ADVANCED TREATMENT AND FOOD PRODUCTION BY HYDROPONIC TYPE WASTEWATER TREATMENT PLANT

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ABSTRACT

Hydroponic type advanced wastewater treatment system, which consists of a water channel packed with porous concrete and hydroponic type cultivation tanks (HTCT), was developed and its applicability to advanced treatment of secondary effluent and polluted river and drain water was experimentally studied. Porous concrete (PC) provided enough interfacial area for reaeration and enough space for attached microbial growth and improved treatment capability of water channel tremendously. It was revealed that TOC could be removed efficiently under TOC loading rate of 80 mg-TOC/L·day. Owing to the high sludge entrapment capacity of PC, the observed sludge yield (Y_{obs}) decreased to 0.25-0.33 g-MLSS/g-TOC. Crop yield of pak-bung plant during continuous treatment of effluent from water channel was proved experimentally to be 1.18 kg fresh weight/m²-month. Hydroponic cultivation of midi-tomato was succeeded by using the effluent from the water channel with low nutrient concentration which indicated that this advanced wastewater treatment process has a high applicational potential for direct purification of polluted river and drain water.

KEY WORDS

Advanced wastewater treatment; direct purification; polluted river and drain water; hydroponic type wastewater treatment system; water channel; hydroponic type cultivation tanks; porous concrete; pak-bung; sweet midi-tomato.

INTRODUCTION

Nutrient (N and P) removal using aquatic plants such as water hyacinth (Eichhornia crassipes) has been the subject of a number of investigations (Dings, 1978; Rebecca and Wolverton, 1980; Jeffrey, 1984), but many problems associated with harvesting and disposal methods for the enormous amounts of grown aquatic plants are left unsettled. Nutrients in wastewater have long been an important nutrient source in agricultural fields. Hence, the usage of these nutrients for food production is a promising idea. Secondary effluent may have highly prolific value as a good nutrient source for plants, because of its high N/BOD and P/BOD values compared with that of raw wastewater.

Small municipal rivers and drains in Japan have been polluted with grey water from the areas with no sewage works service, but recreational functions of water were reevaluated and the maintenance of clean water quality was demanded recently owing to the improvement of life standard. Direct purification of these polluted municipal rivers and drains by contact gravel bed treatment, which is anyhow a transitional mean until sewage works is provided, attracted much attention (Sudo, 1990). Comparing to the water quality of secondary effluent, polluted small municipal river and drain water, whose component ratios
are quite similar to that of secondary effluent, is 2 to 5 times diluted. If plants could be cultivated on contact gravel bed, food production and gardening using nutrients in polluted river and drain water is possible simultaneously with direct purification of such water.

In this study, the possibilities of application of porous concrete (PC) (Tamai, 1988) as contact material instead of gravel and vegetables as nutrient absorber from polluted small municipal river and drain water were investigated experimentally by employing a pilot plant of hydroponic type wastewater treatment system. Pak-bung, which is a common edible aquatic plant in South East Asia, was used as the nutrient absorber for this advanced wastewater treatment. Anticipating a positive response of inhabitants and their expected participation in rivers and drains purification, sweet midi-tomato, which may get popularity as gardening vegetable, was then selected as nutrient absorber of these polluted waters.

TESTING DEVICE AND EXPERIMENTAL PROCEDURE

Testing Device

Figure 1 shows the schematic diagram of the pilot plant of hydroponic type wastewater treatment system consisting of water channels and hydroponic type cultivation tanks (HTCT).

![Schematic diagram of hydroponic type wastewater treatment plant.](image)

**Water channel.** Water channels, three in number connected in series, were made of acrylic resin having width of 0.25 metres, height of 0.25 metres, length of 8 metres and available capacity of 300 L each. 100 pieces of PC (30% void space, 100 mm diameter and 200 mm length) were packed in series in 1st water channel only as a contact material so as to increase the contact area of water channel and is shown in Figure 2.

