APPROPRIATE TECHNOLOGIES FOR WASTEWATER TREATMENT AND REUSE IN THE RURAL AREAS OF THE MIDDLE EAST- CASE STUDY OF SUCCESSFUL REGIONAL COOPERATION

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ABSTRACT

As an initiative to catalyze the introduction and the implementation of appropriate and sustainable wastewater treatment solutions and to realize the benefits of reuse in rural areas, a collaborative project of Palestinian, Israeli and Egyptian organization was undertaken. For five years now, the partner teams have been investigating appropriate, low-cost, efficient, safe and replicable wastewater treatment and reuse for sustainable agriculture. At the heart of the project is the Sakhnin demonstration plant focusing on wastewater treatment and the irrigation pilot site in El-Sadat city, Egypt. Both pilot plants have been functioning successfully and innovatively during the last 4 years. Other major parts of the project include: the establishment of a full-scale wastewater treatment and irrigation system in Bany-Zaid, a small village in the west Bank (Palestine); A training program for municipalities and farmers on wastewater reuse; and the establishment of regional resource centers in Palestine, Israel and Egypt for knowledge exchange, providing information, and educational programs on wastewater issues.

The results indicate that the combination of extensive and semi intensive treatment systems is an efficient way for treatment and reuse of wastewater in rural areas. Specifically, it was found that the up flow anaerobic sludge blanket (UASB) bioreactor system can be a good alternative for anaerobic ponds, significantly reducing the required area with better performance. The effluent of the UASB can be fed directly to either intermittent sand filter (ISF), or constructed vertical or horizontal wetlands.

KEYWORDS: Anaerobic treatment; Extensive systems; Reuse; Rural areas; Wastewater

INTRODUCTION

Water scarcity and contamination of surface and ground water are major regional Middle East problems. Middle East is the driest region in the world with only 1% of the world's freshwater resources (World Bank, 1996). Water resources are also insufficient to meet rising demands due to dramatic increases in population and water consumption. A lack of natural resource planning and inadequate wastewater management in rural areas in the Middle East has resulted in the serious contamination of existing watersheds.

Wastewater management at all stages of handling is inadequate in rural areas. Poorly maintained or non-existent sewage systems, runoff from animal wastes, unregulated landfills with leachate that pollute aquifers, poorly maintained greenhouses, and increasingly, industrial effluents factor in to the wastewater and contamination problems. Untreated sewage in rural villages often flows freely into streets, agricultural fields, and wades, directly contaminating food and water, and directly contributing to a critical community and environmental health crisis. An increasing proportion of surface and ground water resources in the region is being polluted mainly due to inappropriate disposal of municipal wastewater and infiltration from poorly constructed and maintained on-site sanitation facilities (World Bank, 1996; UNEP, 1999).

Attempted transfers of urban intensive technology to rural areas in the region have failed; and there are currently almost zero wastewater treatment systems in the region which use appropriate extensive technologies or natural ecosystem regenerative functions. Rural communities also typically lack the technical and management capacity to solve the problem alone. In Israel, the inappropriate transfer of urban intensive technology through external top-down management to rural and semi-urban areas has failed (Kanaaneh and Ghattas 1991). No systematic attempt has been made to establish comprehensive and integrated programs for extensive wastewater treatment and reuse in rural areas (Ghattas and Sabbah, 1997). In addition, transporting the wastewater away from the generating community, several reuse opportunities can be lost.

