#36

Hybrid Wastewater Treatment System Using Anaerobic Microorganisms and Reed (*Phragmites communis*)[1]

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A small hybrid wastewater treatment system consisting of a settling tank in series with an anaerobic filter-reed (Phragmites communis) *treatment cell was evaluated and compared with a similar plant-free system. Data demonstrated that by combining anaerobic filters, also referred to as attached film filters, and vascular aquatic plants a synergistic effect is produced which increases the treatment efficiency of each individual system. The plant-free system reduced the BOD_5 from 114 to 31 mg/l in 6 h as compared to a reduction of 110 to 9 mg/l in the anaerobic filter-reed system in the same length of time. The BOD_5 and TSS after 24 h in each component of plant-free system were reduced from 114 mg/l to 14 mg/l and 51 to 15 mg/l, respectively. Under the same conditions, the hybrid system reduced the BOD_5 from 110 to 3 mg/l and the TSS from 68 to 6 mg/l. The hybrid system also reduced the total Kjeldahl nitrogen (TKN) from 16.1 to 2.9 mg/l, total phosphorus (TP) from 4.4 to 2.0 mg/l, and the ammonia (NH_3-N) from 12.4 to 0.6 mg/l after 24 h of exposure while the plant-free system demonstrated insignificant reduction of these components.*

The most important recent wastewater regulation by the United States Environmental Protection Agency (EPA) requires secondary treatment as the minimum acceptable level of treatment prior to surface water discharge. This, combined with increased industrial waste discharged into domestic sewers, has increased significantly the need for improved wastewater treatment methods to meet the secondary standards as well as the removal of hazardous chemicals in many areas.

In many locations where the available supply of fresh groundwater has become contaminated with toxic chemicals or inadequate rainfall has drastically lowered the groundwater table, advanced wastewater treatment and reuse of wastewater will be a necessity in the near future.

Because of these increasing demands to improve wastewater treatment methods, innovative wastewater treatment technology must be developed. The present economic conditions in the United States also dictate that this technology must be less energy intense, cost effective and more efficient than present wastewater treatment methods.

The separate uses of anaerobic microorganisms and vascular aquatic plants have been evaluated during the past 15 yr and show promise as alternate wastewater treatment methods. Water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub.) in wastewater treatment has been researched and studied extensively both in the laboratory and field applications (Boyd, 1970; Cornwell et al., 1977; Duffer and Moyer, 1978; Dunigan et al., 1975; McDonald and Wolverton, 1980; Ornes

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and Sutton, 1975; Rogers and Davis, 1972; Sheffield, 1967; Stephenson et al., 1980; Stewart, 1970; Wolverton et al., 1976). This plant has been successfully used in wastewater treatment in the south and southwestern United States (Dinges, 1978; Wolverton, 1979; Wolverton and McDonald, 1979).

The anaerobic filter concept for treating domestic wastewater was first demonstrated by Young and McCarty (1969). Since that time the development of this technology for both energy production and wastewater treatment has developed rapidly (Koon et al., 1979; Switzenbaum and Jewell, 1978; Wolverton and McDonald, 1981).

Research conducted at NASA's National Space Technology Laboratories (NSTL) in Mississippi during the past several years has led to the development of a simplified natural biological process which promises to be a major technological contribution to wastewater treatment and water recycling. This process is made up of a combination of the oldest of wastewater treatment technology (septic tanks and trickling filters) and the latest development in anaerobic filter and vascular aquatic plant wastewater treatment technology.