![1st water channel packed with porous concrete.](image)

**Hydroponic type cultivation tanks.** HTCT consists of 12 basins each of width 0.32 metres, length 0.57 metres, height 0.18 metres and available cultivation area of 0.18 m². Gravel was used as packing material in cultivation basins. Surface of these basins was covered with black vinyl sheet in order to prevent the algal growth on the gravel surface.
Test aquatic Plants

Pak-Bung. The technical name of pak-bung is *Ipomoea aquatica*; its common names include Entsai and Water Glory. In Thailand, it grows in ponds, swamps, ditches and streams together with other aquatic plants such as water hyacinth. It is easy to cultivate, grows quickly in hot climates and is tolerant to wastewater. Therefore, with proper climatic conditions, it is well suited to assist in wastewater treatment. Its purification capabilities in water basins are mainly attributed to the functions of its root hairs, that is, metabolic activities of bacteria, algae and plankton attached to these root hairs, and also the root hairs function of adsorption and filtration. Pak-bung contains abundant nutritive elements, i.e., amino acids and vitamins, and is a vegetable of extremely high nutritive value (Hashimoto et al. 1986). Pak-bung's strains potted from seeds were directly transplanted on the gravel media and the grown pak-bung was harvested by cutting germinated stem parts.

Sweet midi-tomato. Sweet midi-tomato used in this study was a hybridized tomato between a bacterial wilt resistant variety, which is a multigenic controlled characteristic, and mini-tomato with high sugar content. Clone strains of sweet tomato, which were kindly gifted by Dr. Y. Mori of Fukui Prefectural College, were multiplied by planting the cutting mother strains on rock fiber or mixed medium of vermiculite and chaff, and were dipped in basin filled with tap water. Clone strains grown to 30 cm. height were transplanted to gravel bed of HTCT.

Synthetic Wastewater.

Synthetic wastewater consisted of 20 to 50 mg glucose, 47.6 to 119 mg (NH₄)₂SO₄, and 8.8 to 22 mg KH₂PO₄ per liter of tap water. Concentrated synthetic wastewater and tap water for dilution were fed continuously by pump 1 and pump 2 at flow rate of 20 L/day and 980 L/day, respectively. In case of the treatment of polluted river water, influent TOC concentration was decreased to 5 mg/L, and influent flow rate was increased to 2.880 L/day.

Operational Conditions

Water channel. Table 1 shows the operational conditions of water channel. Water channel was operated under flow-through mode without artificial aeration. Experiments were performed by varying the influent TOC concentration and the influent flow rate. RUN 1 was conducted as control without PC, while Run 6 was conducted to evaluate the treatment possibility of polluted river water by water channel under dark conditions.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Q* (m³/d)</th>
<th>Influent(mg/L)</th>
<th>Presence of PC</th>
<th>Shield from light</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>10</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>10</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>15</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2.88</td>
<td>20</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>25</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>2.88</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Q*: Influent flow rate

Hydroponic type cultivation tank. A part of the effluent from water channel was taken at the flow rate of 350 L/day. Effluent from HTCT was recycled at the flow rate of 3,000 L/day in order to keep aerobic conditions within HTCT.

Analytical methods

Chlorophyll content of sludge was measured by sonicating sludge sample at 1 KW for 10 min. extracted by acetone or methanol and centrifuged (Vonshak et al., 1979). The other components were analyzed based on the Wastewater Examination Methods (Japan Sewage Works Association).
RESULTS AND DISCUSSION

Treatment Capability of Water Channel Packed with Porous Concrete

Figure 3 shows the treatment results of water channel from Run 1 to 5.

Changes in DO. In the treatment of water channel, oxygen was supplied by the respiration both at the water surface and connection parts of water channels and algal photosynthesis. Figure 4 shows the typical distribution of DO concentration which was measured at the depth of 7.5 cm. As shown in this figure, changes in DO concentration in first water channel are obvious, and this changing extent is higher with the increase of influent TOC concentration. In case of Run 5, in which influent TOC concentration elevated to 25 mg/L, DO dropped to 3 mg/L only within 2 m of channel length, indicating that active TOC removal occurred in this region. DO deficiency took place under high loading regions, but DO value never fell to 0 mg/L. This indicates that PC provides a favourable condition for oxygen dissolution, i.e., high interfacial area is produced by setting about half part of PC above water level.

TOC Removal. Water channel without PC could remove 70% of the influent TOC of 10 mg/L at hydraulic retention time of 21.5 h. Effluent TOC concentration of 1st water channel was 1 to 2 mg/L higher than that of final effluent from 3rd water channel, but 3 to 4 mg/L of effluent TOC was obtained from 1st water channel in case of influent TOC below 15 mg/L.
This indicates that treatment capability of water channel increases about 3 times by using PC as packing material.

About 80 % of TOC was removed even under influent TOC concentration of 25 mg/L (Run 5), but sewer smell and turbidity was recognized in the effluent from 1st water channel. Hence, it manifested that the treatment of high strength secondary effluent, whose TOC concentration is above 25 mg/L, is not recommended for water channel packed with PC.

