

# Treatability of Recreational Vehicle Wastewater in Septic Systems at Highway Rest Areas

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## ABSTRACT

Recreational vehicle (RV) owners commonly use chemical toilet additives containing formaldehyde to minimize odors from their wastewater holding tanks. The purpose of this study is to determine the character and treatability of this wastewater using conventional septic tank-drainfield systems at highway rest areas. RV wastewater is a high-strength waste. Mean concentrations from 72 samples are 5-day biochemical oxygen demand (BOD<sub>5</sub>) 3110 mg per liter, chemical oxygen demand (COD) 8230 mg per liter, total suspended solids (TSS) 3120 mg per liter, and volatile suspended solids (VSS) 2640 mg per liter, with a formaldehyde concentration of 170 mg per liter. The average volume per vehicle is 62 liters. Because RV wastewater is highly concentrated, sludge and scum accumulation and pumpout interval should be considered in addition to hydraulic residence time when sizing septic tanks for RV waste. A model for sludge and scum accumulation is developed based on the concept that some organic material in sludge and scum is readily degradable and compactible, some is degradable and compactible with extended residence time, and some material is inert and not compactible.

Recreational vehicles (RVs) including campers, trailers, motor homes, and fifth wheelers have become popular as a means of transportation and shelter for people on vacations and weekend trips. During the summer, about 16 percent of the traffic using Interstate highway rest areas in Washington is composed of RVs.

Many RVs have built-in toilets and holding tanks. It is common practice to empty the holding tank after a few days on a long trip or at the end of a short trip. RV holding tank disposal stations are provided at some private and public campgrounds, some service stations, and, in some states, at selected highway rest areas.

Many people use additives in their holding tanks to minimize odors and to prevent clogging of their drain lines. Common commercial additives for RV holding tanks contain formaldehyde or pH buffers or enzymes. Formaldehyde inhibits biological degradation, thereby preventing the formation of odorous compounds. pH buffers prevent odors by maintaining the solution pH in a range where most odorous volatile compounds dissociate into ionic, nonvolatile species. Enzymes are used to increase the rate of biological degradation in order to liquefy solids and prevent clogging. Other ingredients in commercial RV additives include surfactants, dyes, and perfumes. Some people add other chemicals, usually soaps and surfactants, to their holding tanks instead of commercial preparations.

Common sewage treatment systems for RV wastewater include septic tank-drainfield systems, sewage lagoons, and activated sludge treatment plants. A few sites have holding tanks, and the waste is transported elsewhere for treatment. Some operators of RV disposal stations report that the chemicals in the additives upset their system. Others report that this high-strength waste overloads their system (1).

## PROCEDURE

Wastewater from 72 recreational vehicles was collected and sampled at RV dump stations in western Washington to determine average values for volume, composition of waste, and formaldehyde concentration. Fifty-three vehicles were sampled at the Sea-Tac Rest Area on Northbound Interstate 5 near Tacoma, Washington. Fourteen vehicles were sampled at the Silver Lake Rest Area on Southbound Interstate 5 near Everett, Washington. Five vehicles were sampled at the Thousand Trails Campground near LaConner, Washington.

The RV owners usually discharge their holding tanks through a 10.2-cm diameter flexible plastic hose that is connected to the holding tank outlet. To collect waste as it was being dumped, a second hose was coupled to the owner's hose and connected to a heavy-duty, kitchen-style garbage disposal. The outlet of the disposal was connected with tygon tubing to a 19-liter-per-minute positive displacement, Vanton Flexiliner pump. The pump discharged into a 210-liter barrel.

All black (toilet waste) and gray (washwater) water that the owner wished to dump, as well as any water that the owner used to rinse the holding tank and hose, was collected in the barrel. Thus, the sample had about the same composition as the water that the owner would typically discharge at an RV dump station. The volume of total wastewater and rinse water was measured, and a sample was put on ice and brought back to the laboratory. In the laboratory, a volume-proportional composite sample was created from between 1 and 6 individual samples.

Septic tank water samples were collected from the RV disposal septic tank systems at Wenberg State Park in Snohomish County and Dash Point State Park in King County. Drainfield water samples at Wenberg were obtained through a lysimeter plate, which was buried in the drainfield soil about 30 cm horizontally away from, and about 15 cm below the bottom of, a gravel-filled trench. At Dash Point, a hole about 90 cm deep was dug about 30 cm away from a gravel-filled drainfield trench. Septic tank water was allowed to seep out of the saturated soil and collect in the hole.

Water samples were put on ice and brought to the laboratory where they were stored at 5°C until analyzed. They were analyzed for total and volatile suspended solids, total and soluble chemical oxygen demand, and total 5-day biochemical oxygen demand using Standard Methods (2). Soluble COD samples were obtained by filtering the wastewater through 0.45 micron membrane filters. Samples filtered through 0.45 micron filters also were analyzed for formalde-

hyde using the chromotropic acid method (3). Sludge and scum samples were taken from the Wenberg septic tank and analyzed for total and volatile solids concentration.

To determine potential toxic effects of formaldehyde on anaerobic bacterial cultures, anaerobic toxicity assays (ATAs) were conducted (4). A mesophilic anaerobic culture was maintained in an incubator at 34°C. The culture was daily fed 660 mg per liter of COD (acetate and propionate) and 8 mg per liter of formaldehyde. The ATA was conducted in 250-ml serum bottles. Forty-eight ml of anaerobic culture and nutrient media and a dose of formaldehyde were put into a serum bottle and spiked with 2.0 ml of organic feed consisting of 75.0 mg acetate and 26.5 mg propionate. The bottles were sealed with serum caps and placed in an incubator at 34°C. Gas production was measured periodically using glass syringes with 20-gauge needles. Average cumulative gas production for several replicates was plotted, and toxicity was indicated if test bottles had significantly less gas production than controls, which contained all the same ingredients but no formaldehyde.

## RESULTS

A summary of the analytical results for RV wastewater characterization is given in Table 1. Analytical results for septic tank water samples are given in Table 2 and results from the drainfield water samples are given in Table 3.

