Treatment of wastewater by natural systems

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Abstract

Experimental results from a pilot-scale constructed wetland (CW) treatment plant have been described. The study was conducted at two different systems: continuous and batch. In the continuous system, the treatment yields were monitored in different loading conditions in 1-year period. The pilot plant consists of two serially connected tanks settled up with fillers; Cyperus was used as treatment media and wastewater between the two tanks was recycled periodically. Chemical oxygen demand (COD) and suspended solid (SS) removal efficiencies were obtained as 90% and 95%, respectively. The effluent COD concentration at an average loading of 122 g COD/m² day was satisfactory for the Turkish Water Pollution Control Regulation. This means that a 0.8 m² of garden area per person is required. Other removal values for the same conditions were as follows: total Kjeldahl nitrogen (TKN) was 77%, total nitrogen (TN) was 61%, and PO₄³⁻ -P was 39%. The batch experimental systems consist of 12 pairs of serially connected tanks, with each pair having a surface area of 1 m². Each set was filled with sewage once a day, and the wastewater between the paired tanks was recycled periodically by the pump. Each pair of tanks was filled with materials such as gravel, peat, and perlite. Seven of them were vegetated with Phragmites, Cyperus, Rush, Iris, Lolium, Canna, and Paspalum, while the other five were not seeded. The best performances were obtained by Iris for COD (% 94), by Canna for ammonia nitrogen (% 98), and by Iris for total nitrogen (% 90) and phosphorus (% 55) removal. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Wastewater treatment; COD removal; Nitrogen removal; Phosphorus removal; Constructed wetland; Low-cost treatment

1. Introduction

Wetlands are considered as low-cost alternatives for treating municipal, industrial, and agricultural effluents. Constructed wetlands (CWs) 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 (Kadlec, 1995). This new developing technology may offer a low cost and maintenance to domestic wastewater treatment, which is especially suitable for developing countries (Ayaz and Saygin, 1996; Haberl et al., 1995; Hammer, 1989; Kadlec, 1995). Considering the uncontrolled expansion of big metropolitan cities of Turkey (e.g., Istanbul, Izmir, Antalya), CW technologies might be a good solution due to the following advantages (Ayaz and Akçä, 2000):

- No need to establish the sewerage system for single houses or small communities.
- Lowering the initial costs by using cheap materials and allowing self-construction.
- Developing a pathogenically safe, as well as aesthetic treatment unit that combines water treatment with hobby garden activities and reuse possibilities (toilet flushing).

One of the disadvantages of such systems may be the requirement of a large area. Area requirements for different configurations and different treatment purposes (BOD removal, nitrification, etc.) have been given in the range of 1.3–10.3 m²/person (1 m²/person for BOD removal and 2 m²/person for BOD removal and nitrification) by Cooper and Findlater (1990).

The plants growing in wetlands are adapted for growing in water-saturated soils. The wetland plants (macrophytes) have many functions related to the treatment of wastewater in CWs. 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 Canna-lilies, and this way makes sewage treatment systems aesthetically pleasing (Brix, 1994).
Although the plants are the most obvious components of the wetland ecosystem, wastewater treatment is accomplished through an integrated combination of biological, physical, and chemical interactions among the plants, the substrata, and the inherent microbial community. The role of the macrophytes in treatment wetlands is well-documented by several authors (Brix, 1997; Wood, 1995; Armstrong et al., 1990; Burka and Lawrence, 1990).

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 (Armstrong et al., 1990; Brix, 1994). The limited aeration around the roots ensures that anaerobic conditions will predominate, unless the organic load to the wetland is low and wetland is shallow.

2. Materials and methods

In the experiments, domestic wastewater from toilets of the Marmara Research Centre (MRC) campus was used after primary treatment in a settling tank. The average wastewater characteristics were given in Table 1.

The continuous study was carried out in a system made of two gardens (polyester tanks of 0.3 × 1.5 × 3.5 m) having a small level difference of 30 cm between them. The wastewater was recycled periodically between two gardens in the following way: Wastewater was pumped from lower to the upper garden by a pump, controlled by a timer. When the pump was switched off, the water flowed from the upper to the lower garden by gravity. The wastewater was pumped from lower to the upper garden in 15 min, while backflow by gravity took about 20 min. In the system, the total hydraulic retention time was 6 h. The gardens were filled with gravel (0 – 5 mm) and Cyperus and fed with wastewater continuously at a flow rate of 42 l h⁻¹.

When the Cyperus has covered the system fully, the parameters (chemical oxygen demand (COD), suspended solid (SS), NH₄⁺-N, PO₄³⁻) in the influent and effluent of the system were monitored. The treatment efficiencies of the system for COD, nitrogen, and phosphorus removal were investigated during a 1-year period (May 1996–February 1997). The air temperatures during the experimental period were also monitored. The monthly average temperature varied between 5–6°C (in February) and 23–25°C (in August). All analyses were carried out according to Standard Methods (1992).