The objective of this regional project is to establish low-cost, efficient, and replicable wastewater treatment and reuse systems in rural areas of the Middle East. The goal for the design and operation of the Sakhnin pilot plant is to implement a replicable, comprehensive model for appropriate technology for wastewater treatment and reuse in sustainable agriculture in rural areas in the Middle East. Based on land availability, population size, climatic conditions and socioeconomic considerations, the appropriate technology should be an extensive, reliable, simple, low-cost and low impact system. However, the classical combination of extensive treatment units (anaerobic ponds- facultative ponds-reservoir) results in high water losses due to the high evaporation rates in Mediterranean region and possible environmental nuisances (bad odors, flies etc). Therefore, it would be advantageous if 60%-80% of the BOD were removed by semi-intensive units with reduced land demand, before treatment by classical extensive units. Using either modified UASB reactor or Vertical bed with passive aeration followed by the more classical Wetland unit, Intermittent Sand Filter (ISF) and polishing reservoir, a reliable-low cost integrated system was planned.

MATERIALS AND METHODS

Sakhnin Pilot Plant (wastewater treatment)

The experimental pilot plant system in Sakhnin consists of up flow anaerobic sludge blanket (UASB) reactor, passively aerated vertical bed (PAVB), Intermittent Sand Filter (ISF), constructed wetland (CWL) and reservoir. In general the pilot plant was designed for maximum flexibility to allow for different wastewater treatment schemes.

UASB reactor. A modified version of the well known UASB, with a conical shape and no gas separator was used as a first step treatment unit after primary sedimentation (working volume of $7m^3$ and surface area of $8.6m^2$). This UASB type was designed, developed and implemented at many sites in Brazil for municipal wastewater treatment.

Passively aerated vertical beds (PAVB). Three vertical bed units were designed to include a passive aeration system achieved by a fill and draw operational sequence of the vertical bed (Green *et al.*, 1998). Each unit had a height of 2.2 m and a diameter of 2.4 m with an upper surface area of 4.5 m^2. The units were filled with two main layers of gravel: the active upper layer consisting of smaller size (Fig. 1). An aeration pipe supplying air to the process traverses the upper layer of media and connects the coarse media layer to the atmosphere. The influent was evenly distributed on top of the upper layer of the bed and drained at the bottom. An electrical valve actuated by a level switch governed the intermittent outflow. The units were filled with gravel whose particle size decreased with each sequential bed: 15 mm in the first VB, 6.5mm in the second and 3.5 mm for the third unit. The performance of one, two, or three units operating in series was studied. Previous results showed the importance of passive aeration for the units containing the two smaller size media units (6.5 and 3.5 mm) while in the larger size media particles unit (15 mm) the contribution of the passive air pump was negligible (Admon *et al.*, 2002).

Constructed Wetland (CWL). A 130 square meter horizontal subsurface flow constructed wetland with a width to length ratio of 3:1 and bed depth of 0.6m was used for polishing purposes. The media used was gravel with a mean diameter of 1.0 cm and void space of 0.45. A manifold with drip irrigation outlets was used for influent distribution. One meter wide inlet and the outlet zones were prepared with stones (5-10 cm) larger than the main media. The CWL was planted with *Phragmitis australis*. During the reported period the CWL operated at a daily organic loading of about 7.5 g BOD/m^2.