TABLE 1 Average RV Wastewater Characteristics

Number of Samples	72
Volume, liters	62 ± 10 <sup>a</sup>
standard deviation <sup>b</sup>	43
Total Suspended Solids, mg l <sup>-1</sup>	3120 ± 490
standard deviation	2120
Volatile Suspended Solids, mg l <sup>-1</sup>	2460 ± 410
standard deviation	1780
Total COD, mg l <sup>-1</sup>	8230 ± 1430
standard deviation	6140
Soluble COD, mg l <sup>-1</sup>	2930 ± 560
standard deviation	2350
Total BOD <sub>5</sub> , mg l <sup>-1</sup>	3110 ± 530
standard deviation	2200
Formaldehyde mg l <sup>-1</sup>	
All RV Users	170 ± 60
standard deviation	250
Formaldehyde Additive Users Only	250 ± 60
standard deviation	180

Note: mg l<sup>-1</sup> = milligrams per liter.

<sup>a</sup>Ranges given are the error of the mean value at a 95% confidence level.

<sup>b</sup>Standard deviation for individual RV samples.

Wenberg septic tank sludge total solids concentration was 8.5 percent and volatile solids concentration was 5.3 percent; scum total solids concentration was 19.1 percent and volatile solids concentration was 13.1 percent. Results for the anaerobic toxicity assays for formaldehyde-dosed cultures are shown in Figure 1.

TABLE 2 Septic Tank Water Analytical Results—Wenberg State Park Septic Tank

11- 9-80	Compartment #1	Compartment #2	Compartment #3
Scum, cm	46	0	—
Sludge, cm	30	30	—
Total COD, mg l <sup>-1</sup>	1620	—	—
3-10-81			
Scum, cm	38	0	—
Sludge, cm	20 to 36	15	—
Total COD, mg l <sup>-1</sup>	5360	2500	—
Soluble COD, mg l <sup>-1</sup>	3290	1850	—
TSS, mg l <sup>-1</sup>	700	80	—
VSS, mg l <sup>-1</sup>	550	70	—
Temperature, °C	12	12	—
pH	6.9	7.05	—
Formaldehyde, mg l <sup>-1</sup>	5	5	—
8-20-81			
Scum, cm	58	0	0
Sludge, cm	30	25	18
Total COD, mg l <sup>-1</sup>	3180	2870	2870
Soluble COD, mg l <sup>-1</sup>	1900	1980	1820
BOD <sub>5</sub> , mg l <sup>-1</sup>	1780	1490	1430
TSS, mg l <sup>-1</sup>	460	170	170
VSS, mg l <sup>-1</sup>	410	140	150
Formaldehyde, mg l <sup>-1</sup>	5.5	6.8	8.7
9- 9-81			
Dash Point State Park Distribution Box			
Total COD, mg l <sup>-1</sup>	2310		
BOD <sub>5</sub> , mg l <sup>-1</sup>	1360		
TSS, mg l <sup>-1</sup>	300		
VSS, mg l <sup>-1</sup>	240		
Formaldehyde, mg l <sup>-1</sup>	9.2		

Note: mg l<sup>-1</sup> = milligrams per liter.

<sup>a</sup>Septic tank had three compartments in series with volumes of 3780, 2530, and 1250 liters, respectively.

TABLE 3 Drainfield Water Analytical Results

	Dash Point 9-9-81	Wenberg 9-14-81
Total COD, mg per liter	1,880.0	1,240.0
Soluble COD, mg per liter	—	870.0
BOD <sub>5</sub> , mg per liter	910.0	460.0
Formaldehyde, mg per liter	6.0	4.8

## DISCUSSION

### Wastewater Characteristics

The data in Table 1 indicate that RV wastewater is a very high-strength waste with a BOD<sub>5</sub> of 3110 mg per liter and a TSS of 3120 mg per liter. Variability in waste strength among vehicles is high as evidenced by the large standard deviations. These results are generally consistent with other studies of recreational wastewaters (5-7) as indicated in Table 4.

Waste strengths and volumes for typical domestic wastewater and for highway rest area restroom wastewater measured by several investigators are given in Table 5. These values permit comparison with the high strength RV waste characteristics and are important when considering combining RV dump station waste with rest area or domestic waste in treatment

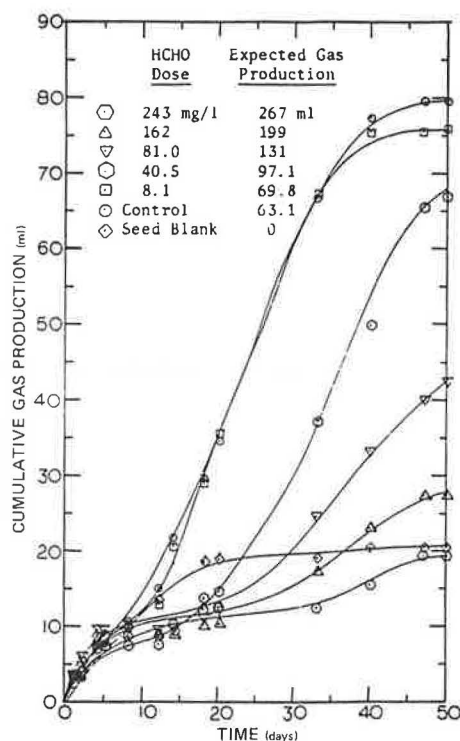


FIGURE 1 Response of anaerobic toxicity assay cultures to formaldehyde.

systems. Rest area waste strength is typical of weak-to-average domestic waste.

Formaldehyde preparations are by far the most popular additives in use today with 67 percent of the RV owners using them. Average formaldehyde concentration for wastewater from formaldehyde users was 250 mg per liter.

A significant portion of RV users were not using any additive—usually people on a short weekend trip. Phenol-based products were not found in either this survey or on the shelves of some Washington retail RV accessories stores. Only one person was

found using a zinc-based additive, which is no longer on the market. In the early and mid-1970s, zinc was the most common active ingredient in additives (5-7). In 1978 California prohibited the sale or use of zinc and other nonbiodegradable additives. In response, manufacturers switched to other active ingredients, usually formaldehyde-based. The manufacture and sale of zinc products has apparently disappeared completely from the RV additive market.

