THE EFFECT OF BAFFLE INSTALLATION ON THE PERFORMANCE OF A SINGLE-CELL STABILIZATION POND

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ABSTRACT

The effect of baffles on the performance of an ineffective, single-celled stabilization pond with theoretical retention time of 5-10 days, was investigated. The efficiency of the pond was evaluated by comparing the microbiological and chemical quality of pond's influent and effluent, as well as by hydraulic tests. Removal of indicator microorganism (1 log) and BOD$_5$ (55%) remained unchanged, regardless of the number of baffles. Tracer study findings were characterized by the appearance of a peak of tracer within 15-20 hours after injection of the tracer, followed by a long "tail" of lower concentration. These findings, along with optical observations, indicated that the baffles succeeded in channeling influent flow to the planned routes (resulting in increased traveling distance of the wastewater). However, the actual retention time of the influent, particularly a small but important fraction of it, remained short regardless of baffle installation. The lack of mixing caused by thermal stratification of the water column resulted in rapid bottom flow in the cool hypolimnion. These findings may explain, in part, the lack of success in improving treatment efficiency.

KEY WORDS

Baffles; Indicator microorganisms; bacterial removal; Retention time; Stabilization ponds; Stratification, Tracer.

INTRODUCTION

Waste stabilization ponds (SP) are a common facility for the treatment of sewage. This widespread practice in developing countries is a result of low operation and maintenance costs as well as high effluent quality. The purpose of treating wastewater in SPs is to remove organic loading, expressed as Biological Oxygen Demand (BOD$_5$), pathogenic microorganisms (both viruses and bacteria) and parasites (helminths and protozoa). It has been reported that SP effluents do not always reach the required quality (Nascimento, 1977; Saqqar and Pescod, 1991).

The efficiency of treatment in such ponds depends greatly on retention time - which is controlled by the flow rate, the size and shape of the pond and hydraulic flow patterns. Flow patterns
are influenced by pond shape, dead spaces, existence of density currents, and inlet-outlet configurations (Middlebrooks et al., 1982; Moreno, 1990). The hydraulic flow characteristics obviously affect the dispersion of waste material, as well as the average retention time, and, ultimately, the removal efficiency of organic material (BOD₅) and pathogenic microorganisms.

Baffle installation has been proposed by several investigators (Middlebrooks et al., 1982; Killani and Ogunrombi, 1984) as a means of improving the hydraulic characteristics of SPs. This practice is expected to break stratified (density) flow, decrease dead spaces and reduce short circuiting, thereby increasing retention time.

The aim of our study was to evaluate the degree of improvement in the removal of indicator microorganisms and BOD₅ in a full-size operating SP by the installation of low cost plastic-cloth baffles. The effect of baffle installation on hydraulic flow patterns was also evaluated.

MATERIALS AND METHODS

System Description

The stabilization pond of Kibbutz Sha'alabim located in the Judea plains, was chosen as our study site. Wastewater flowing into the system was of domestic origin only. SP dimensions were: length - 50m, width - 30m, average depth - 1m, (total capacity 1500m³). The influent flow rate ranged from 125 to 350m³/d, resulting in a theoretical retention time of 5-10 days. In practice the flow rate was 300 m³/day, so that the average retention time was 5 days.

The system consisted of 2 anaerobic sedimentation ponds operating alternately (during the study pond # 1 was in operation) and a stabilization pond, see Fig. 1.

A total of four horizontal plastic-cloth baffles were installed, one at a time. The baffles were hung on a steel cable; floats were attached to the upper part to keep the baffles above the water surface, weights were attached to the bottom of the baffles to ensure complete settling on the pond bottom. Fig. 1 shows the pond with four baffles at the final stage of the project.

Samples for biological and physico-chemical analyses were taken when the system had stabilized, i.e. two weeks after the installation of each new baffle. Pond efficiency was assessed by comparing influent and effluent quality, in the period March - October 1991. Calculations were made on a yearly basis, after measurements were made for each baffle added. Hydraulic characteristics were investigated using tracers. Two in situ sets of measurements of temperature and other biological and physico-chemical profiles of the water column were carried out. Profiles were measured early in the morning and in the afternoon.
Tracer Studies
A slug of 500 ml of Rodamin Water Tracer (RWT) (Intracid-20% w/v) diluted in 20 liters of influent was injected into the pond's inlet. Samples were collected continuously by an automatic sampler (Manning S-4000 Portable Discrete Sampler). RWT concentration was determined with a Turner Fluorometer model 111.