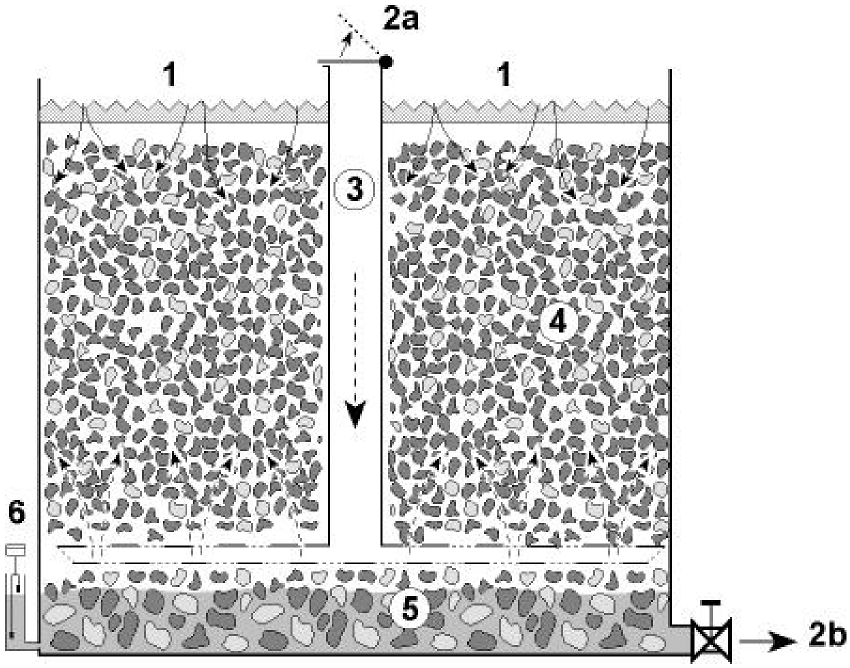

Fig. 1. Diagram of passively aerated vertical bed (PAVB). Downward arrows in the media show water flow and upward arrows show airflow. 1) Wastewater distribution weir 2) Electrical valves activated by level control: (a) air intake (b) water discharge. 3) Air intake pipe and bottom manifold. 4) Fine gravel layer. 5) Coarse gravel layer. 6) Level control.

Intermittent Sand Filter: A sand filter with a diameter of 2.5 m and height of 2 m was used at the Sakhnin pilot site. The filter media consisted of two main sand layers with particle size ranging from 0.4 to 1 mm. Two support layers of gravel were used in the bottom of the filter, while the drainage layer consisted of 20 cm of 40-60 mm rocks. The system included a gravity-dosing tank (0.5 m^3) set high enough to ensure dosing and uniform distribution throughout the system. Facultative pond effluents were pumped into the tank (reservoir) and were applied intermittently by a time controlled electrical valve. The distribution network was built from six 0.5-inch diameter PVC pipes with 4-6 orifices of 3 mm in each. To maintain good distribution of wastewater on the filter surface, an equal ratio between the number of orifices and the surface area of sand was considered.

Influent wastewater. Wastewater from the Sakhnin town after primary sedimentation was used as the influent for the treatment system. As is often the case in pilot scale operations, the control over the influent characteristics was limited. The result was very large variations in influent characteristics, both in COD and in suspended solids concentration. The average influent COD concentration was 1050±315 mg/l, varying between 300 and 1700 mg/l. The average influent TSS concentration was 257±90 mg/l and the average BOD was 562±180 mg/l. The temperature varied from as high as 30^{o}C during the summer to as low as 12^{o}C during the winter.

Sadat Pilot Plant (Reuse System)

The site in Egypt is located outside Sadat City adjacent to the City's 30,000-m3/day wastewater treatment facility. The systems essentially use natural treatment processes for polishing stabilization pond effluents and further treating that effluent with a constructed wetland. The constructed wetland cultivated with ***(Phragmited australis, Cyperus papyrus, Roushes SP, Typhe spp, Cana indica)***. A solar disinfection unit is also provided, allowing the final effluent exposure to the sun's ultraviolet radiation in a thin film over plastic liners before reuse. Thus the three water types used in the pilot plots are "wetland", "polishing pond" and "fresh" water for control.

The pilot site at Sadat City is divided into four equal quadrants. Each quadrant is planted in a variety of seven different species of non-food crops. Two diagonally opposing quadrants are irrigated with "wetland" water, one quarter with "polishing pond" effluent, and the last one with "fresh" water from a local groundwater supply. The plant species grown in the pilot sites are: ***pins sp, Jojopa, Khaya Senegalinsis, Cypres, Taxodium, Volkamarian, Cleopatra mandrin.***