By using the treatment results of 1st water channel except Run 1, TOC removal capability of water channel packed with PC was evaluated. Figure 5 shows the relationship between TOC loading rate and TOC removal rate. About 70 % of TOC removal is achieved under TOC loading rate below 80 mg/L/day. Results of TOC removal for Run 6 were also included in this figure, whereby lighting condition was shown not to influence the TOC removal capability of water channel.

Fig. 5. TOC removal capability of water channel.

Nitrogen Removal. Only 13 % of total nitrogen (T-N) was removed in Run 1, but T-N removal efficiency was improved to 18 % and 24 % on the basis of effluent T-N concentration of 1st water channel and 3rd water channel respectively after Run 2. As shown in Figure 3, main effluent nitrogen was in the form of NH₄⁻N, and NO₃⁻-N concentration in 2nd and 3rd water channel in which TOC removal finished already, did not increase. Judging from these experimental results, establishment of stable nitrifying microflora was proved to be difficult in water channel.

Phosphorus Removal. Total phosphorus (T-P) was removed at the efficiency of 28 % in Run 1. But T-P removal efficiency was increased to 50 % after packing PC in water channel. This increase may be closely related to the dissolution of calcium component of PC. As shown in Figure 3, T-P was removed even in 2nd and 3rd water channels in which pH shifted to alkaline region owing to the dominant attached algal growth on the walls of water channel. This pH shift might have stimulated the formation of calcium hydroxyapatite.

Sludge Production in Water Channel

The knowledge as to the amount of sludge production is concerned, its distribution in water channel and safety operational period without clogging of PC are important for the quantitative evaluation of treatment capability of water channel.

Biofilm Formation on Porous Concrete. It was recognized that lighting using plant rearing fluorescence lamp stimulated the algal growth on side walls in 2nd and 3rd water channels. In experiments in which influent TOC concentration was more than 15 mg/L, dominant growth of Beggiatoa sp. was noticed by the formation of white slime layer indicating the presence of anaerobic zone inside PC. Biofilm consisting of algae and gelatinous polymer was observed on the upper part of PC which was packed on the upper layer. On the other hand, attached biofilm could not be observed with the naked eye, but the color of PC turned black by the formation of sulfide compounds showing the presence of anaerobic conditions inside PC.

Biomass Accumulation. The biomass distribution in water channel measured at the end of Run 1, 4 and 5 is shown in Figure 6. About 80 % of sludge existed in 1st water channel packed with PC. This showed the excellent sludge entrapment capability of PC. However, the amount of sludge entrapped in 1st water channel increased substantially leading to the
increase of anaerobic conditions in water channel.

Fig. 6. Distribution of attached biomass in water channel. 
- : biomass attached on walls. 
- : biomass attached on porous concrete.

Sludge Yield. Table 2 shows the observed sludge yield ($Y_{obs}$) which was calculated from the amount of biomass produced and the amount of TOC removed in the treatment by water channel. $Y_{obs}$ determined at the end of Run 1 was 0.52 g-MLSS/g-TOC which is similar value to that of conventional activated sludge process. But $Y_{obs}$ values determined at the end of Run 4 and Run 5 were 0.33 and 0.25 respectively, which are about half of that of Run 1. $Y_{obs}$ for Run 6, which was operated under dark operational conditions, was 0.33 g-MLSS/g-TOC. This result shows that there was no big difference in lighting condition of water channel. $Y_{obs}$ is related with sludge retention time ($\theta_c$) as shown in the following equation:

$$Y_{obs} = Y / (1 + b \theta_c)$$

where $Y$ and $b$ denote sludge yield (g-MLSS/g-TOC) and sludge decay constant (day$^{-1}$) respectively. Owing to the high sludge entrapping capacity of PC, $\theta_c$ for the sludge in water channel packed with PC increases, so that $Y_{obs}$ inevitably decreases as shown in equation (1).

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Experimental Period</th>
<th>Observed Yield (g-MLSS/g-TOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/29 - 10/3</td>
<td>0.52</td>
</tr>
<tr>
<td>2 - 4</td>
<td>10/4 - 1/13</td>
<td>0.33</td>
</tr>
<tr>
<td>2 - 5</td>
<td>10/4 - 2/18</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>6/1 - 1/22</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Soluble synthetic wastewater was used throughout the experiments. However, real secondary wastewater and polluted municipal river water contain suspended solids. Organic suspended solids are first entrapped within PC and then are translocated to downstream. Solubilization of organic suspended solids occur during translocation but inorganic suspended solids accumulate within water channel, which implies that the settling in grit chamber and regular withdrawal of removed inorganic solids is required.