Physico-chemical measurements
Temperature and dissolved oxygen (DO), were measured with a YSI model 54 oxygen meter, pH was measured with a Radiometer Copenhagen pH meter, 29b. BODs, TSS and VSS were determined according to APHA (1989). TOC was determined with a Dohrmann carbon analyzer DC/80. Chlorophyll (CHL-a) was extracted using the method of Talling and Driver (1963), and determined with an H.P. Diode Array Spectrophotometer.

Microbiological measurements
Fecal coliform and enterococci were enumerated by the membrane filtration technique, using Sartorius 4.7 cm Cellulose Nitrate (pore size 45 μm) filters. Fecal coliform were determined according to Dufour et al. (1981). Enterococci were determined according to Levin et al. (1975). F+ bacteriophages were determined by plaque assay techniques, according to Havelaar and Hogeboom, (1984). The host bacterium was Salmonella typhimurium WG-49.

RESULTS
Profiles
Temperature, DO and pH profiles measured on the 3rd of June, in the afternoon (15:00 h), when the pond contained one baffle, are presented in Fig. 2. Thermal stratification was observed, with a sharp thermocline at a depth of 30cm. The difference in temperature between the epilimnion and hypolimnion was 10°C. An oxycline developed at the same depth, showing a transition from
supersaturation in the upper water layer to anaerobic conditions in the lower layers. The top-bottom difference in pH was within one unit. In addition, differences of up to 5000 µg/l CHL-a were found between the epilimnion and hypolimnion. The stratification usually faded at night, although there were indications that the water column did not necessarily undergo diurnal turnover as was reflected by the existence of pH and CHL-a stratification in morning measurements. Similar results were obtained when the system included four baffles.

![Graph of temperature, dissolved oxygen, and pH](image)

**Figure 2. Profiles of temperature, dissolved oxygen and pH measured at 16:00h on the 3rd of June in Shaalabim's SP.**

**BOD**

The BOD levels of influent ranged from 170 to 475 mg/l with loads of 34 to 95 kg/dunm³/day, creating organic loads more than 200% greater than those recommended (30-40 Kg/Dunm/Day) (Mara and Pearson, 1987). Reductions in BOD ranged from 42% to 72% and averaged about 55% throughout the sampling period.

**Tracer studies**

Tracer studies showed the rapid appearance of a peak after some 15-20 hours (representing 5% of the initially applied RWT), followed by a long "tail" of lower concentration. The mean retention time, as calculated from these studies, ranged from 2.5 to 4.5 days in all baffle combinations. Dispersion index (d) values ranged from 0.95 to 2.5 in all baffle combinations. The results of tracer studies on the nonbaffled pond and the 4-baffled system are presented in Fig. 3A and 3B, respectively. As can be seen there was no evident change in hydraulic flow pattern. Sampling in the first tracer study (Fig. 3A) was less intensive, due to technical problems. An interesting observation was the nonappearance of tracer at the pond surface after injection of RWT, and its presence (verified visually) in the hypolimnion where it was rapidly moving downstream in the path dictated by the baffles, towards the outlet.

* 1 dunm = 1000 m³.
Microbiological Assays

The geometric mean concentration of indicator microorganisms in the influent was $1.6 \times 10^5$ cfu/100ml for the F.coliform, $4 \times 10^3$ cfu/100ml for the enterococci and $6.3 \times 10^2$ pfu/100ml for the F+ bacteriophages. The log reduction rates of the indicator microorganisms are summarized in Table 1. The average mean log$_{10}$ reduction of F.coliforms and enterococci (regardless of baffle number) was similar; 1.0±0.72 and 1.1±0.82, respectively. The average mean log$_{10}$ reduction of F+ bacteriophages was lower (0.82±0.27). Moreover, fluctuations in F+ bacteriophages reduction (as reflected in the Standard Deviation) were also lower than those observed for the bacterial indicators.
Table 1. Reduction of indicator microorganisms as a function of the baffle number.