#### Disposal Station Usage Rate

To estimate usage rates of RV disposal stations in Washington, short-term traffic counts were made by people stationed at sites throughout the state on various weekdays and weekends during the summer of 1981 and on Labor Day, 1981. On Labor Day, 68 RVs used the two disposal stations at the Sea-Tac Rest Area between 3:00 and 6:00 p.m. Generally, the flow of RVs through the stations was heavy and steady, and a short line of RVs had formed. Thus, the maximum usage rate for a station is estimated to be 11.3 RVs per hour.

The following scenario of a busy day gives the expected maximum wastewater generation rate for a disposal station and may be used for design purposes. Although lights are sometimes provided, few people use the disposal station at night. Assume that people begin using the station regularly at 8:00 a.m. on a holiday morning and the usage rate is one-half the maximum rate until about noon. From noon until 5:00 p.m., assume that usage is at the maximum of 11.3 RVs per hour. Finally, assume that evening use between 5:00 and 9:00 p.m. tapers off to one-half the maximum rate again. This gives a realistic maximum usage rate for a very busy day of about 100 RVs per day and corresponds to a wastewater volume of 6200 liters per day.

#### RV Septic Tank Effluent Characteristics

The data in Table 1 indicate that effluent from an RV wastewater septic tank is very strong in total and soluble COD and BOD<sub>5</sub> and has high total and volatile suspended solids concentrations.

TABLE 4 Literature Review of Recreational Wastewater Characterization

Reference	(5)			(6)	(7)	Present Study
Wastewater Type	RV Black	RV Gray	RV Combined	RV	Powerboats, Sailboats, and Houseboats	RV including rinse
	(excluding rinse water)					
Number of Samples	140	140	140	14	43	72
Volume, l per vehicle	38	38	38	--	--	62±10 <sup>a</sup>
TSS, mg l <sup>-1</sup>	4200	550	3850	1120-20500	2430±980 <sup>a</sup>	3120±490
VSS, mg l <sup>-1</sup>	3743	481	3329	1020-18400	1910±800	2640±410
COD, mg l <sup>-1</sup>	11684	2390	6209	5600-22000	6140±1780	8230±1430
BOD <sub>5</sub> , mg l <sup>-1</sup>	11700	1870	3080	1838-7590	2560±900	3110±530
Formaldehyde, mg l <sup>-1</sup>	276	16	18	_b	_b	170±60
Zinc, mg l <sup>-1</sup>	8	0.5	9	1.7-4.6	150±100	_b
Phenol, mg l <sup>-1</sup>	1.4	0.13	0.5	_b	_b	_b

Note: mg l<sup>-1</sup> = milligrams per liter.

<sup>a</sup>Ranges given are the error of the mean value at a 95% confidence level.

<sup>b</sup>No analyses made for these components.

TABLE 5 Rest Area and Typical Domestic Wastewater Characterization

Reference	(8)	(9)	(10)	(11)	(12)	(13)
Wastewater Type	Rest Area	Rest Area	Rest Area	Rest Area	Domestic (Medium Strength)	Domestic
Volume						
liters per person-day	19	--	--	13	280	380
liters per vehicle	--	--	21	--	--	--
TSS, mg l <sup>-1</sup>	56-230	165	124 to 224	--	220	180-300
VSS, mg l <sup>-1</sup>	--	--	--	--	165	140-230
COD, mg l <sup>-1</sup>	--	405	203 to 383	--	500	550-700
BOD <sub>5</sub> , mg l <sup>-1</sup>	110-204	165	78 to 210	--	220	160-280
Nitrogen, mg l <sup>-1</sup> N	--	140	--	--	40	40-50
Phosphorous, mg l <sup>-1</sup> P	--	29	--	--	8	10-15

Note: mg l<sup>-1</sup> = milligrams per liter.

For comparison, domestic wastewater septic tank effluent characteristics (14) are given in Table 6. These data were derived from a survey of four conventional septic tank systems servicing individual residences in Snohomish and Pierce counties in Washington.

Formaldehyde levels in both RV septic tank water and drainfield water were found to be about 5 to 10 mg per liter. If there was no mechanism for formaldehyde removal in the tank, a concentration of 170 mg per liter would be expected, which is the average concentration found in RV holding-tank water. The anaerobic toxicity results show substantial reduction in biological activity at 50 to 150 mg per liter formaldehyde and no significant reduction in activity at levels of 5 to 10 mg per liter. If there was biological degradation of formaldehyde, degradation would be expected to continue until formaldehyde concentrations were reduced below 5 to 10 mg per liter. Formaldehyde is probably removed from septic tank systems by nonbiological mechanisms as well as by biodegradation. It appears that, for reasons not well understood at this time, formaldehyde removal ceases in anaerobic systems when formaldehyde concentration drops to about 5 mg per liter.

A sample of sludge from the Wenberg septic tank was placed in a glass flask and small gas bubbles were observed rising from the sludge, confirming the presence of biological activity. Thus, at the formaldehyde levels in RV septic tank water, biological activity is not totally eliminated, though it may be inhibited.

#### Septic Tank Design Practices

The primary function of a septic tank is to provide removal of suspended solids by settling or flota-

tion. Other important functions include biological decomposition of solids and storage of sludge and scum.

Several design manuals are available for guidance in septic tank design. In these manuals, septic tanks are sized to provide adequate detention time for solids removal based on experience.

The Washington Highway Hydraulic Manual (1972) (23) simply requires a 24-hr minimum detention time:

$$V = Q \quad (1)$$

where V is septic tank volume in liters, and Q is design flow rate in liters per day.

The following equation (15) is given for septic tank design at highway rest areas:

$$V = 4,250 + 0.75 Q \quad (2)$$

where V is septic tank volume in liters, with a 5700-liter minimum; and Q is design flow rate in liters per day. They state that the design flow rate should be 1.25 times the average daily rate.

Nomographs were developed for septic tank sizing (7,15) that specify a 36-hr minimum detention time:

$$V = 1.5 Q \quad (3)$$

Additional design constraints include a minimum volume of 5700 liters.

