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THE EFFECT OF THREE HOLDING TANK CHEMICALS ON ANAEROBIC WASTEWATER TREATMENT

by

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(ABSTRACT)

Sewage-holding tanks aboard recreational boats store human wastes, thereby preventing the direct discharge of wastewater to the aquatic environment. Water-conserving toilets and limited holding tank volumes produce a highly concentrated waste that must be periodically dumped to a wastewater treatment system. Prior to disposal, many boat operators add commercial preparations to control odors produced in their chemical toilets and holding tanks.

The objective of this study was to determine the effects of three holding-tank chemicals on anaerobic wastewater treatment. Specifically, septic-tank performance with respect to effluent total suspended solids (TSS) and chemical oxygen demand (COD) was evaluated. Potential drain-field failure was the concern that led to the selection of TSS and COD. Drain-field failure could result from high solids carry-over or from a high concentration of COD in the effluent which would promote excessive bio-mat growth and clog the system. Laboratory

septic tanks were constructed and operated for this evaluation.

Methanol, paraformaldehyde and formaldehyde were each listed as an active ingredient in one of three chemical compounds used by recreational boat owners to deodorize sewage-holding tanks. Septic-tank effluent TSS concentrations were not adversely effected by the shock-loading with wastewater containing these chemicals. Concentrations expected to be achieved by dilution (20 and 50 percent of the recommended additive dose) resulted in septic-tank effluent COD within an acceptable range, which was determined by operation of a control system. Wastewaters containing these concentrations were not detrimental to the septic-tank treatment system. However, the full manufacturers' recommended dose of the odor-control chemicals disrupted the system's ability to degrade COD. At full strength, the paraformaldehyde and formaldehyde deodorants were particularly detrimental; no recovery occurred after the two-day shock-dose was completed.

Acknowledgements

Thanks everyone.

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I thank my parents, Barbara and Sam. Without them, this study would not have been possible.

Rob, Scott, and Ron, my room-mates and friends, are owed a large debt for their "constructive" dinner table criticisms. Pizza!

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I. INTRODUCTION

Recreational boating is enjoyed by many citizens on the lakes and navigable waterways of Virginia. A consequence of this activity is the potential degradation of water quality when populations interact with the aquatic environment. Sewage-holding tanks store human wastes generated on vessels and prevent the direct discharge of the wastewater to this environment. The holding tanks have limited capacity; and therefore, the contents must be periodically removed. The disposal of holding-tank wastewater is commonly accomplished at dump stations conveniently located at marinas. Marina dump stations are equipped with the necessary appurtenances to safely remove the boat holding-tank contents and to convey the wastewater to the local sewage treatment system.

Operators of recreational boats commonly utilize commercially available holding-tank chemicals which contain bacterial growth inhibitors and deodorants. Odor-control additives are designed to minimize the formation of noxious odors in boat wastewater-holding tanks, and to mask tank odors with perfumes. There are numerous holding tank chemical additives commercially available under different proprietary name brands. These odor-control additives may contain toxic substances. "Aqua-Kem", "Dri-Kem" (Thetford

Corporation, Ann Arbor, Michigan), and "D-Odor-It" (Land and Sea Products, Grand Rapids, Michigan) are some of the deodorants available on the market. Major active ingredients on product labels and manufacturers' correspondence are; formaldehyde, paraformaldehyde, and methyl alcohol, respectively. These active ingredients are incorporated in most other holding-tank deodorant products (1-3, 11-13). Inhibitory effects of these chemical additives may significantly disrupt the on-site biological wastewater treatment systems of isolated marinas that do not have access to municipal sewers.

If, in addition to the wastewater generated on site, marinas accept private boat holding-tank wastewater for disposal in septic-tanks, potential problems exist for their on-site treatment systems. The additional marina wastewater flows may not provide sufficient dilution volumes to overcome the toxic or inhibitory effects of the additives. These additives could produce a high effluent chemical oxygen demand (COD) and / or total suspended solids (TSS). A potential result is the discharge of inadequately treated wastewater or the total system failure, due to drain-field clogging, necessitating major reconstruction.

The objective of this study was to examine the impact of three holding-tank additives (D-Odor-It, Dri-Kem, and

Aqua-Kem) on anaerobic wastewater treatment, specifically on septic-tank performance. Relative biological activities, based on gas production at various deodorant doses, were measured in this study. Effluent TSS and COD concentrations from laboratory-scale, septic tanks shock-loaded with wastewater containing three levels of the three deodorant compounds were compared.