Instead of floating vegetation, this system uses a rooted vascular aquatic plant—the reed *Phragmites communis* Trin. This common reed, whose ability to purify wastewater has been well established (DeJong, 1976; Seidel, 1976), grows throughout the world and is the most widespread of the emergent aquatic plants (Sculthorpe, 1967). It can tolerate a pH range of 2.8–8.5 and prefers salinities below 10 ppt, but can tolerate up to 40 ppt for short periods (Haslam, 1972; Nikolajevskij, 1971; Philipp and Brown, 1965). The nitrogen removal potential of reed is 330–800 and 350–850 kg/ha for above and below ground mass, respectively; the phosphorus removal is 10–80 and 38–74 kg/ha, respectively (DeJong, 1976; Dykyjova and Hradecka, 1976; Dykyjova, 1978; Gallagher and Plumley, 1979; Kvet, 1973; Mason and Bryant, 1975; Mochnacka-Lawacz, 1974; Nikolajevskij, 1971; Stake, 1968; Zdanowski et al., 1978). Biomass production reported for reed in the United States ranges from 6,540–39,990 kg/ha (Westlake, 1963). Combined above- and below-ground production in hydroponic culture ranges from 8,230–74,010 kg/ha/yr in 1–3-yr-old cultures (Dykyjova, 1971; Dykyjova and Veber, 1978).

Data from this new hybrid system using the common reed and rock filters are presented in this paper.

DESCRIPTION OF EXPERIMENTAL SYSTEMS

The experimental systems shown in Fig. 1 consisted of plastic-covered containers with 113-l capacities, which were used as anaerobic settling tanks for receiving raw sewage. In each experiment, 87 l of raw sewage was collected in the settling tanks. After the raw sewage settled 24 h, it was pumped into metal troughs, 50.5 cm wide, 30.5 cm deep and 298 cm long, filled to 16 cm with 2.5–7.5 cm diameter railroad rocks with a top layer, 5 cm deep, of 0.25–1.3 cm diameter pea gravel. One trough was free of plants and another trough contained reeds (*Phragmites communis*) which were grown on the surface of the rock filter. The wastewater retention time in the troughs was 24 h.