RESULTS

UASB performance

During the first stage of the experiments the performance of the UASB unit as a stand-alone system was studied. The results show COD removal efficiencies of about 60% in summer (20°C – 27°C), and lower COD removals of between 20% and 40% during winter (12°C – 14°C). The deteriorating effect of low temperatures on UASB performance is a well known phenomenon which limits the implementation of this technology for domestic wastewater treatment to tropical countries (Lew *et al.*, 2003; Elmitwalli *et al.*, 2001; Lettinga *et al.*, 1981; Grin *et al.*, 1983; Vieira & Souza, 1986; Seghezzo *et al.*, 2000). However, recent results of the new constructed cylindrical UASB reactor indicate that the performance of this unit is more efficient that the conical shape reactor where removal of 70-80% of total COD in the summer and removal of 40-50% in the winter were observed (Sabbah et al., 2004).

PAVB performance

The performance of the passively aerated vertical bed (PAVB) was studied for the two following cases: 1) Pre-settled wastewater as the feeding solution and 2) UASB effluents as the feeding solution. In both cases the PAVB was operated continuously (active cycle) until clogging was observed. A subsequent rest period was initiated, during which no feeding was supplied and no water was recirculated through the bed, i.e., no passive aeration occurred. During the rest period the change in total available pore space was monitored and the subsequent feeding period started only when no further increase in available pore space was observed (Admon *et al.*, 2002).

Table 1 summarizes operational conditions and results from the PAVB operation with pre-settled wastewater (run 1-3) and UASB effluent (run 4) as the feeding solution to the PAVB. The most striking difference is the very long length of active cycle achieved (85 days) during run four, as compared to 18 - 25 days during runs one through three. This large difference cannot be explained by the two-fold difference in the HLR (9m/day in runs 1-3 vs. 4.5 m/day in run 4). The results show that in spite of the big difference in operational conditions and especially the difference in the active cycle length, the total TSS removed in each active cycle (till clogging) was quite similar, between 100 kg and 180 kg. In contrast, the total COD removed in each active cycle was very different, between 89 and 459 kg COD. Therefore, it seems that the TSS loading rate was the most influential parameter affecting the rate of bed clogging.

Table 1. PAVB operation: runs 1, 2 and 3 using pre-settled domestic wastewater. Run 4 using UASB effluent.

Parameter	Pre-settled wastewater Run 1	Pre-settled Wastewater Run 2	Pre-settled wastewater Run 3	UASB Effluent Run 4
HLR (m/d)	9	9	9	4.5
Days of active treatment	25	27	18	85
Days of regeneration	50	50	50	23
Influent COD_t (mg/l)	536	333	828	525
Influent TSS (mg/l)	240	320	416	124
CODt loading rate ($g/m^2/d$)[a]	5146	3197	7949	2520
TSS loading rate ($g/m^2/d$)[a]	2304	3072	3994	595
Total COD_t introduced (kg)	579	388	644	964
Total TSS (VSS) introduced (kg)	259 (163)	373 (190)	323 (224)	295 (171)
COD_t removed (mg/l)	260	76	148	250
COD_t removal rate ($g/m^2/d$)[b]	832	256	376	944
Total COD_t removed (kg)	281	89	115	459
TSS (VSS) removal rate ($g/m^2/d$)[b]	288 (NA)	NA	590 (252)	246 (185)
Total TSS (VSS) removed (kg)	100 (NA)	NA	180 (77)	119 (90)

[a] - calculated only for the active period, does not include the rest period days

[b] - including the active and rest periods

The overall COD removal rate was calculated, taking into account the following rest period for each cycle. The COD removal rates were 832, 256, 376 and 944 g COD/m^2/d for runs 1,2,3 and 4, respectively. The higher removal rate calculated for run 4 was the result of the high ratio of active to rest periods, made possible by the relatively low TSS loading rate. The low TSS content in run 4 was mainly a result of TSS entrapment in the UASB reactor. The results clearly show the advantage of using UASB effluent as the feed water to the PAVB as opposed to using wastewater after primary sedimentation with high TSS and COD concentrations, typical to rural areas in the Middle East.