The batch experimental system consisted of 12 pairs of tanks connected to each other serially (Fig. 1). Each tank has an area of 1 m² (1 × 1 × 0.3 m). The pair of
tanks was placed with a level difference of 30 cm between them. Each set was filled with 140 l of sewage once a day and wastewater between the two tanks was recycled periodically by the pump. As the pump was switched off, the water flowed back to the lower tank through the pump by gravity. “On-and-off” periods of the pump could be adjusted separately by two timer relays. The timers were adjusted so that the water flowed as completely as possible out of each tank. After 24 h, the tanks were fully drained, the samples were taken and prepared for the new feeding period. Each pair of tanks was filled with materials such as gravel, peat, and perlite. Seven of them were vegetated by *Phragmites*, *Cyperus*, *Rush*, *Iris*, *Lolium*, *Canna*, and *Paspalum*. The other five

<table>
<thead>
<tr>
<th>System</th>
<th>COD</th>
<th>TOC</th>
<th>SS</th>
<th>NH$_4^+$-N</th>
<th>NO$_3^-$</th>
<th>PO$_4^{3-}$</th>
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</thead>
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<tr>
<td>A1</td>
<td>79 ± 33</td>
<td>23.3 ± 7.69</td>
<td>18.4 ± 10.4</td>
<td>7.94 ± 8.05</td>
<td>75.88 ± 60.15</td>
<td>18 ± 10</td>
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<tr>
<td>A2</td>
<td>73.3 ± 46.4</td>
<td>22 ± 7.5</td>
<td>15.2 ± 14.5</td>
<td>7.4 ± 9.6</td>
<td>88 ± 57</td>
<td>19 ± 13</td>
</tr>
<tr>
<td>A3</td>
<td>68 ± 33</td>
<td>22 ± 7.9</td>
<td>17.3 ± 14.5</td>
<td>10.4 ± 11.3</td>
<td>77.4 ± 53.3</td>
<td>17 ± 11</td>
</tr>
<tr>
<td>A4</td>
<td>72 ± 29.1</td>
<td>23 ± 8</td>
<td>8.5 ± 4.4</td>
<td>7 ± 6.6</td>
<td>73 ± 57</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>A5</td>
<td>89.5 ± 49.5</td>
<td>26 ± 7.7</td>
<td>35 ± 48</td>
<td>13 ± 12</td>
<td>73 ± 60</td>
<td>16 ± 10</td>
</tr>
<tr>
<td>A6</td>
<td>81 ± 48</td>
<td>23 ± 8.12</td>
<td>26 ± 46</td>
<td>12 ± 13</td>
<td>75 ± 60</td>
<td>17 ± 13</td>
</tr>
<tr>
<td>A7</td>
<td>66 ± 32</td>
<td>22 ± 8.86</td>
<td>23 ± 36</td>
<td>12 ± 25</td>
<td>61.4 ± 47.2</td>
<td>19 ± 20</td>
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<td>B</td>
<td>77.3 ± 34.8</td>
<td>31.3 ± 38.14</td>
<td>23 ± 41.3</td>
<td>6.6 ± 6.2</td>
<td>88.2 ± 55</td>
<td>27 ± 31</td>
</tr>
<tr>
<td>C</td>
<td>61.3 ± 26.8</td>
<td>21.4 ± 6.2</td>
<td>14 ± 13.1</td>
<td>7.7 ± 8.6</td>
<td>108.2 ± 50.6</td>
<td>20 ± 15</td>
</tr>
<tr>
<td>D</td>
<td>72.6 ± 28.1</td>
<td>25 ± 9.2</td>
<td>16 ± 16</td>
<td>12 ± 10</td>
<td>47 ± 26</td>
<td>14 ± 3</td>
</tr>
<tr>
<td>E</td>
<td>84.3 ± 33.2</td>
<td>26.2 ± 9.6</td>
<td>31 ± 41</td>
<td>13.3 ± 10.4</td>
<td>65.4 ± 62.4</td>
<td>15 ± 5</td>
</tr>
</tbody>
</table>

Fig. 3. Relations between loading and removal rates in the batch systems.
were not seeded with plants. The characteristics of the experimental systems have been summarized in Table 2.

