as follows:

In conventional pond, the concentration of BOD_5 was 250 ± 4 mg/L in influent. The mean concentration reduced from 179 mg/L to 134.5 mg/L in effluent (Table-1).

The influent concentration of total suspended solid in both ponds was 320 ± 80 mg/L. The mean concentration was reduced to a minimum of 106 mg/L and a maximum of 193 mg/L by conventional pond, 137 mg/L and 211 mg/L in digestion pit and 15 mg/L and 47 mg/L by baffled pond (Table-1).

The influent concentration of total kjeldahl nitrogen in both ponds was 35.37 ± 11.85 mg/L. The mean concentration was reduced to a minimum of 16.6 mg/L and a maximum of 32.4 mg/L by conventional pond, 13.6 mg/L and 28.4 mg/L by digestion pit and 11.8 mg/L and 21.2 mg/L by baffled pond (Table-1).

TABLE-1
INFLUENT AND EFFLUENT CONCENTRATIONS IN ANAEROBIC PONDS AND WETLAND CELLS

Parameter	Conventional pond	Digestion pit	Baffled pond	Cell I	Cell II
BOD_5 (mg/L)					
In	250 ± 41	250 ± 41	182.5 ± 48	157 ± 22.50	83.52 ± 19.35
Out	157 ± 22.50	182.5 ± 48	83.52 ± 19.35	78.00 ± 19.50	25.89 ± 7.68
Removal (%)	30.86 ± 17.52	22.84 ± 13.63	48.70 ± 11.44	45.35 ± 21.54	54.35 ± 15.65
Total suspended solid (mg/L)					
In	320 ± 80	320 ± 80	174 ± 37	150 ± 43.7	32.64 ± 15.55
Out	150 ± 43.7	174 ± 37	36.64 ± 15.55	55.65 ± 15.55	15.21 ± 12.44
Removal (%)	48.63 ± 22.54	49.38 ± 12.56	59.36 ± 18.41	58.13 ± 16.74	64.7 ± 13.35
Total kjeldahl nitrogen (mg/L)					
In	35.37 ± 11.85	35.37 ± 11.85	21.12 ± 7.36	24.45 ± 7.95	16.58 ± 4.72
Out	24.45 ± 7.95	21.12 ± 7.36	16.58 ± 4.72	6.22 ± 3.25	3.54 ± 1.65
Removal (%)	28.63 ± 9.35	20.31 ± 9.53	27.43 ± 7.52	62.66 ± 15.65	74.42 ± 8.46
Total phosphorus (mg/L)					
In	11.26 ± 8.63	11.26 ± 8.63	8.90 ± 2.45	9.55 ± 3.45	7.92 ± 1.28
Out	9.55 ± 3.45	8.90 ± 2.45	7.92 ± 1.28	1.92 ± 0.71	1.15 ± 0.78
Removal (%)	17.28 ± 3.67	8.17 ± 4.23	16.30 ± 3.35	69.64 ± 8.33	80.47 ± 6.75
Total coliform counts/100 mL					
In	$2\times10^8 \pm 1.2\times10^7$	$2\times10^8 \pm 1.2 \times 10^7$	$2.75\times10^7 \pm 1.2 \times 10^6$	$9.22\times10^6 \pm 8.32\times10^5$	$4\times10^6 \pm 2.25\times10^5$
Out	$9.22\times10^6 \pm 8.32\times10^5$	$2.75\times10^7 \pm 1.2 \times 10^6$	$4\times10^6 \pm 2.25 \times 10^5$	$1.40\times10^6 \pm 3.86\times10^5$	$3.24\times10^5 \pm 1.3\times10^4$
Removal (%)	74.92 ± 8.66	15.25 ± 4.65	66.64 ± 4.65	84.66 ± 3.78	92.59 ± 2.35

The influent concentrations of total phosphorus in both ponds were 11.26 ± 8.63 mg/L. The mean concentration was reduced to a minimum of 6 mg/L and a maximum of 13 mg/L by conventional pond, 6.5 mg/L and 11.35 mg/L by digestion pit and 5.6 mg/L and 8.2 mg/L by baffled pond (Table-1).