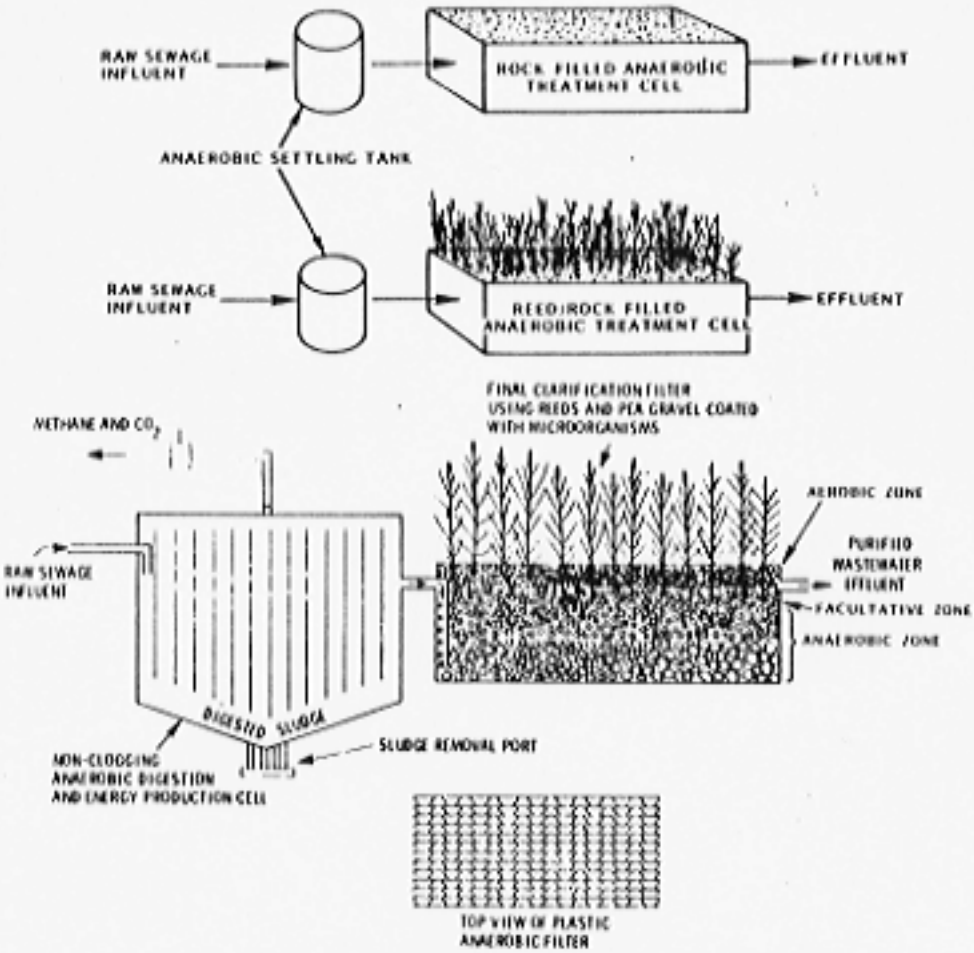

Fig. 1–2. Fig. 1. Experimental wastewater treatment systems using anaerobic microorganisms and reed (*Phragmites communis*). Fig. 2. Anaerobic filter-vascular aquatic plant wastewater treatment system.

SAMPLING AND ANALYSIS

Raw sewage for all experiments was obtained from NSTL Sewage Lagoon #1 influent. The raw sewage was pumped directly into the settling tanks and transported back to the laboratory. Initial samples were removed from the settling tank at the laboratory. The delay of approximately 30 min prior to sample collection for analysis caused the initial data to be low. Analyses were performed according to *Standard Methods* (American Public Health Assn., 1971). The 5-day biochemical oxygen demand (BOD_5) was determined on all samples. Total suspended solids (TSS) were determined on all samples except those after 6 h in the anaerobic filter. Total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP) were determined on initial and final samples.

The initial and final liquid volumes were measured to calculate evaporation and

TABLE 1. BOD_5 AND TSS DATA FOR RAW SEWAGE TREATED FOR 24 H IN ANAEROBIC SETTLING TANK (STEP 1), FOLLOWED BY 6 (STEP 2) AND 24 (STEP 3) H IN ROCK FILTERS WITH AND WITHOUT REED.

		Concentration, mg/l							
		Initial		1		2		3	
Parameter	Anaerobic filter	Av	σ	Av	σ	Av	σ	Av	σ
BOD_5	Without reed	114	24	81	29	31	15	14	6
	With reed	110	34	72	23	9	6	3	2
TSS	Without reed	51	18	27	10	*	*	15	8
	With reed	68	35	36	20	*	*	6	5

* TSS analyses not performed at this point.

evapotranspiration rates from the plant-free filter and the rock-reed filter, respectively. Minimum and maximum daily greenhouse temperatures averaged 19° and 35°C, respectively.

RESULTS

The raw data for BOD_5 and TSS of the plant-free anaerobic filter system are presented in Table 1. The average of the 10 experiments performed demonstrated that a plain anaerobic filter in series with a settling tank can reduce the BOD_5 from 114 to 14 mg/l and the TSS from 51 to 15 mg/l in a total of 48 h. The primary settling tank is effective for TSS removal for secondary treatment. However, a BOD_5 of 81 mg/l still far exceeds the 30 mg/l EPA maximum discharge requirements. The anaerobic filter was far more efficient for BOD_5 removal due to the increased surface area for microbial growth.

The hybrid system was the same as the previous system except for the addition of reeds to the anaerobic filter. The settling tank for this system showed approximately the same efficiency for BOD_5 and TSS removal as the one for the plant-free system as seen in Table 1. The hybrid anaerobic system reduced the BOD_5 from 110 to 3 mg/l and the TSS from 68 to 6 mg/l in a total of 48 h. However, a 24 h retention time is not needed with the hybrid system. A 6-h sampling of this filter showed that the BOD_5 had already been reduced to 9 mg/l, and all the data were well under the 30 mg/l maximum. A direct comparison of the average BOD_5 and TSS of both systems can be seen in Fig. 3 and 4, respectively.