Microflora. Because water channel is operated under plug flow mode, water quality changes continuously along flow direction. Hence, microflora also changed along flow direction. Geotrichum sp. dominated at the inlet port, but then Beggiatoa sp., which prefers slight anaerobic conditions, dominated after increase of loading rate. Various varieties of protozoa and metazoa such as Rotaria sp., Diplogaster sp., and Paramecium caudatum were
observed under the microscope in the sludge of 1st water channel. In Run 5. *Amoeba* sp. was observed in sludge taken from every sampling point of 1st water channel indicating the limit of treatment.

By setting PC in water channel as packing material, attached algal growth was stimulated and various kinds of blue green algae such as *Chroococcus* sp., *Dactylococcopsis* sp., *Microcytis* sp. and *Oscillatoria* sp. and diatoms such as *Navicula* sp. and green algae such as *Scenedesmus* sp. were observed.

**Cultivation of Pak-Bung by Hydroponic Type Cultivation Tank**

The cultivation of Pak-bung, which is a subtropical aquatic plant, is possible only in summer season in Japan. Thus, the experiments were conducted outdoor in this season. Pak-bung strains planted on gravel bed grew and covered the surface of gravel bed within 2 weeks. whereas Scots continuous harvesting was carried out every 7 to 10 days.

**Nutrient Removal.** Figure 7 shows the daily changes of effluent T-N and T-P concentrations from HTCT using pak-bung, and cumulative harvested weight of pak-bung during continuous experiments. Nutrient removal was not evident at early stage of experiments. But T-N and T-P removal efficiencies increased to 30 % and 20 % respectively with the weight increase of harvested pak-bung. Figure 8 shows material balances of T-N and T-P during 155 days of continuous experiments. About 67 % of T-N removal and 55 % of T-P removal could be explained by the nutrient uptake capabilities of pak-bung. This indicates high contribution of pak-bung in the nutrient removal by HTCT.

![Graph showing daily changes of cumulative harvested weight of pak-bung and effluent T-N and T-P concentrations.](image)

![Pie chart showing material balances of T-N and T-P during 155 days of continuous experiments.](image)

**Sludge Production.** All sludge produced in HTCT during experiments was recovered at the end of experiments and its weight and ash content for each basin was measured and is shown in Figure 9. About 41.8 % of sludge was retained in the first two basins. Retained sludge
weight decreased gradually in 2nd and 3rd basins and same amount of sludge was retained in the 4th to 6th stage of basins. Ash content of sludge in 6th basin increased to 75% which shows the progression of sludge mineralization.

![Composition of recovered sludge in HTCT](image)

**Nutrient Removal Capabilities of Pak-bung.** Table 3 shows the crop yield and nutrient removal capabilities of pak-bung determined in this study. During experimental period, it was possible to harvest pak-bung continuously at the crop yield of 1.98 kg/m²-month. Based on this crop yield, N and P removal rates were respectively calculated to be 6.72 and 1.86 g/m²-month from their N and P content. These values are comparable with that of water hyacinth, which is regarded to be a potent nutrient absorber from wastewater. Although pak-bung is edible and nutritional vegetable, yet there remain problems as to the accumulation of toxic substances such as heavy metals. However, it has been proved experimentally that heavy metals accumulate mainly in root portion of pak-bung (Hashimoto, 1987) which implies that it is possible to use harvested pak-bung as food effectively.

<table>
<thead>
<tr>
<th>Aquatic Plant</th>
<th>Crop Yield (kg/m²-month)</th>
<th>N Removal Rate (g-N/m²-month)</th>
<th>P Removal Rate (g-P/m²-month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pak-bung</td>
<td>1.98</td>
<td>6.72</td>
<td>1.86</td>
</tr>
<tr>
<td>Water Hyacinth</td>
<td>4.86</td>
<td>9.88</td>
<td>1.92</td>
</tr>
</tbody>
</table>

**Cultivation of Sweet Midi-Tomato by Hydroponic Type Cultivation Tank**

Figure 10 shows the cultivation history of midi-tomato by HTCT. Clone strains planted on gravel media flowered only after 10 days and formed buds after one month. Harvesting of tomato fruits was possible one month later and continued until beginning of September.

