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Integrated Low-cost Wastewater Treatment for Reuse in Irrigation

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For sustainable wastewater management in developing countries, the implementation of low-cost, simple treatment systems should be encouraged. In this study, the performance of three treatment schemes was evaluated. The first step in all schemes was upflow anaerobic sludge blanket (UASB). The post treatment was either Algal Pond (AP). Lemna Pond (LP) or Rotating Biological Contactor (RBC). The results show that the performance of the UASB was satisfactory. Mean COD and BOD removal values were 78% and 85% respectively. The combination of UASB with an AP achieved significant improvement in the microbiological quality of the effluent. The geometric mean of fecal coliform in the effluent was 1.3×10^3 MPN/100ml. Residual COD was 143 mg O_2/L. This relatively high value was due to the presence of algae in the AP effluent. The use of the LP as a post treatment achieved better quality effluent. As indicated by the physico-chemical characteristics. However, fecal coliform removal was less by one log as compared to the AP effluent. When the RBC was used as a second stage. COD and BOD removal rates were 47% and 66% respectively. Also complete nitrification took place. Fecal coliform density declined by 5 logs.

INTRODUCTION

Increasing pressure on available fresh water resources in arid and semi-arid areas in the Middle East region creates continued interest in the use of marginal quality water. Consequently, treated wastewater is becoming an acceptable substitute for fresh water in irrigation and aquaculture. In applying the most appropriate technologies for water reclamation, cost factor as well as simplicity of the technological installations are important in assuring sustainability of the systems and allow multiple repetitions in the region.

Waste stabilization ponds are usually the method of choice in warm climates wherever land is available at reasonable cost (Mara, 1976; Arther, 1983). A series of ponds with a total retention time of 8-10 days can be designed to achieve adequate removal of heiminthic ova, but at least twice that time is usually required in a hot climate to reduce bacterial numbers to the guide-line level (Mara & Silva, 1986).

To reduce the pond area required a number of options has been investigated. Increasing pond depth is one approach. Research carried out by Oragui (1987) has shown that ponds 2-3 m deep can achieve degrees of bacterial and viral removal comparable uo those in ponds with conventional depth of 1-1.5 m. An alternative is to aerate the facultative pond (El-Gohary *et al.*, 1993). However, operational problems regularly occur due to the presence of high algal counts in the pond effluent. The third approach is to apply duckweed as macrophyte cover on the lagoon. Duckweed grows fast on nutrient-rich water in homogeneous single-layer blanket. It has been shown to be good fodder for fish, poultry and cattle (Haustein,

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Gilman and Skillicon, 1990; Skillicorn, Spira and Journey, 1993).

In many cases the required land for algal or macrophyte ponds is not available. Therefore, a combination of low-cost pre-treatment, such as anaerobic digestion, with an appropriate post-treatment represents the ideal solution for environmental protection in developing counteries.

Anaerobic digestion offers two advantages over the conventional aerobic treatment. The first is a reduction of the sludge produced and the second is energy conservation. Most of the reported experiments on anaerobic digestion of sewage have been carried out using UASB reactors. The UASB concept has been explained widely in the literature since the first experiments carried out in the Netherlands in 1976 (Lettinga *et al*., 1980; Lettinga *et al*., 1982; Man *et al*., 1986). Basically, the influent is distributed to the bottom of the reactor, passed through the bed of the sludge, and leaves the reactor from its upper part. During passage, suspended solids are entrapped and degraded. The biogas produced gives rise to a gentle mixing of the contents of the reactor, which promotes the contact of the substrate with the microorganisms. The main objective of this study was to assess the performance of an integrated low-cost treatment system for municipal wastewater reclamation.

MATERIALS AND METHODS

The pilot plant consisted of three treatment schemes. The first step in all schemes was a UASB reactor. The post-treatment was either an Algal Pond (AP), Lemna Pond (LP) or Rotating Biological Contactor (RBC). The effluent of the AP was used for fish culture. Fig. 1 is a block diagram of the pilot plant set-up. The pilot plant was fed continuously with municipal wastewater from the sewerage system. Dimensions and operating conditions of the treatment systems are given in Table 1.

The performance of the system was evaluated by monitoring the quality of the feed and effluent of treatment units. The analysis was performed on composite samples. All physico-chemical and microbiological examinations were carried out in accordance with the Standard Methods (1995). Examination of the presence of helminthic ova was carried out according to the method recommended by the WHO (1989). Algal types in the AP have been identified.