Combined UASB and VB performance

Based on the results an integrated system consisting of a UASB reactor followed by two sequential PAVB and horizontal flow wetlands (CWL) was operated in order to achieve the required effluent qualities during the whole year. In addition, a second scheme based on the UASB unit and three sequential PAVB with decreasing gravel size (no CWL) was also tested. Similar COD, BOD and TSS results were observed in both schemes of the combined system and the average values for each system component are given in Fig. 2.

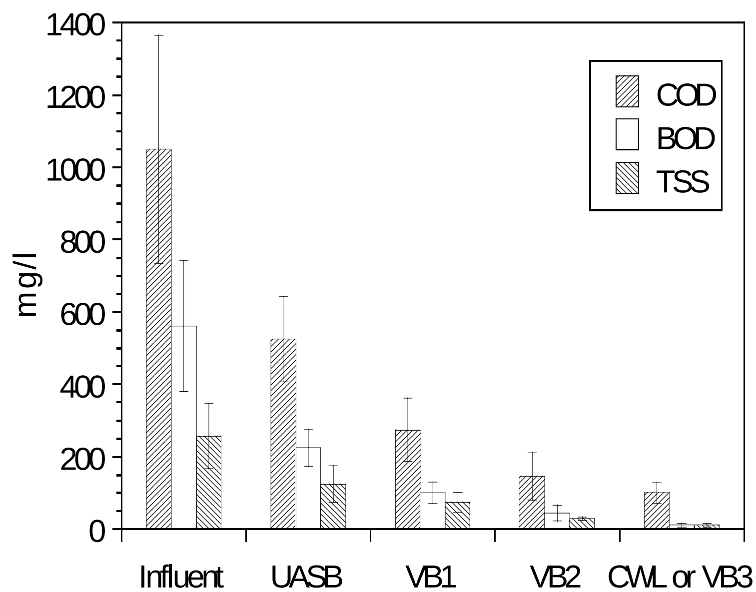

Fig. 2. Yearly average system performance.

The yearly average COD, BOD and TSS removal efficiencies were higher than 90% with effluent BOD and TSS concentrations always less than 20 mg/l. The average effluent concentrations of the combined system contained 100±29 mg/l COD, 11±5 mg/l BOD and 11±7 mg/l TSS.

While the organic and TSS removal efficiencies were similar in the two schemes of the combined system, the total surface area was very different. In the first scheme (CWL as last stage) the system total area was 150 m^2 while in the second scheme (3 sequential VB and no CWL) the total area was only 22.5 m^2. In both cases the system treated 22 m^3 per day. It should be emphasized that even the higher surface area in the first scheme is still much smaller than that of classical extensive systems based on ponds and had only minor impact on the resulted water produced (assuming evaporation rates of 5 to 10 mm per day, the expected water loss is 3 to 7%).

The ability of the combined system to deal with nitrogen compounds transformations and removal was studied as well. Reduction of about 50% in ammonium concentration due to oxidation to nitrate was observed in the second PAVB as opposed to negligible nitrification in the preceding units. This can be explained by reduced heterotroph competition due to favorable C/N ratio for nitrification. The typical anaerobic conditions prevailing in the subsurface flow CWL in the first scheme prevented further nitrification in this unit, and facilitated almost complete denitrification. In contrast, in the second scheme, the aerobic conditions in the third PAVB allowed for almost complete ammonium oxidation while no denitrification activity was detected. This alternative can be used when ammonium toxicity and oxygen demand are of major concern. For cases when complete nitrogen compound removal is required, a subsurface flow CWL unit can be incorporated in the scheme with effluent recirculation.