A 24-hr liquid detention time is required at maximum sludge path and scum accumulation (16). For flows between 2800 and 5700 liters per day, the tank may be sized for a 36-hr detention time as in Equation 3. This allows 33 percent of the tank volume to be used for sludge and scum storage. For flows between 5700 and 57 000 liters per day, Equation 2 may be used. The Washington State Department of

TABLE 6 Typical Effluent from Domestic Wastewater Septic Tanks (8)

	System					Standard Deviation
	Number 1	Number 2	Number 3	Number 4	Average	
COD, mg per liter	189	251	486	265	300	130
BOD <sub>5</sub> , mg	112	123	241	123	150	60
TSS, mg	26	27	70	23	37	23
VSS, mg	15	19	55	17	27	19

Transportation (WSDOT) no longer uses Equation 1 for design. Instead, criteria from the Washington State Department of Social and Health Services, which are similar to those suggested by Otis et al. (16), are used (17).

Figure 2 shows septic tank size as a function of design flow rate for each of these design correlations. Figure 3 presents these correlations showing detention time as a function of daily flow.

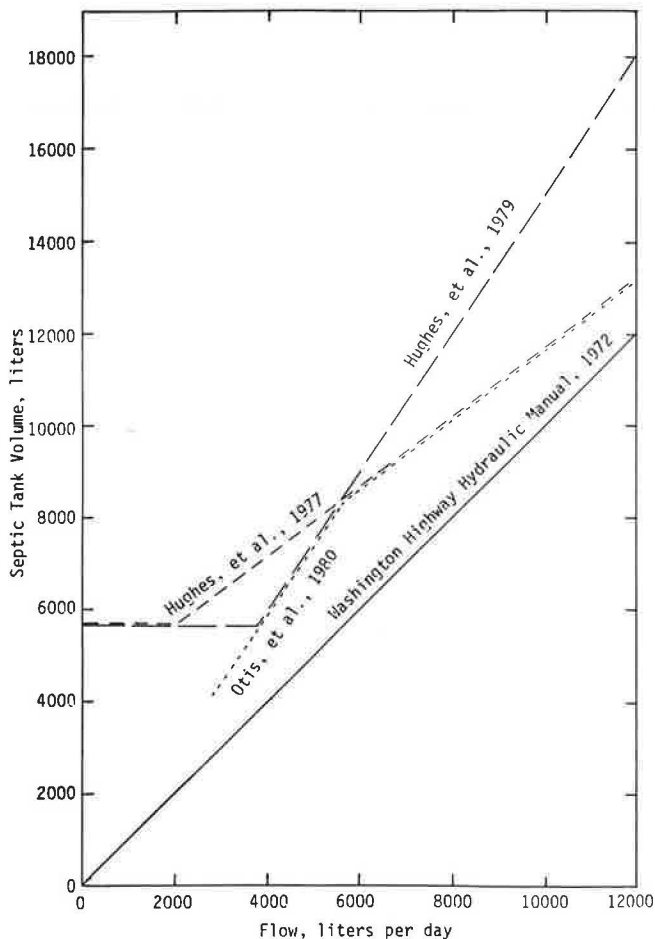


FIGURE 2 Septic tank design equations.

Each of these septic tank sizing equations is based on providing hydraulic detention time for settling of solids. None addresses sludge and scum accumulation or designed service intervals between pumpout. Common practice is to pump domestic waste septic tanks every 3 to 5 years without measuring sludge or scum accumulation (12,16).

The tank should be pumped no later than when the bottom of the scum layer is within 7.5 cm of the outlet or when the sludge level is within 20 cm of the outlet (16). This recommendation does not appear consistent with the septic tank sizing Equation 3 and a minimum 24-hr hydraulic detention time. For a typical 1.0-meter-deep tank, this recommendation allows the tank to be three-quarters full of sludge and scum. However, Equation 3 coupled with a minimum 24-hr detention time provides for only one-third of the tank volume to be filled with sludge and scum.

Because RV wastewater contains very high concentrations of suspended solids as well as formaldehyde (which may inhibit anaerobic digestion of sludge and scum) solids accumulation in RV waste

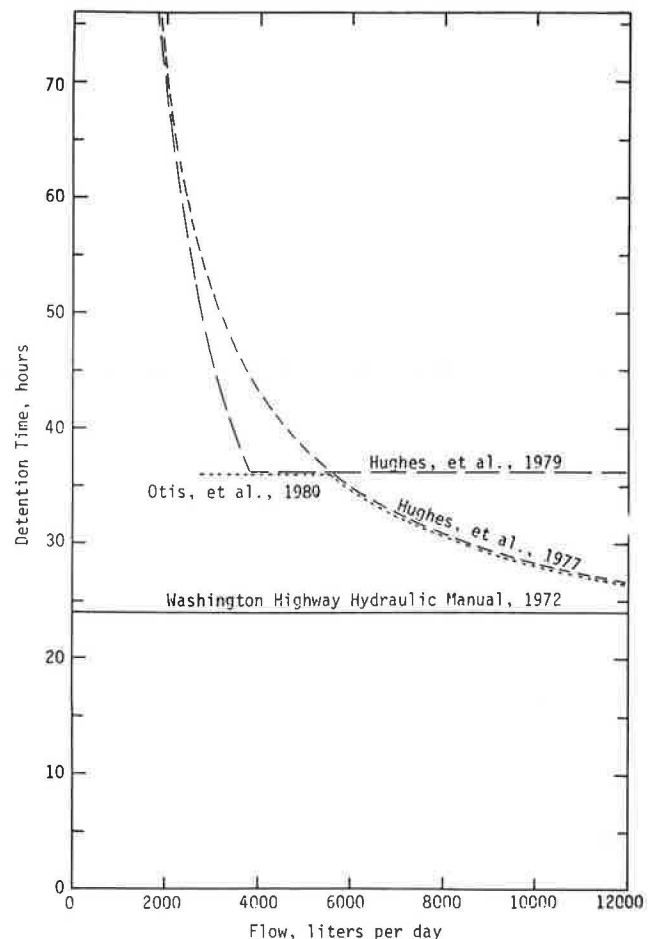


FIGURE 3 Septic tank detention time.

septic tanks will be substantially greater than in domestic waste septic tanks treating an equal volume of wastewater. Therefore, sludge and scum accumulation and pumpout interval should be considered in addition to hydraulic residence time when sizing septic tanks for RV waste.