The hybrid system was also superior for nutrient removal. The plant-free system data in Table 2 show that this system reduced the TKN from 15.4 to 13.6 mg/l, the NH_3-N from 12.6 to 11.6 mg/l, and the TP from 5.8 to 5.3 mg/l after 24 h in each component. The average data are presented in bar graph form in Fig. 5. The hybrid system with reeds reduced the TKN from 16.1 to 2.9 mg/l, the NH_3-N from 12.4 to 0.6 mg/l, and the TP from 4.4 to 2.0 mg/l as shown in Table 2. The mean data are presented in Fig. 6. The data for the hybrid system meets tertiary nutrient standards of 3 mg/l for nitrogen and almost the requirement of 1 mg/l for phosphorus.

The average evaporation loss from the plant-free filter was 6.3 $l/m^2 \cdot d$. The evapotranspiration rate for the reed-rock filter was 11.3 $l/m^2 \cdot d$.

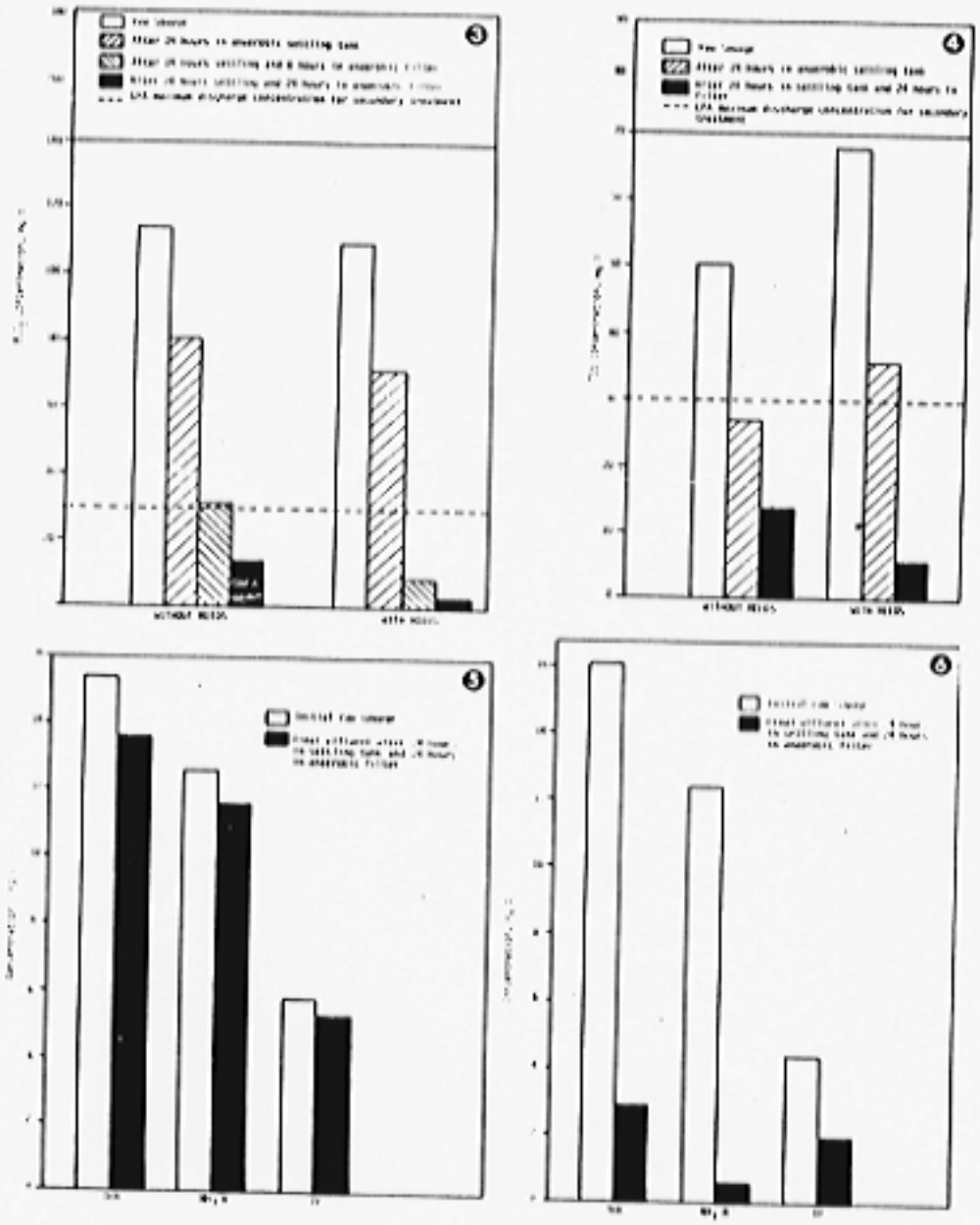

Fig. 3–6. Fig. 3. HOD_5 of raw sewage after 24 h settling and 6- and 24-h exposure to anaerobic filters with and without reeds. Fig. 4. TSS of raw sewage after 24 h settling and 24 h in anaerobic filters with and without reeds. Fig. 5. TKN, NH_3-N, and TP of initial raw sewage and the final effluent after 24 h in anaerobic settling tank and 24 h in plant-free rock filter. Fig. 6. TKN, NH_3-N, and TP of initial raw sewage and the final effluent after 24 h in anaerobic settling tank and 24 h in reed-rock filter.

TABLE 2. TKN, NH_3-N, AND TP DATA FOR INITIAL RAW SEWAGE AND FINAL EFFLUENT AFTER 24 H IN ANAEROBIC SETTLING TANKS AND 24 H IN ROCK FILTERS WITH AND WITHOUT REEDS (DESIGNATED AS STEP 3).

Parameter	Anaerobic filter	Concentration, mg/l			
		Initial		Step 3	
		Av	σ	Av	σ
TKN	Without reed	15.4	7.0	13.6	5.7
	With reed	16.1	5.3	2.9	1.8
NH_3-N	Without reed	12.6	5.2	11.6	3.2
	With reed	12.4	4.8	0.6	0.6
TP	Without reed	5.8	1.6	5.3	1.4
	With reed	4.4	1.2	2.0	0.6

DISCUSSION