Combined Facultative Pond and Intermittent Sand Filter (ISF)
The filter was operated at different hydraulic and organic loads and different dosing rate regimes (see Table 2):

Table 2. Operational Parameters

Run	Operation time (Months)	Number of doses	Hydraulic loading $m^3/m^2/day$	Organic loading $gBOD/m^2/day$	Rest period (Weeks)
1*	2	2	0.14-0.2	28 ± 5	8**
2	4	5	0.1	41 ± 10	4
3	2	10	0.1	28 ± 4	2
4	1	10	0.1	27 ± 13	6
5	1	10	0.1	30 ± 7	***
6	4	10/3	0.1	20 ± 5	

*Start-up period

**Forced rest period due to a failure in the system

*** Clogging due to electrical problems

Sabbah et al. (2003), reported high removal efficiency of around 90% that was observed for organics, ammonium and TSS at hydraulic loading of 0.11-0.2 $m^3/m^2/day$ and organic loading of 20-40 $gBOD/m^2/day$. These loads are relevant to 5-10 persons/day or 2-4 persons/m^2 of ISF required. This study shows that 2-4 weeks of rest period had no effect on the removal efficiency in subsequent runs. However, a rest period of more than 30 days was found to negatively affect removal efficiency and then several weeks were required for full recovery of the microbial population. High nitrifying bacterial activity was observed, probably due to the relatively hot weather. Reducing the daily number of doses from 10 to 3 resulted in a 20-30% reduction in the removal efficiency of the ISF. The application of mechanically controlled accessories, such as a siphon, may be more appropriate and reliable in small systems.

Sadat Pilot Plant (Reuse pilot)

Effect of reclaimed wastewater reuse on clogging. The clogging was relatively higher when using polishing pond effluent than wetland effluent. There is considerable scope for reducing the undesirable effects of wastewater use in irrigation through appropriate selection of irrigation methods. Bubbler and sprinkler systems are more susceptible to clogging due to water quality than surface irrigation systems, primarily as a result of the clogging of orifices in sprinkler heads and bubblers, potential leaf burns and phyto-toxicity when water is saline and contains excessive toxic elements. (WHO, 1989). When using gated pipes there was no change in discharge during the growing season.

Effect of the wetland aquatic plant on uptake of heavy metals. Plant samples were collected from the constructed gravel wetland to represent the best growing species, i.e. Cattails, Papyrus and Reed. Two sets of plant samples were collected and analyzed. Plant samples were kept in paper bags then dried and sent for analyses with special reference to heavy metal content, after 21 months growing season
Table 3 shows the heavy metal contents of biomass produced in the gravel-constructed wetland at the two dates of sampling. In both cases Cattails and papyrus produced more biomass than Reeds. However Reeds remove more heavy metals than both Cattails and papyrus, but produce less biomass. The absolute removal then was greater using Cattails and Papyrus than the absolute removal using Reed. The important observation in Table 3 is that Reed is removing more cadmium than the Cattails and Papyrus.

Table 3: Concentration of some Heavy metals (mg/L) in some cultivated water reeds in the gravel constructed wetland.

Pollutants	Cattails	Papyrus	Reed
Co	1.4	1.5	0.95
Pb	ND	ND	ND
Cd	ND	0.7	0.85
Zn	19.5	26.6	31.5
Cu	7.5	10.1	18
Fe	189.5	424.5	337.5
Mn	219	187.5	185.4

CONCLUSIONS

The combination of extensive and semi intensive treatment systems is an efficient way to treatm and reuse wastewater in rural areas. Specifically, it was found that the up flow anaerobic sludge blanket (UASB) bioreactor system can be a good alternative for anaerobic ponds, significantly reducing the required area with better performance. The effluent of the UASB can be fed directly to either passively aerated vertical bed (PAVB), intermittent sand filter (ISF) or constructed wetlands.

This combined system of UASB and PAVB was found to significantly reduce land requirement, minimize water loss and avoid increased effluent salt concentration. The units are characterized by simple, low cost operation and maintenance with minimal energy input since oxygen supply is not required for the removal of both organic matter and nitrification. The combination of the different units ensures year round stable effluent quality in the semi arid climate typical to the Middle East.

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