#### Sludge and Scum Accumulation in Domestic Septic Tanks

As sludge and scum accumulate in a septic tank, the effective liquid volume and detention time decrease. With large accumulations, sludge scouring increases, treatment efficiency decreases, and suspended solids pass through the tank. One cause of clogged drainfields is failure to pump out the septic tank.

Sludge and scum quantities in 300 operating domestic septic tanks were measured. This yielded mean values for accumulation volumes for a number of septic tanks with a specified service life since the last pumpout (18). These data are shown in Figure 4.

A simple first order kinetic model for sludge and scum degradation in septic tanks can be developed, assuming that the sludge removal rate is proportional to the amount of sludge in the tank. Such a model does not work well for extended residence times because no provision is made for refractory materials. In this study, an accumulation model was developed based on the concept that some organic material in sludge and scum is readily degradable and compactible, some is degradable and compactible with extended residence times, and some material is inert and not compactible.

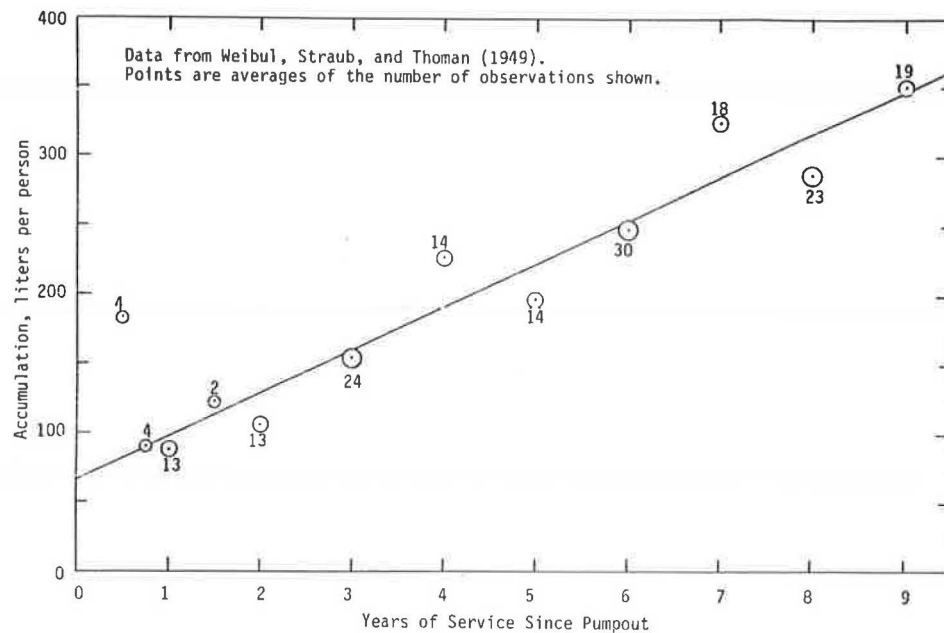


FIGURE 4 Domestic septic tank sludge and scum accumulation.

By material balance, the volume of sludge and scum in a septic tank is the difference between the volume input and the volume removed by degradation and compaction. Removal of sludge and scum with outflow is neglected as shown in the following equation:

$$\text{Volume accumulated} = \text{Volume input} - \text{Volume removed by degradation and compaction} \quad (4)$$

The volume of the input during a time period  $t$  is given by

$$V_i = r_i \Delta t \quad (5)$$

where

$V_i$  = volume of sludge and scum input;  
 $r$  = volumetric rate of sludge and scum input; and  
 $\Delta t$  = duration of input.

For a given incremental volume,  $V_i$ , of sludge and scum entering the tank during one day, the initial rate of degradation will be relatively fast. At short residence times, it is assumed that the first order rate model applies, so the volume of this increment that disappears is proportional to both the volume of the original increment and the residence time:

$$V_r, \text{ short } t_R = a t_R V_i \quad (6)$$

where

$V_r$  = volume removed from the incremental input volume,  $V_i$ , by degradation and compaction;  
 $t_R$  = residence time of the incremental volume; and  
 $a$  = constant.

For long residence times, the volume that has disappeared from the original increment will be proportional only to the original volume of the increment:

$$V_r, \text{ long } t_R = (a/b) V_i \quad (7)$$

where  $a$  and  $b$  are constants. The volume removed after long residence times will be the fraction of sludge and scum that is ultimately degraded or compacted. The inert, noncompactible fraction will remain accumulated in the tank.

The dependence of volume removed from an incremental input volume on residence time can be modeled using Equation 8:

$$V_r = a t_R / (1 + b t_R) V_i \quad (8)$$

Note that at short residence times ( $b t_R \ll 1$ ), Equation 8 reduces to Equation 6; at long residence times, Equation 8 reduces to Equation 7. Thus, Equation 8 is consistent with the limiting cases that comprise the conceptual model.

The total volume removed from the tank from time 0 to time  $t$ , designated  $V_r(t)$ , will be the sum of the volumes removed from each incremental input volume:

$$V_r(t) = \sum_{i=1}^n V_r = \sum_{i=1}^n [a t_{R,n} / (1 + b t_{R,n})] V_i \quad (9)$$

where  $t_{R,n}$  is residence time of the  $n$ th incremental volume. Substituting Equation 5 gives:

$$V_r(t) = \sum [a t_{R,n} / (1 + b t_{R,n})] r_i \Delta t \quad (10)$$

Using differential input times, Equation 10 becomes:

$$V_r(t) = \int_0^t [a t / (1 + b t)] r_i dt \quad (11)$$

Integrating gives:

$$V_r(t) = [a r_i t / b] - [a r_i / b^2] \ln(1 + b t) \quad (12)$$

The difference between the input volume given by Equation 5 and the volume removed given by Equation 12 gives the volume of the accumulation:

$$V(t) = r_i t - [a r_i t / b] + [a r_i / b^2] \ln(1 + b t) \quad (13)$$



The value for the sludge and scum input rate,  $r_i$ , in Equation 13 can be determined using data for domestic wastewater. Typical wastewater parameters for residences using on-site sewage treatment systems are 166 liters per person per day and 200 to 290 mg per liter TSS (16). This results in a TSS loading of 34 to 49 g per person per day. Values of 166 liters per person per day and 220 mg per liter of TSS will be used as typical septic tank input parameters, giving a TSS loading of 37 g per person per day.