The influent counts of total coliform in both anaerobic ponds were $2 \times 10^8 \pm 1.2 \times 10^7$ per 100 mL and the influent concentration of BOD_5 in cell I and cell II was 157 ± 22 mg/L and 83 ± 9 mg/L respectively (Table-1).

The influent concentrations of total suspended solid in cells I and II were 150 ± 43.7 mg/L and 32.6 ± 15.5 mg/L, respectively. These concentrations were reduced to a minimum of 40 mg/L and a maximum of 70 mg/L by cell I and 3.5 mg/L and 27.4 mg/L by cell II (Table-1). Efficiency in cell I was 63 % and in cell II was 75 % (Table-2).

The influent concentration of total kjeldahl nitrogen in cell I and II were 24.45 ± 7.92 mg/L and 16.58 ± 4.72 mg/L, respectively. These concentrations were reduced to an average of 6 mg/L and 2.54 mg/L by cells I and II, respectively (Table-1).

The influent concentration of total phosphorus in cells I and II were 1.92 ± 0.71 mg/L and 1.15 ± 0.78 mg/L, respectively (Table-1). The mean effluent counts of total coliform in cell I and cell II were 1.4×10^6 and 2.9×10^5 per 100 mL, respectively (Table-2).

In the present investigation, 8 across baffles were used in anaerobic pond. Results revealed that the mean BOD_5 removal increased to 16 %. It should also be pointed out that the detention time was reduced to 36 h. In optimized pond constructing digestion pit and changing the place of inlet wastewater pipe from surface to deep, increased the mean BOD_5 removal efficiency to 68 % which was 31 % higher than conventional pond.

The mean total suspended solid removal efficiency was 53 % in conventional pond and 85 % in optimized pond. As mentioned before that the mean total suspended solid removal efficiency was 32 % higher in optimized pond than the conventional pond. Thus total suspended solid removal increased as the result of the appropriate biological filter of sludge layer and also suspended solid capture in addition to detention time. The comparison of BOD_5 and total suspended solid removal efficiency in optimized pond showed that the mean total suspended solid removal efficiency was 17 % higher than BOD_5. Therefore application of across baffles and digestion pit was more effective for removal of total suspended solid.

The mean total kjeldahl nitrogen removal efficiency in conventional and optimized ponds was 32 % and 50 %, respectively. These concentrations were reduced to 1.92 mg/L by cell I and 1.15 mg/L by cell II. It is also illustrated that nitrogen removal in subsurface flow wetlands depends on the kind of plant, sand diameter, hydraulic detention time and ambient conditions[15].

The mean total phosphorus removal efficiencies in conventional and optimized ponds were 18.8 % and 28 % respectively. Arceivala[18] reported that the removal of nitrogen and phosphorus in waste stabilization ponds takes place by biosorption, precipitation, de-nitrification and percolation. In this research, the algae did not exist so the anaerobic condition could be the cause of the removal of both total phosphorus and total kjeldahl nitrogen. The mean total kjeldahl nitrogen and total phosphorus removal efficiencies in optimized pond were 18 % and 9 %, respectively that were also higher than the total kjeldahl nitrogen and total phosphorus removal in conventional pond. The high sludge settlement, high anaerobic condition in digestion pit and high contact of microorganisms with settled sludge were among the main causes of higher efficiency in optimized pond.