II. LITERATURE REVIEW

Regulations

Environmental protection and public safety are two of many reasons why recreational boating is subjected to numerous governmental controls. With respect to sewage disposal, boating activities are regulated in Virginia by federal and state agencies. The Coast Guard requires certification that marine sanitation devices prevent the discharge "... of untreated sewage into the waters of the United States" (19). Additionally, the Environmental Protection Agency prohibits vessels from discharging sewage into freshwater bodies, necessitating boat holding tanks (20). State agencies involved in the regulation of pollution from boating activities include The State Water Control Board and the State Board of Health (4, 5). Specific health requirements include a provision that marinas must provide facilities for the removal and safe disposal of boat holding tank contents. Furthermore, the State Board of Health recognizes that boat holding-tank deodorants may disrupt small on-site wastewater treatment systems (18).

Additives

There is a variety of holding-tank additives. Formaldehyde and paraformaldehyde based products currently dominate the market (3). In 1974, Robins and Green (13) surveyed nine companies that manufacture boat holding-tank additives. From a sample of ten products, they found that; three used liquid formaldehyde, three used paraformaldehyde, two used quaternary ammonium, and two used zinc sulfate as the active ingredient. Pearson et al. (12), in a study of recreational vehicle (RV) black-water holding tanks (RV sewage-holding tanks), determined average preservative concentrations of 75 mg/L and 18 mg/L for formaldehyde and zinc, respectively. Brown (1) questioned 178 RV owners in Washington to determine holding-tank additive usage. The results of that survey indicated; 67 percent used a paraformaldehyde or formalin (formaldehyde and methanol solution) based deodorant, eight percent did not use holding-tank additives, and less then one percent added products containing zinc sulfate. Additionally, aspirin, enzyme formulations, pine oil, soap, pH buffers, and quaternary ammonium compounds were listed as active ingredients used by some RV owners to control holding-tank odors. Zinc compounds were removed from the Washington RV market.

Wastewater Characteristics

Mobile sanitation devices typically conserve flush water. Burrows (3) reports that domestic toilets use 20 times more water for flushing than RV toilets. Therefore, holding tank wastewater is a strong waste, approximately 20 times more concentrated than domestic wastewater. Pearson et al. (11) analyzed undiluted RV black-water holding tanks. The COD and TSS concentrations of this wastewater were "...24 times higher than for domestic waste" (11). Washdown water dilutes the strength of holding-tank wastewater that enters the treatment system. The wastewater characteristics of holding-tank contents including washdown and other dilution waters is given in Table 1. The average COD and TSS concentrations for these wastes are 14 times the values generally given for domestic wastewater of 500 mg/L and 200 mg/L, respectively.

Treatment

Biological treatment of high strength, complex wastewater requires that the wastewater be biodegradable. Chemical substances may stimulate or inhibit biological treatment systems depending on the concentration of the substance. Figure 1 graphically presents the relationship between dose and stimulation, inhibition, and toxicity effects.

Robins and Green (13) investigated biological treatment of water craft holding-tank wastewater using the activated sludge process. Measuring biomass respiration, they found adverse effects could be overcome on wastewaters containing zinc chemical additives by dilution.

Table 1. Characteristics of Holding Tank Wastewater from Recreational Vehicles (RV) and Recreational Boats (1).

	Robins and Green (13)	Pearson, *et al.* (12)	Brown (1)
Wastewater	Boat Holding Tank	RV, Black Water	RV
TSS, mg/L	2430	4200	3120
COD, mg/L	6140	11684	8230