About two-thirds of the solids accumulation in the tanks was sludge and one-third of the volume was scum (18). Measured values for solids concentration of septic tank sludge and scum in this study were 8.5 percent and 19 percent, respectively. Therefore, each liter of total accumulation contains approximately 57 g solids in 0.67 liters of sludge and 63 g solids in 0.33 liters of scum. Assuming a density of 1 g per cubic centimeter for the solids, there are 120 g solids per liter of combined sludge and scum accumulation.

Based on these values, the input rate of solids into a septic tank is 13 400 g per person per year. Because the solids concentration of sludge and scum in the tank is 120 g solids per liter, the sludge and scum input rate,  $r_i$ , is 111 liters per person per year.

Weibul's sludge and scum accumulation data, shown in Figure 4, can be used to estimate values for the constants  $a$  and  $b$  in Equation 13. Values of  $a$  and  $b$  were chosen by trial and error to give the minimum sum of the squares of the difference between each data point and calculated accumulation from the model. This resulted in values of 1.9 per year and 2.5 per year for the constants  $a$  and  $b$ , respectively. With these constants, Equation 13 becomes:

$$V(t) = 26 t + 34 \ln (1 + 2.5 t) \quad (14)$$

where  $V(t)$  is accumulation at time  $t$ , liters; and  $t$  is service time since last pumpout, years. This model is plotted with Weibul's data in Figure 5.

The data indicate that after a couple of years, the accumulation rate is practically constant with time. This indicates that accumulation of removable solids after a year or two is a small term in the

mass balance compared to the accumulation of nonremovable solids.

The ratio of the constants  $a$  to  $b$  is 0.76. From Equation 7, this implies that three-quarters of the input sludge and scum volume will be ultimately removed by degradation and compaction. It is concluded that Equation 14 provides a reasonable model for domestic septic tank sludge and scum accumulation.

#### Declining Rate Model Applied to RV Waste

The declining rate model for septic tank accumulation can be applied to RV wastewater by adjusting the constants  $a$ ,  $b$ , and  $r_i$ . Table 1 gives the suspended solids concentration of RV wastewater as 3120 mg per liter and the volume per vehicle as 62 liters. Thus, the suspended solids loading per vehicle is 190 grams. Assuming 120 grams of solids per liter of sludge plus scum, this results in 1.6 liters of sludge and scum per RV. On the basis of a unit loading of one RV tank per day, this gives an input rate of 590 liters of sludge and scum per year. It is assumed that the fraction of RV sludge and scum ultimately removable is the same as domestic waste, so the ratio of  $a$  to  $b$  is still 0.76.

The initial rate of biodegradation is proportional to the constant  $a$ . If formaldehyde in RV wastewater inhibits the rate, but not the ultimate extent, of anaerobic digestion of the solids, the values of  $a$  and  $b$  decrease proportionately (5,19). However, the magnitude of any initial inhibition is unknown. The effect that various degrees of inhibition of the initial degradation rate would have on sludge and scum accumulation is shown in Figure 6. Fifty percent inhibition means that the value of  $a$  for RV waste is one-half of the value of  $a$  for domestic waste.

The model for sludge and scum accumulation using these constants is given by Equation 15:

$$V_{t,RV} = 140 t + 448/b [\ln(1 + b t)] \quad (15)$$

where

$V_{t,RV}$  = accumulation, liters;  
 $t$  = time since last pumpout, years; and  
 $b = 2.47 \times (1 - \% \text{ inhibition}/100)$ .

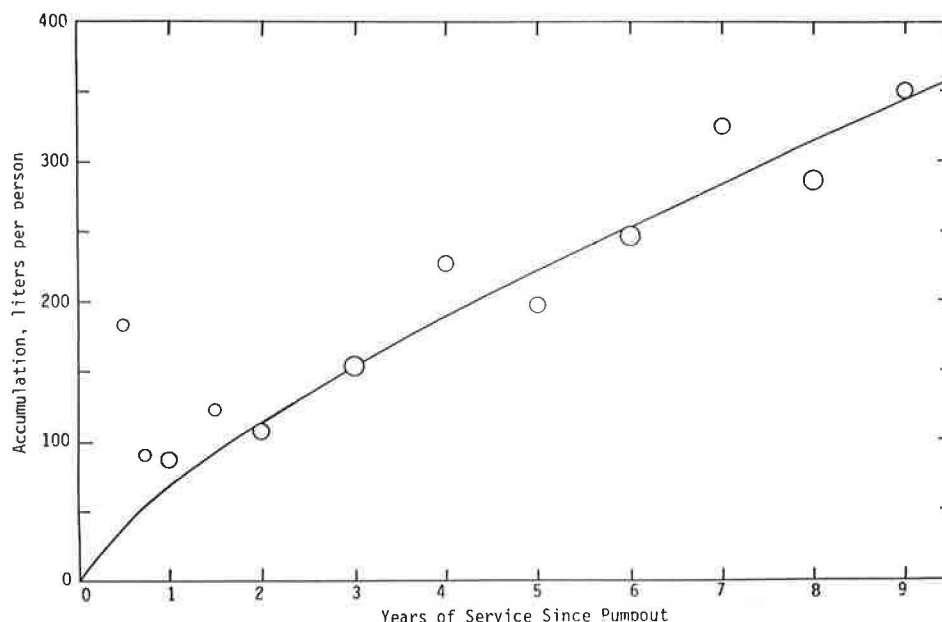


FIGURE 5 Comparison of declining degradation rate model.