Ayaz *et al.*[19] have reported that the BOD_5 removal in subsurface flow wetlands depends on hydraulic detention time, temperature and kind of plants. In subsurface flow wetland with 6 days hydraulic detention time and three bulrushes, the removal efficiency of BOD_5 was 95, 81 and 74 % respectively. These concentrations were reduced to minimum of 58.5 mg/L and maximum of 97.5 mg/L by cell I and 17.5 mg/L and 32.5 mg/L by cell II. The mean BOD_5 removal efficiency in cells I and II were 50 and 62 %, respectively. Therefore, removal of BOD_5 was about 12 % higher in cell II than cell I. However the different removal efficiency in wetland cells depends on the pretreatment of cells.

TABLE-2
AVERAGE CONCENTRATION AT THE INLET AND OUTLET OF THE ANAEROBIC PONDS AND WETLAND CELLS

Parameter	Conventional pond	Digestion pit	Baffled pond	Cell I	Cell II
BOD_5 (mg/L)					
In	250	250	182	157	83
Out	157.50	182.50	83	78	32
Removal (%)	37	27.82	53.46	50.41	62.52
Total suspended solids (mg/L)					
In	320	320	141	150	45
Out	150	141	45	55	18
Removal (%)	53.43	56.80	67.60	63.65	75.80
Total kjeldahl (mg/L)					
In	35	35	26	24	16
Out	24	26	18	6	2.54
Removal (%)	32.54	25	31	75.54	86.40
Total phosphorus (mg/L)					
In	11.20	11.20	10.90	9.55	8.92
Out	9.55	10.90	8.92	1.92	1.15
Removal (%)	18.85	9.15	18.30	79.64	87.44
Total coliform counts/100 mL					
In	2×10^8	2×10^8	1.75×10^8	9.22×10^6	4×10^6
Out	2×10^6	1.75×10^8	5.95×10^7	1.4×10^6	2.9×10^5
Removal (%)	47.92	15.25	66.64	84.66	92.59

In Santee wetland pilot with three bulrush and a one day hydraulic detention time, the total suspended solid removal efficiency were 50, 80 and 45 %, respectively[20]. Thus the total suspended solid removal in wetland cells varies with ambient condition, type of the plant and hydraulic detention time. The results of present investigation also showed that pretreatment of wetland cells was also very important factor in removal of total suspended solid. In cell II the pretreatment was appropriate and thus the high percent of total suspended solid was removed in digestion pit and baffled pond. In cell I, the removal of total suspended solid was also low in pretreatment stage. It can be concluded that the re-suspended particles transferred to cell I, has caused the clogging and short circuiting.

In this research two wetland cells were similar but the mean total kjeldahl nitrogen removal efficiency in cell II was 11.5 % higher than that of cell II. It seems that in addition to these parameters, the clogging phenomenon in cell I was an important factor in removal of total kjeldahl nitrogen. It is stated that the nitrogen removal in the wetland cells is done by nitrification and de-nitrification. In cell I, due to clogging and fading of plants, the rate of both oxygen transfered by plants and penetration by soil surface were reduced. Thus nitrification of ammonia was lower in cell I in comparison to cell II.

The mean total phosphorus removal efficiency in cell II was 8 % higher than that of cell I. Greenway[15] reported that the phosphorus removal in wetland cells depends on clay soil at bed, precipitation and plant absorption. In the present investigation, the two wetlands' cells were constructed using compressed clay soil at the floor and the plants were bulrushes as well.

In three wetland cells that were connected in series, the influent counts of total coliform were reduced from 11×10^4 to 10^4/100 mL[21]. Thus the number and the method of pond and wetland combination are important in total coliform removal.

In wetland cells, the removal efficiency according to distance from entrance is shown in Figs. 2 and 3. Alamdari and Vossougi[22] reported that by one bench scale wetland cell (1.7 m long, 0.5 m wide and 0.36 m deep and constant COD = 200 mg/L), the most removal efficiency took place in one third of the entrance (65 %-70 %). As shown in Fig. 2, in cell I, the influent BOD_5 was reduced from 157 mg/L to 90 mg/L in the first 5 meters from entrance and in cell II it was reduced from 82 mg/L to 60 mg/L, *i.e.* 42 % and 26 % reduction at one fourth of entrance distance, respectively. The hydraulic load was equal in both cells but the organic load in cell I was higher than that of cell II. Hydraulic load equally decreases as the organic load does.