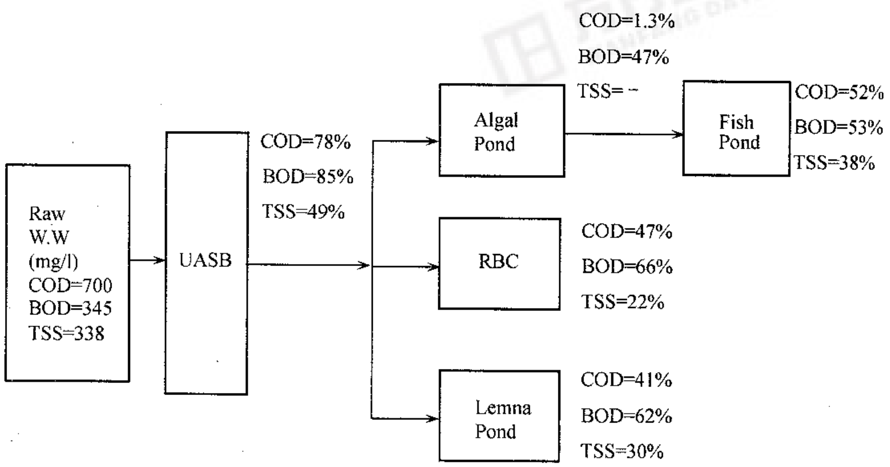

FIG. 1. Block diagram of the treatment units and their performance (% removal).

TABLE 1

Operational Parameters of the Treatment Schemes

Parameter	Unit	UASB	Algal Pond	Lemna Pond	RBC
Internal Diameter	cm	16	–	–	–
Depth	cm	240	20	20	11.5
Volume	litre	40	400	400	3.6
HRT	h	8	240	240	1.4
Initial Biomass	g/L	22	–	–	–

Sewage biodegradability was determined according to Zeeuw (1984). Sludge age was calculated according to the following Equation:

$$\text{Sludge Retention Time (SRT)} = \frac{\text{Solid Content in the Reactor}}{\text{TSS Leaving the Reactor/day}}.$$

To recommend the appropriate treatment scheme for Egyptian climatic and socio-economic conditions, the strength and weakness of each treatment configuration have been identified.

RESULTS AND DISCUSSION

Sewage Characteristics

Physico-chemical characteristics of raw sewage fed to the UASB Reactors were consistent with sewage above average strength. Average values of total chemical oxygen demand (COD) and biological oxygen demand (BOD) were 700 mgO_2/l and 345 mgO_2/l, respectively. The corresponding maximum values were 1281 mgO_2/l and 553 mgO_2/l.

The COD/BOD ratio was around (2.0) which is considered slightly higher than normal (1.5). This could be due to the high oil and grease content of the wastewater which ranged between 23.4 mg/l and 152 mg/l during the study period. Total suspended solids (TSS) ranged between 90 mg/l and 680 mg/l, with an average value of 338 mg/l. Mean concentrations of total nitrogen and total phosphorous were 40 mg N/l and 9 mg P/l, respectively (Fig. 2).

Bacteriological examination during the study period revealed a great variation in total and fecal coliforms density. Total coliforms ranged from 2×10^{10} to 1.3×10^{14} MPN/100 ml. Fecal coliforms counts ranged between 2×10^{7} and 5×10^{9} MPN/100 ml.

Examination of the presence of helminthic ova (Nematodes, Trematodes and Cestodes) indicated the presence of Ascaris spp. in almost all the samples examined. Ascaris ova ranged between 80 and 2500 ova/l. Ancylostoma spp. was also detected in 2 samples during the study period. Trematodes (Fasciola spp.) was observed only once with a concentration of 80 ova/l. Among Cestodes, Taenia spp. and Hymenolepis nana ova were identified. The biodegradability of the sewage was around 83%.

UASB Results

The performance of the UASB at 8 h HRT was quite satisfactory (Fig. 2). Total COD removal values ranged from 54% to 84% with an average value of 78%.

Corresponding mean residual value was 145 mgO_2/l. Average percentage removal values of BOD and TSS were 85% and 49%, respectively. Residual suspended solids concentration in the reactor effluent ranged from a minimum value of 10 mg/l up to a maximum value of 40 mg/l, with a mean value equivalent to 24 mg/l. Oil and grease concentrations, varied from 10 to 18 mg/l. Corresponding percentage removal values of oil and grease varied between 69% and 85% with an average value of 82%.