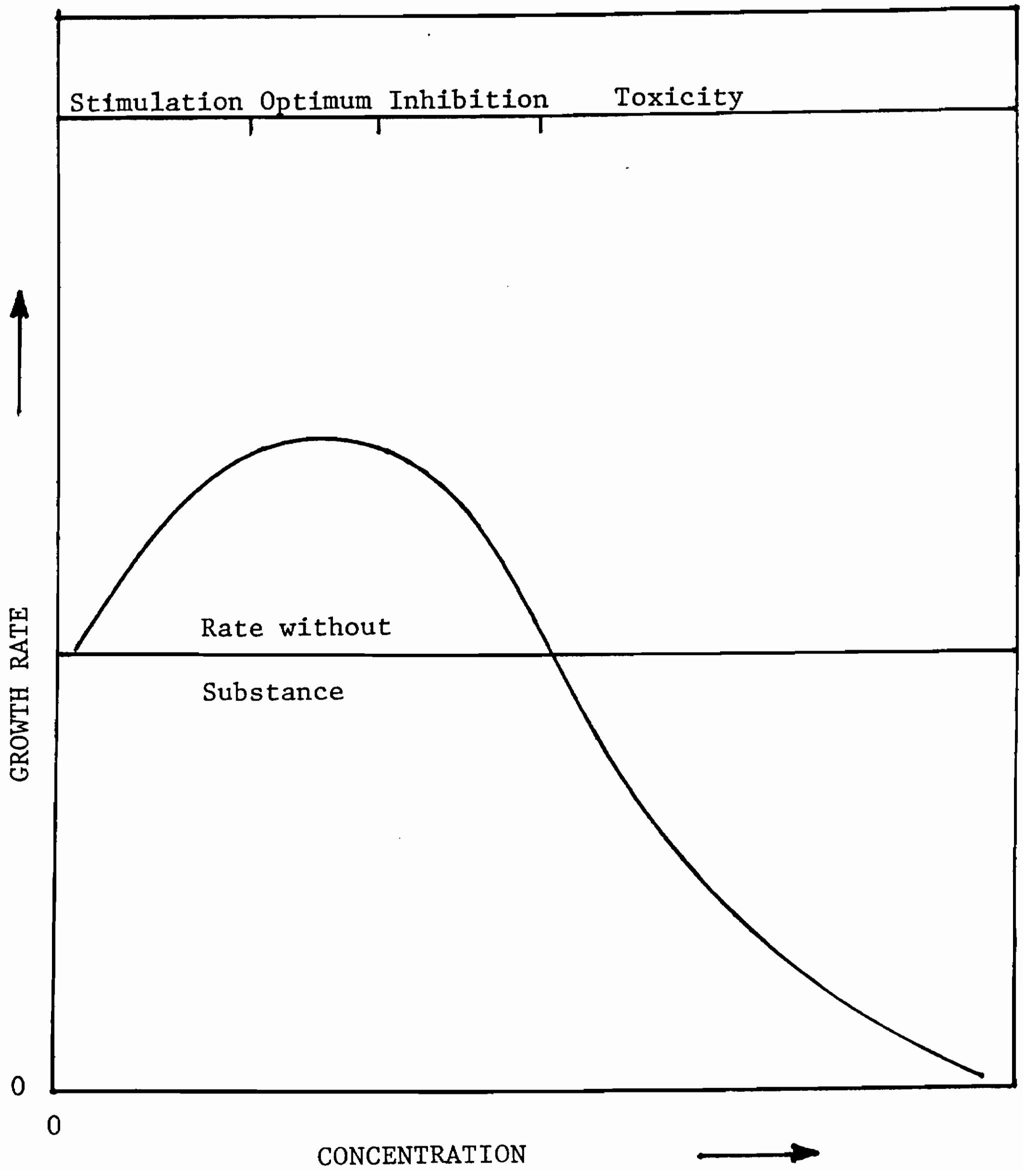

Figure 1. The Effect of Substrate Concentration on Biological Growth Rates (8, 10).

Formaldehyde did not adversely impact sludge respiration rates at the concentrations examined.

Additionally, studies have been undertaken by a number of different authors to ascertain possible inhibitory or toxic effects holding-tank chemicals have on anaerobic treatment systems. Hovious et al. (7) measured anaerobic gas production from batch reactors dosed with formaldehyde, frequently an active ingredient in boat holding-tank additives. Also, relative biological activity for anaerobic systems was defined to be the ratio of the volume of gas produced in the dosed system to the volume of gas produced in a control. Formaldehyde and other aldehydes, acrolein and crotonaidehyde, were inhibitory at low concentrations of 20 to 100 mg/L. Additionally, it was difficult to acclimate continuously fed systems to the aldehydes. Parkin and Owen (10) overcame inhibitory effects of formaldehyde at 250 mg/L in digester feed by increasing the sludge age from six to 23 days. Pearson et al. (12) determined that anaerobic systems tolerated formaldehyde in shock loadings at higher levels then continuous loads. Anaerobic gas production decreased 50 percent from formaldehyde dosed systems at 200 and 100 mg/L in unacclimated and acclimated systems, respectively. Speece (15), however, states:

> ...formaldehyde or phenol are common disinfectants at high concentrations, but in the range of 400 to 2000 mg/L, respectively, these substances are readily converted to methane by anaerobic treatment.

Septic Tank Systems

Scalf et al. (14), studied residential septic tank-drain field systems. Septic-tank, treatment systems require two physically distinct components. The first is the septic-tank treatment unit. Sludge and scum are separated by gravity, and anaerobic biological degradation of organics occurs in properly functioning septic tanks. The soil treatment occurs in the absorption field and is the second component of the system. The drain field develops a biological mat at the liquid-soil interface that biologically treats the septic tank effluent. Accumulation of solids in the septic tank and insufficient infiltration of wastewater in the absorption field commonly result in system failure. Failure of on-site treatment systems could result in contamination of water supplies by the seepage or runoff of inadequately treated effluent.