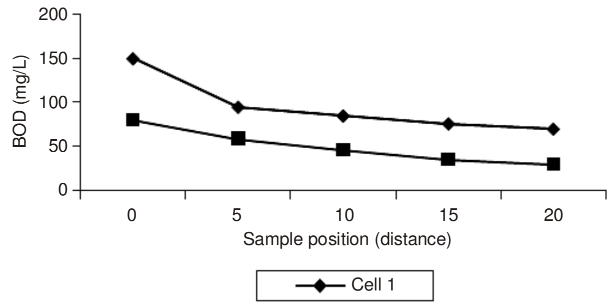

Fig. 4. Removal of biochemical oxygen demand in cell I and in different sample positions

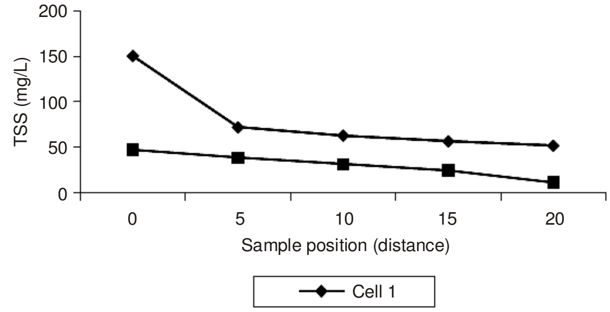

Fig. 5. Removal of total suspended solid in cell I and in different sample positions

As shown in Fig. 5, the mean total suspended solid removal efficiency at the one fourth from entrance in cell I, was 68 % and in cell II was 31 %. Figs. 4 and 5 show that the removal efficiency in wetland cells varies in different length of cells. The per cent and the place of removal efficiency from entrance and the kind of concentration in wetland cells were not constant for every wetland cell. These depend on the pretreatment, type of the plant, hydraulic and organic loads.

The removal efficiency in combined optimized pond and cell II was higher than the combined conventional pond and cell I for these reasons:

1) In optimized pond, influent wastewater is distributed at the bottom of the digestion pit and travels in an up flow mode through the sludge layer. In the anaerobic baffled pond, baffles are used to direct the flow of wastewater in an up flow and down flow mode through a series of sludge layer. Thus the organic and inorganic materials in mixture of settled waste-water and sludge are converted biologically under anaerobic condition. Particles that reach surface of the digester are captured and removed in the baffled pond. In conventional pond, influent wastewater is distributed in total volume and travels at the length of the pond in curve line. When a colder or warmer wastewater enters the pond, a portion of the wastewater can travel along the bottom or across the top of the pond without complete mixing. These phenomena causes short circuiting, lower sludge settlement and also lower contact sludge.

2) The across baffles shapes are important to increase efficiency, because the L in dispersion number (D/UL) was long and the flow regime in the pond was limited to plug flow reactor.

3) In cell I, the pretreatment was lower and the percent of influent pollution load was higher when compared with cell II. Thus it causes clogging in initial bed.

4) Clogging causes short circuiting in cell I.

5) In cell 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.

6) In wetland cells, 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 cell I. As a result, nitrification will be reduced and the total kjeldahl nitrogen removal efficiency stands at a lower level than cell II.

Conclusion

In general, waste stabilization ponds will enjoy high ability in wastewater treatment if they are designed by proper methods. One of the most effective methods for optimization ponds is the application of digestion pit and baffles. In this manner, the efficiency removal increases and the treatment area decreases. In this research, it was shown that the dispersion number was decreased with increasing flow length and number of baffles which indicated more plug flow conditions. The result of operation and maintenance of wetland cells showed that if the pretreatment was not sufficient, clogging and short circuiting would take place and ultimately the removal efficiency would decrease.

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