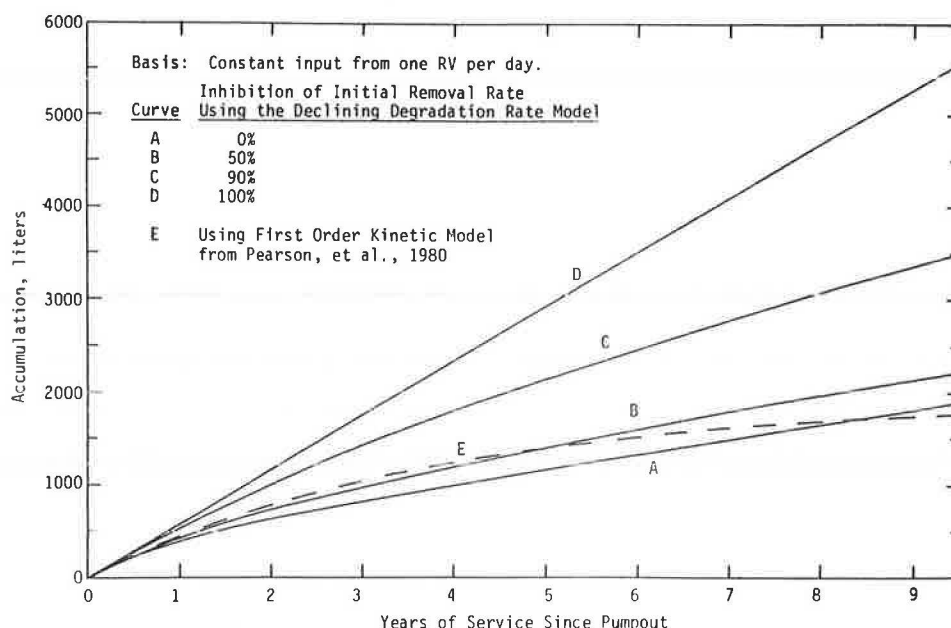


FIGURE 6 RV wastewater septic tank sludge and scum accumulation.

Figure 6 shows the resulting sludge and scum accumulation in an RV waste septic tank based on this model. The curves are based on one RV input per day. To adjust to any other basis, the accumulation is multiplied by the desired daily RV input rate. For comparison, Figure 6 shows sludge and scum accumulation based on a first order kinetic model.

Although the anaerobic toxicity assays were not really designed to give kinetic information, the gas production rates during the growth phases may be used to obtain rough estimates of inhibitory effects on degradation rate. For formaldehyde concentrations of 0, 40, 80, 160, and 240 mg per liter, gas production rates during the growth phases were 2.5, 2.0, 1.1, 0.7, and 0.5 ml per day, respectively. This corresponds to 0, 20, 57, 74, and 80 percent inhibition in gas production rate for the respective formaldehyde concentrations. Therefore, an assumption of 90 percent reduction in the initial removal rate in RV waste septic tanks would be a conservative estimate for design purposes. Recall that although formaldehyde concentration in RV tanks was 170 mg per liter, it was quickly reduced by physical, chemical, or biological reactions to much lower levels in bench scale and in operating septic tanks.

#### Recommendation for Sizing RV Waste Septic Tanks

Septic tanks for RV wastewater should be sized with consideration for both hydraulic detention time and solids accumulation. Because RV waste is very concentrated, there will be much more sludge and scum accumulated for a given quantity of water than in domestic tanks. The relationships given in engineering manuals are based only on hydraulic detention time and do not address accumulation or pumpout interval.

The hydraulic detention time should be 24 hr at the maximum sludge and scum accumulation (16). This detention time should be for the maximum daily flow rate. Thus, a septic tank for RV wastewater can be sized by adding the volume required for a minimum 24-hr detention time to the volume required for sludge and scum at the designed service period before pumpout. The resulting septic tank sizing

equation using 90 percent reduction of the initial degradation rate is given by adding Equations 1 and 15:

$$V = Q_{\max} + n/365 [140 t + 1,800 \ln (1 + 0.25 t)] \quad (16)$$

where

- $V$  = septic tank size, liters;
- $Q_{\max}$  = designed peak flow rate for system, liters per day;
- $n$  = designed average number of RVs per year; and
- $t$  = designed service interval between pumpout, years.

This relationship is plotted in Figure 7 for average use rates of 1,000, 5,000, and 10,000 RVs per year and a maximum daily wastewater flow rate of 6200 liters per day.

Figure 7 demonstrates the importance of considering sludge and scum accumulation when sizing septic tanks. At 1,000 vehicles per year, the hydraulic flow rate term in Equation 16 dominates. However, at 5,000 RVs per year, the accumulation term becomes increasingly important for more than 1 year of service time, and at 10,000 RVs per year, the accumulation term dominates Equation 16 after 1 year of service time.

#### Drainfield Design

Where soil conditions are suitable, subsurface soil absorption is a simple, effective method of treating septic tank effluent. Partially treated wastewater is discharged below the ground surface where it is absorbed and treated by soil as it percolates to the groundwater.

Several different designs of subsurface soil absorption systems may be used including trenches, beds, seepage pits, mounds, fills, and artificially drained systems. All of these systems are covered excavations filled with porous media with a means for introducing and distributing the wastewater throughout the system. The following discussion



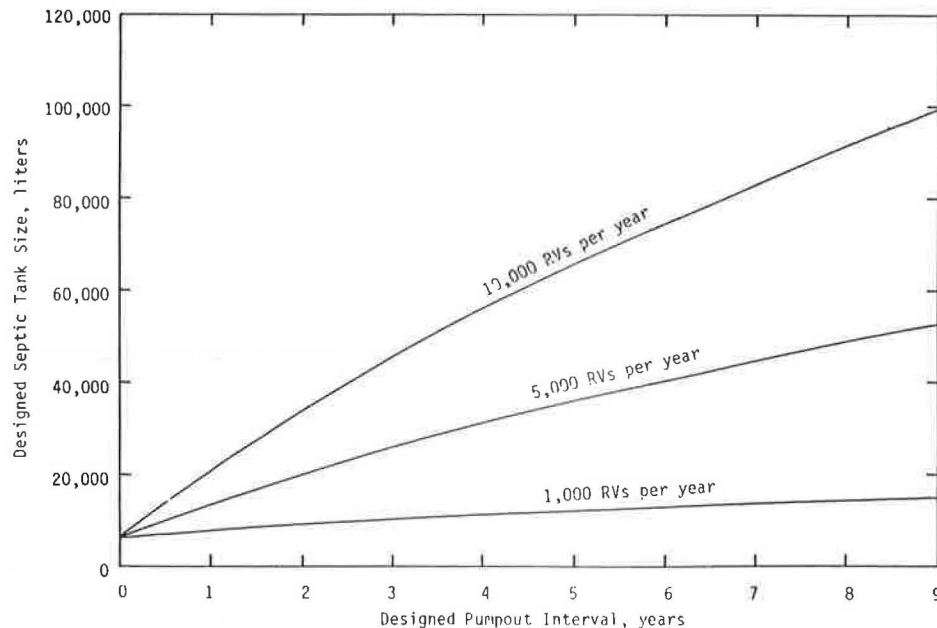


FIGURE 7 Septic tank volume for RV disposal stations.

concentrates on the trench drainfield system, because it is the most commonly used soil absorption system (16).