<table>
<thead>
<tr>
<th>NUMBER OF BAFFLES</th>
<th>INDICATOR</th>
<th>MEAN LOG REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F. Coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td>1</td>
<td>-0.96 ± 0.32</td>
<td>-1.28 ± 0.47</td>
</tr>
<tr>
<td>2</td>
<td>-1.23 ± 0.53</td>
<td>-0.86 ± 0.32</td>
</tr>
<tr>
<td>4</td>
<td>-1.21 ± 0.42</td>
<td>-1.34 ± 0.50</td>
</tr>
<tr>
<td>Average</td>
<td>-1.0 ± 0.72</td>
<td>-1.1 ± 0.82</td>
</tr>
</tbody>
</table>

1 Standard Deviation
2 Mean log regardless of baffle number.

DISCUSSION

The installation of up to four baffles failed to improve the hydraulic flow characteristics, despite the fact that the baffles channeled the flow. These results might indicate that there is a factor limiting pond mixing and contributing to the existence of stratified flows.

It is possible that reports on the positive effect of baffle installation by other investigators (Middlebrooks et al., 1982; Killani and Ogunrombi, 1984) were limited to model SP that are not exposed to direct solar radiation and remain unstratified in contrast to full scale SP. The rapid appearance of a tracer peak points to short circuiting. Therefore the retention time of about 5% of the effluent was very short, i.e. this portion had very applied purification processes. It is clear that a mixture of 5% influent containing F. coli concentrations of 1.6x10⁸ cfu/100ml and 95% pond water with F. coli concentrations of 3.5x10⁴ cfu/100ml will have significantly high bacteriological (calculated value due to dilution - 4.1x10⁸ cfu/100ml) and BOD₅ values, as were actually detected (1.3x10⁴ cfu/100ml). The calculated mean retention time (2.5-4.5 days) was shorter than the theoretical one (5 days) but not to the extent that could allow the low removal efficiencies.

The hydraulic behavior, as seen in the tracer studies, bore small resemblance to the less complex flow models; the completely mixed flow (Marais, 1974) or the plug flow (Bowles et al., 1979). The more complex "Active and Dead Zone" proposed by Ferrara and Harley, (1981) produces a better description of the flow in this SP.

The removal of indicator microorganisms in the SP was of relatively low efficiency (about 1 log₁⁰), regardless of baffle installation, resulting in effluents containing average F. coli concentrations of 1.3x10⁴ cfu/100ml. This value is higher than WHO criterion for unlimited wastewater use in
Effect of baffle installation

The low removal efficiency of microorganisms was reflected by the rapid RWT peak at the outlet after some 15-20 hours as mentioned above. Microorganism reduction was probably attributable to dilution and/or sedimentation rather than to bacteriocidal activity due to elevated temperature, high pH and DO, sunlight, starvation etc. F+ bacteriophages were detected in all the samples and its concentrations in influent and effluent were surprisingly constant. The lower reduction rate of F+ bacteriophages is in agreement with the findings of Lijkelma et al. (1987), reflecting its increased resistance to environmental factors.

Strong thermal stratification may account for lack of improvement in hydraulic flow patterns and poor pond performance. The finding that the stratification may have been stable is in agreement with other reports (Marais, 1966). It could be hypothesized that the relatively cold influent sank to the bottom of the pond and rapidly moved in a confined flow pattern to the outlet. With an increasing number of baffles resulting in smaller surface area available for flow, the velocity of the confined flow increased with peaks appearing at similar times as the unbaffled pond, at the outlet (despite the fact that the traveling distance was longer). It can further be postulated that the lack of improvement in microbiological reduction was associated with bottom flow and minimal exposure to high levels of bacteriocidal factors such as light, pH, DO, and high temperature, found in the epilimnion.

CONCLUSIONS

1. The detention time of a small but meaningful portion of the influents in Sha'labims stabilization pond was very short.
2. Installation of up to four baffles did not improve pond hydraulic flow patterns nor the efficiency in removing microorganisms or the reduction of BODs.
3. Effluent quality remained lower than the recommended criteria, thus necessitating additional treatment in order to allow its unlimited use in agriculture.
4. F+ bacteriophage proved its potential promise as an indicator of fecal pollution of water.
5. The severe short circuiting, resulting in short retention time and low treatment efficiency may have been due to thermal stratification.

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