**Growth of Midi-Tomato on Gravel Media** \( \Sigma D^2H \) was proved to be a good growth index for midi-tomato as shown in Figure 11. D and H denote the diameter and length of stem respectively. Figure 12 shows the daily changes of \( \Sigma D^2H \) of test strains and the strain planted on soil as control. The clone strains planted on rock wool (RW strains) showed better growth than the clone strains planted directly on gravel (DR strains) at the beginning of experiments, but this difference was not so obvious in the harvesting periods. Tomato growth on gravel bed was only half of the growth of control strains (CR...
strains) which were cultivated under enough sunlight and nutrients. Figure 12 also shows the cumulative number of harvested tomatoes during experiments. About 350 midi-tomatoes could be consecutively harvested from 22 potted strains on HTCT since the end of June.

![Graph showing the relationship between $I^2H$ and dry weight for midi-tomato.](image)

**Fig. 11. Relationship between $I^2H$ and dry weight for midi-tomato.**

![Graph showing growth curve and cumulative number of harvested fruits of midi-tomato.](image)

**Fig. 12. Growth curve and cumulative number of harvested fruits of midi-tomato.**

Table 4 shows the analytical results of sugar content of harvested midi-tomato. Average sugar content of harvested midi-tomato was revealed to be 7.7%, which is higher than that of normal tomato and mini-tomato.

**TABLE 4 Sugar Content of Harvested Midi-Tomato**

|          | Midi-Tomato | Mini-Tomato | Tomato
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>HP st.*</td>
<td>CR st. #</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>9.4</td>
<td>10.7</td>
<td>7.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.0</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Average</td>
<td>7.7</td>
<td>8.7</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.9</td>
</tr>
</tbody>
</table>

*: Hydroponic strain. #: Pot strain

There were no big differences in the growth and number of harvested tomato fruits between RW strains and DR strains. From these results, it can be concluded that simultaneous purification of polluted river water and hydroponic culture of midi-tomato is possible only by direct planting of midi-tomato on gravel bed.

**Nitrogen and Phosphorus Removal Capabilities of HTCT.** Table 5 shows the treatment results of HTCT. HTCT planted with midi-tomato removed 40% of TOC, 20 to 40% of T-N and 60% of T-P. This indicates high nitrogen and phosphorus removal capability of HTCT compared with the treatment results of water channel. In order to evaluate the nutrient removal capability of HTCT, material balances on T-N and T-P during July 25 to August 9, in which consecutive harvesting of midi-tomato was possible, were made and are shown in Figure 13. It was revealed that the percentages of nitrogen and phosphorus which transformed to tomato fruit were higher than that transformed to leaf, stem and root.

**TABLE 5 Treatment Results of HTCT Using Midi-tomatoes**

<table>
<thead>
<tr>
<th>Date</th>
<th>TOC(mg/L)</th>
<th>T-N(mg/L)</th>
<th>T-P(mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 11</td>
<td>2.7</td>
<td>1.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Jul. 28</td>
<td>1.7</td>
<td>1.1</td>
<td>8.6</td>
</tr>
<tr>
<td>Aug. 10</td>
<td>2.2</td>
<td>1.5</td>
<td>11.1</td>
</tr>
<tr>
<td>Aug. 30</td>
<td>2.8</td>
<td>1.9</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Inf.: Influent. Eff.: Effluent
CONCLUSION

By using pilot plant of hydroponic type advanced wastewater treatment system, which consists of water channel packed with PC as contact material and HTCT, possibilities of simultaneous purification of polluted small municipal rivers and drains water and cultivation of plants such as pak-bung and midi-tomato were investigated experimentally and the following conclusions were obtained.

1) By packing PC in water channel, TOC removal efficiencies were improved through the high sludge entrapment capacity of PC. However, the water channel fell into an aerobic conditions by elevating influent loading rate and subsequently the limit of TOC loading rate for water channel was recognized to be 80 mg/L·day.

2) Yobs for the treatment of water channel decreased tremendously indicating that high sludge retention time was maintained in water channel.

3) Crop yield of 1.16 kg/m²·month was obtained through continuous harvesting of pak-bung in HTCT. N and P uptake rates were revealed to be 6.72 g-N/m²·month and 1.86 g-P/m²·month from this crop yield.

4) Hydroponic cultivation of midi-tomato and advanced wastewater treatment was simultaneously possible even under low nutrient concentration such as that of polluted municipal river and drain water.

5) Through successful utilization of pak-bung and midi-tomato as nutrient absorbers for advanced wastewater treatment, positive response of inhabitants and their participation in small municipal river and drain water purification is anticipated.

REFERENCES