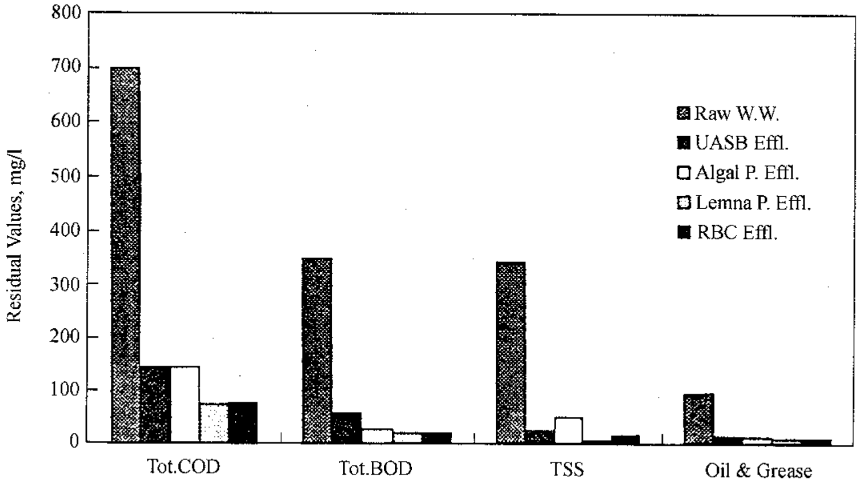

FIG. 2. Performance of wastewater treatment units.

Parasitological examination revealed the absence of almost all the helminthic ova in the UASB effluent Ascaris spp. was present in only one out of the 8 samples examined. This demonstrates the effectiveness of UASB reactor for parasitic ova removal. Results of the bacteriological examination of UASB effluent indicated that maximum reduction of fecal coliforms reached only one log.

Average concentration of volatile fatty acids (VFAs) was 25 mg/l. Mean percentage removal value was 43%. It is worth mentioning, however, that volatile fatty acid (VFA) concentrations in the reactor effluent depends greatly on the reactor efficiency, the higher the efficiency the lower the residual volatile fatty acid concentrations and the higher the pH values. Methane production was 0.22 m^3/kg COD removed. The effluent of the UASB reactor was fed to the three post-treatment units, namely, AP, LP and RBC.

Performance of the First Treatment Scheme

The first system configuration consisted of one-stage UASB reactor, followed by an AP the effluent of which was tested for aquiculture production. Available data indicated that when the AP was operated at an HRT of 3-5 days, no significant reduction in log counts for fecal and total coliforms had been observed. Raising the HRT up to 10 days achieved 99.99% reduction in fecal coliform density. Mean residual count was 1.3×10^3 MPN/100 ml. Soluble COD removal values oscillated between 10% and 58%. Corresponding values for BOD/sol. ranged from 47 to 76%.

Residual COD & BOD values in the Algal pond (AP) effluent averaged 143 and 26 mgO_2/l, respectively. Oil and grease percentage removal averaged 17%. Mean residual value was 11 mg/l. Average residual total phosphorous in the AP effluent was 3.9 mg/l. Algal community structure indicated that the dominant algal groups found in the algal pond and the effluent were chlorophyta (green algae), cyanophyta (blue green algae) and Bacillariophyta (diatoms).

The overall efficiency of the treatment system for carbonaceous matter removal is considered good. The average percentage removals of COD, BOD and Oil and grease were 76%, 92% and 85%, respectively. Removal of suspended solids was 69%. Residual ammonia concentration ranged from 0.0 mg/l to 6.0 mg/l. Average percentage removal of total phosphorus was 59%.

The fish pond was fed continuously with the effluent of the algal pond. Surface BOD loading applied to the fish pond fluctuated between 0.69 and 1.9g $BOD_{tot.}/m^2/d$. Fish pond achieved 52% removal of total COD and 53% removal of total BOD. The corresponding value of soluble BOD was 25%. Average residual values of total COD and total BOD were 68.5 and 22 mgO_2/l, respectively. Total suspended solids concentration was around 24 mg/l. Residual total ammonia concentration in the effluent was 7.2 mgN/l. The total phosphorus concentration was 4.9 mgP/l. Average fecal coliform density was 7×10^2 MPN/100 ml.