3. Results and discussion

Fig. 2 shows the inflow and outflow concentrations of COD, TOC, nitrogen, and phosphorus for the continuous system. COD loading rate changed between 25 and 150 g/m² day and the corresponding effluent concentration ranged from 38 to 120 mg l⁻¹, with an average of 76 mg l⁻¹. The average COD removal efficiency was found as 88%, which assures the discharge standards of Turkish Water Pollution Control Regulations (WPCR, 1984). In another study (Gearheart, 1988), when the loading rate was 14 g COD/m² day, an effluent concentration of 40 mg l⁻¹ COD was found. In this study, the same effluent concentration (40 mg l⁻¹ COD) was obtained with a higher loading rate (40 g COD/m² day). On the other hand, in the literature, 60 g COD/m² day was recommended for an optimum COD removal (Reed et al., 1988). In this study, the discharge standards of Water Pollution Control Regulation could be reached with a much higher loading rate (150 g COD/m² day) and without any operational problem. When a medium-strength domestic wastewater (i.e., 100 g COD/day person) was used as influent, the average treatment area per person for COD removal was calculated as 0.67 m² by considering the effluent COD concentration as 120 mg l⁻¹, which is appropriate for Turkish Standards (WPCR, 1984).

The system also acquired the removal of TOC and SS at satisfactory level as shown in Fig. 2. The average effluent concentrations of TOC and SS were found as 23 and 20 mg l⁻¹, respectively. The removal of ammonium nitrogen (88%) was accomplished by plant assimilation and by nitrification. The effluent and influent average NH₄⁺-N concentrations were 84 and 10 mg l⁻¹, respectively. The average PO₄³⁻-P removal was 48% in the loading range of 0.75–3.0 g/m² day. The relation between PO₄³⁻-P loading and PO₄³⁻-P removal was changed for different seasons. In summer (19–25°C), the PO₄³⁻-P influent loading rates were determined to be 0.75 and 3.0 g/m² day when the corresponding effluent concentration of PO₄³⁻-P were in the range of 4–12 mg l⁻¹. However, in winter (5.0–7.0°C), with influent loading rates of 0.75 and 1.20 g/m² day, the...
effluent concentrations reached between 8 and 16 mg l\(^{-1}\). Plant uptake of phosphorus was determined as 13 g/m\(^2\) year. This value was given at 5–13 P/m\(^2\) year by Brix (1994).

Effluent concentrations of each system for the batch experiments have been presented in Table 3. As can be seen in the table, no significant differences between the treatment efficiencies of the planted and unplanted systems were observed. The COD loading rates were varied between 15 and 75 g/m\(^2\) day for all batch experiments. Similarly, NH\(_4\)^+ -N and PO\(_4\)\(^{3-}\) -P loading rates were in the ranges of 4–12 g/m\(^2\) day and 0.3–0.8 g/m\(^2\) day, respectively. Average effluent COD concentrations are similar and varied between 61 and 90 mg l\(^{-1}\) for all batch systems. The best COD removal performance was obtained by Iris. The average NH\(_4\)^+ -N effluent concentrations were in the range of 6.6–13.3 mg l\(^{-1}\) and the best removal efficiency was obtained by Canna. The effluent nitrate concentrations were found between 60 and 108 mg l\(^{-1}\), which indicate a good nitrification in all systems. On the other hand, effluent PO\(_4\)\(^{3-}\) -P concentrations were found to be between 13 and 27 mg l\(^{-1}\), although this phosphate concentrations were somewhat high, removal efficiency were between 30% and 58%.

The relations between loading and removal rates of COD, total N and phosphorus have been presented in Fig. 3 for all batch experiments. In all systems, very good linear correlations were observed between the loading and removal rates for the COD and total nitrogen, but phosphorus data were somewhat scattered.

4. Conclusion

The purpose of the study was to evaluate the performances of intermittent recycled CW system and removal effects of different plants and mediums. Although the roles of the substratum and plant in the treatment processes are rather complex and not well defined, this study attempts to compare the removal efficiencies of some wetland plants and substratum.
The best COD and NH$_4^+$ -N removal performances were obtained by *Iris* and *Canna*, respectively. In comparing the results of the planted and unplanted reactors, no sharp differences were observed among the COD, TOC, SS, nitrogen, and phosphorus removal efficiencies of the planted and unplanted reactors. The effluent nitrate concentrations of the planted reactors were somewhat higher than the unplanted reactors. This may be so because the major role of the plants in CWs is oxygen transfer from leaves to the roots. These results indicate that the role of the plants in pollutant removal is questionable and needs more research and refining.

COD and SS removal and nitrification are at satisfactory level in all experimental systems. Although the effluent phosphate concentrations were somewhat high, removal efficiencies have changed between 30% and 58%. The area requirement calculated for this study is the lowest (0.67 m$^2$/person) mentioned in the literature. The batch and continuous experiments showed that the recycled CW system described here can be an efficient and cheap secondary treatment system, which might be especially suitable for small settlements and also for individual houses even with a small garden.

**References**


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