Continuous application of wastewater causes a clogging mat to form at the soil infiltrative surface. This mat slows the movement of water into the soil. This can be beneficial because it helps to maintain unsaturated soil conditions below the mat. Fortunately, the mat seldom seals the soil completely. The size of a drainfield must be based on the infiltration rate through the clogging mat that ultimately forms. Formation of the clogging mat depends primarily on loading pattern and soil conditions, although other factors may be important (16).

The clogging mat, when viewed under a microscope, looks like a mass of sewage solids consisting of bacteria, protozoa, cellulose pieces, nematodes, and bacterial slime. It is a living layer that responds to temperature change, food load, oxygen availability, and other environmental factors. Between dosings, the mat gradually dries, cracks, and shrinks in volume. The permeability of the mat varies from time to time and place to place within the trench.

The clogging process is related to the rate of biological growth and therefore to the food and solids load. It might be assumed that a linear relationship exists between increased BOD<sub>5</sub> and solids concentrations and increased clogging. However, studies have demonstrated only small differences in clogging rate over a range of wastewater qualities.

The following relationship adjusts required drainfield area to loading (20,21):

$$\text{Adjusted area required} = \text{Area required for standard septic tank pretreatment} \times (\text{BOD}_5 + \text{TSS}/250)^{1/3} \quad (17)$$

where BOD<sub>5</sub> and TSS are expressed in mg per liter, and 250 mg per liter is the sum of BOD<sub>5</sub> plus TSS for standard septic tank effluent (Table 6 gives this sum as 187 mg per liter for typical septic tank effluent). This relationship is valid only for domestic sewage and does not apply to soils with low

permeability. The wastewater carrying capacity of soils with low permeability may be governed by the hydraulic or flow capacity of the soil rather than the clogging mat.

#### Sizing Drainfields for Servicing RVs

RV septic tank effluent is very strong in COD and BOD, has high suspended solids concentrations, and contains 5 to 10 mg per liter formaldehyde. Because of the high strength of this effluent, it is possible that a drainfield size based on standard application rates will fail prematurely. Some sizing factor should be applied to drainfields receiving this high strength effluent.

A linear relationship for increasing drainfield area with increasing wastewater strength would provide a constant nutrient loading per square meter of drainfield, but this approach is too restrictive. For RV septic tank effluent, which has a total BOD<sub>5</sub> and TSS concentration 8.6 times stronger than typical domestic septic tank effluent, a linear relationship would require a sizing factor of 8.6. Although such a sizing factor would provide the same mass of nutrients per square meter of drainfield clogging mat, and hence a similar clogging mat density as found in domestic system drainfields, the hydraulic flowrate per square meter for an RV system would only be 12 percent of the flowrate that could be transmitted through such a clogging mat. Also, the work of Laak (20) and of Daniel and Bouma (21) does not support a linear relationship between required area for prevention of clogging and wastewater strength. Therefore, an appropriate drainfield sizing factor lies somewhere between 1.0 and 8.6.

Although it is an overextension of the correlation, Equation 17 might be used to give some indication of an appropriate sizing factor for RV septic effluent. Using the BOD<sub>5</sub> and TSS values for RV effluent given in Table 3, the sizing factor becomes:

$$\begin{aligned} \text{Sizing factor} &= (1,430 + 170/250)^{1/3} \\ \text{Sizing factor} &= 1.9 \end{aligned} \quad (18)$$

Therefore, for lack of a better correlation, it is recommended that drainfields for RV septic tank

effluent be double the recommended size for domestic septic tank effluent. This subject should receive further attention.

#### CONCLUSIONS AND RECOMMENDATIONS

RV wastewater is a very high-strength waste. Average total suspended solids, COD and BOD<sub>5</sub> values in this study were 3120 mg per liter, 8230 mg per liter, and 3110 mg per liter, respectively. The average volume of wastewater plus rinse discharged was 62 liters per vehicle.

Measured formaldehyde levels in septic tanks receiving RV wastes were about 5 to 10 mg per liter. BOD<sub>5</sub> of the effluent was about 1430 mg per liter. Total suspended solids were reduced to 170 mg per liter. Biological activity in the septic tank was evident from gas bubbles produced by the sludge.

Removal efficiencies for RV disposal septic tanks are higher than for domestic wastewater septic tanks. However, effluent from RV wastewater tanks is still about ten times stronger in BOD<sub>5</sub> and four times stronger in suspended solids than effluent from domestic tanks.

Several septic tanks sizing equations are used in design manuals. All are based on hydraulic detention times of about 24 to 36 hr. None addresses sludge and scum accumulation or pumpout interval.

A model was developed for sludge and scum accumulation in domestic septic tanks. The model, given by Equation 14, is based on a declining rate of degradation where some organic material in sludge and scum is readily degradable and compactible, some is degradable and compactible with extended residence times, and some material is inert and not compactible.

Because RV waste has a very high solids concentration and because anaerobic degradation may be inhibited by formaldehyde, sludge and scum accumulation should be considered when sizing septic tanks for RV disposal stations. Equation 16 was developed by applying the domestic sludge and scum accumulation model to RV waste.

The strong effluent from RV wastewater tanks may promote growth of a clogging mat and shorten the life of a drainfield. At the present time, it is recommended that drainfields for RV waste be twice as large as given by standard sizing criteria for domestic wastewater flowrates. This subject of drainfield sizing for concentrated effluent should be investigated further.

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