Tilapia nilotica (*Oreochromius niloticus*) in the algal pond effluent had no mortality or external lesions at 0.14 ppm un-ionized ammonia. At 0.46 ppm un-ionized ammonia, the mortality was 27.8%, and they were associated with skin ulcer and inflammation. After a 30-day stocking period at 0.33-0.4 ppm NH_3 there were extensive mucus cell proliferation and clumping of gill lamellae. Increasing the stocking period to 45 and 60 days resulted in severe hyperplasia and proliferation on the lamella. Fish stocked at 0.33-0.46 ppm NH_3 showed hepatocytes vacuolation in the liver congestion of the blood vessels and rupture of hepatocytes. Hematological parameters of Tilapia stocked at 0.45 ppm un-ionized ammonia and 0.22 ppm nitrite for 60 days showed a reduction in hemoglobin, hematocrit and erythrocytes count by 19%, 39% and 23%, respectively.

Performance of the Second Treatment Scheme

The second treatment scheme consisted of the UASB reactor followed by a LP. The HRT in the LP was similar to that in the AP (10 days). The removal efficiencies obtained by the LP are presented in Fig. 1. $COD_{tot.}$ and $COD_{sol.}$ removals ranged from 46% to 70% and from 36% to 56%, respectively. With regard to BOD, mean removal values were $BOD_{tot.}$ 62% and $BOD_{sol.}$ 69%. These values are higher than those obtained with the AP. On the other hand, bacteriological examination revealed lower quality as compared to the AP. Residual fecal coliform counts were around 3.1×10^4 MPN/100 ml (Fig. 3).

Performance of the Third Treatment Scheme

Part of the effluent of the UASB was introduced to the Rotating Biological Contactor (RBC). The hydraulic loading rate of this step was 0.063 $m^3/m^2\cdot d$. The organic loading rate (OLR) was dependent on the UASB effluent characteristics. Mean OLR applied to the RBC averaged 4.2 g $BOD_{tot.}/m^3/d$. The quality of the RBC-effluent confirms the effectiveness of RBC as a post-treatment technology for domestic wastewater. The results obtained indicate very effective elimination of carbonaceous matter as reflected in the removal values of BOD (66%) and COD (47%). Corresponding residual values were 18 mgO_2/l and 75 mgO_2/l, respectively.

Overall percentage removal values of COD, BOD and TSS were 83%, 94% and 71%, respectively. Fecal coliform declined by 5 logs. The geometric mean of the residual fecal coliform density averaged 2.8×10^3 MPN/100 ml.

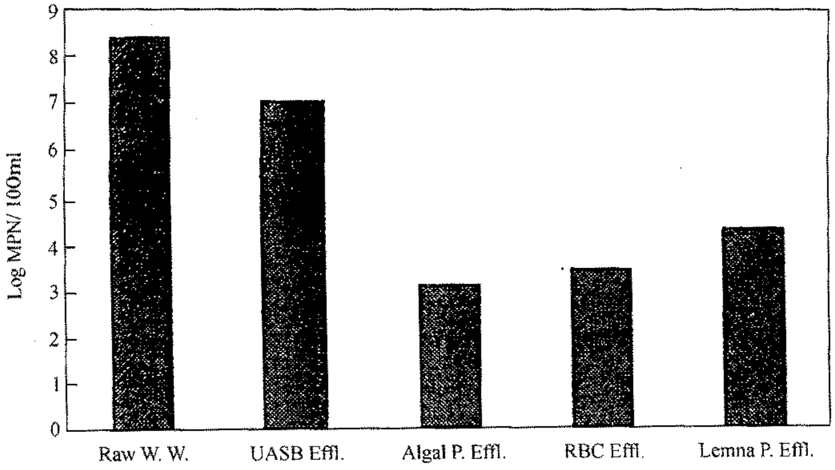

FIG. 3. Variation in fecal coliform density along the treatment units.

CONCLUSIONS

From these results, it may be concluded that the UASB reactor is an efficient process for the removal of organic material and suspended solids from municipal wastewater especially in regions with warm climate like Egypt. Also, the three treatment schemes gave satisfactory results. The choice of the treatment system depends on the environmental conditions, land availability, crop to be irrigated and the irrigation system.

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