The wastewater treatment system discussed in this paper is made up of 2 major components: component 1 is a sludge collecting and digesting chamber which may consist of a simple septic tank, a covered anaerobic lagoon or a high surface area anaerobic digester as shown in Fig. 2; component 2 is a hybrid anaerobic filter containing attached microbial filters and vascular aquatic plants. Rocks or vinyl core media can be used for the bottom microbial filter with pea gravel or related material used on top to support the vascular aquatic plants (reeds, etc.). Vinyl core media have been used for 20 yr for trickling filter type media and can be obtained commercially. They contain up to 214 m^2 of surface area per cubic meter of media. This is approximately four times that of a rock filter. Rocks create a 40–50% void while vinyl core media can create up to a 97% void. Vinyl is also lightweight and easier to transport and install. However, vinyl presently costs more per system than rocks in most parts of the country.

Wastewater from the anaerobic settling tank flows into the bottom of the filter cell then upward to near the top during the treatment process. The lower anaerobic portion of the filter continues the conversion of complex organics which started in the settling tank. The major gaseous end products of anaerobic digestion are carbon dioxide and methane. Complex organics are broken down into simpler compounds which can be assimilated by the reeds. Odorous volatile sulfides produced during anaerobic digestion are either removed by the plants or converted to nonvolatile sulfates by aerobic microorganisms near the surface of the filter cell, thus clarifying the final effluent and completing the treatment process.

This system promises to be cost effective in both installation and operation and more versatile than present systems. It can be installed in modules with additional units added in series when required for expansion or advanced wastewater treatment. This concept also has potential as a lightweight, compact system for wastewater treatment in space stations.

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