Septic tank systems could be employed for the on-site disposal of boat wastewater. Boat holding tank wastewater resembles recreational vehicle wastewater and is likely to effect septic tank systems similarly. Brown et al. (2), for RV wastewater treatment, noted:

> 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 wastewater than in domestic tanks.

Additionally, septic tank treatment systems loaded with RV waste had effluent total suspended solids averaging 8.6 times the 37 mg/L average found from four domestic tanks (2). Pearson et al. (11) determined that 21 gallons of wastewater were generated for each RV dump; and, RV wastewater produced "...20 times the volume of sludge and scum to a septic tank as does the same number of gallons of domestic wastewater." Doubling, with dual fields, the required absorbtion field area has been recommended to prevent failure of systems loaded with high strength waste. Dual drain fields increase the life of the system by allowing part of the system to rest (1, 2, 11, 14).

Summary of Literature

Chemicals incorporated in holding-tank additives can inhibit biological activity, but they are biodegradable when diluted. Proprietary holding tank chemicals have not been examined individually for disposal into septic tank systems. The purpose of this research is to determine the effects of three chemical additives on anaerobic gas production, and septic tank effluent characteristics. Measures of effluent TSS and COD could be used to predict drain field failure. Additionally, additive containing wastes may require dilution below the manufacturers' recommended dose prior to septic tank treatment. This dilution factor is not known for the proprietary compounds. No information on the effects of periodic shock loads of holding-tank additives on septic tanks exists.

III. METHODS AND MATERIALS

Two distinct sets of laboratory experiments were designed to determine the effects of boat holding-tank deodorant additives on septic treatment. The first set of experiments were preliminary and involved the use of bench-scale batch digesters to ascertain the effects on anaerobic gas production (a measure of biological activity) and solids dewatering. Bench-scale septic tanks were utilized in the second series of experiments to determine if three proprietary additives had an effect on septic tank effluent COD and TSS. Aqua-Kem, Dri-Kem, and D-Odor-It, additives available in Virginia, were the additives selected for evaluation.

Equipment

Figure 2 shows a diagram of one of the batch digesters and the gas collection apparatus used in this study. Six digesters were constructed from 300 mL glass Erlenmeyer flasks. The flasks were capped with rubber stoppers that had been equipped with a 7-mm diameter glass tubing port. The ports allowed the discharge of anaerobically produced head gas and directed gas production to the collection and measurement apparatus via plastic and glass tubing. The gas measurement devices were inverted and water filled 100 and 50 mL graduated

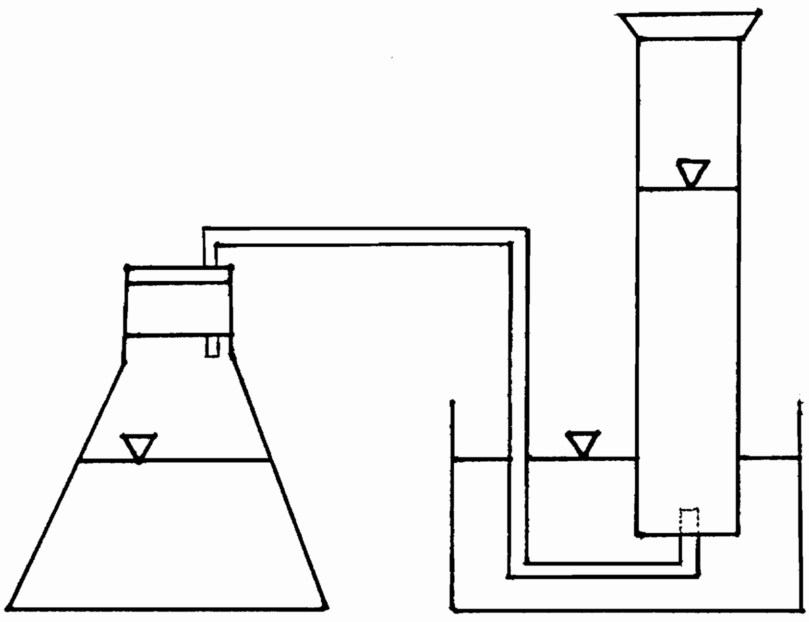

Figure 2. Laboratory Digester and Gas Measurement Device.

cylinders. Gas production displaced water in the graduated cylinders. A preliminary sludge dilution experiment yielded acceptable gas production from 300 mL batch digesters loaded with a 50 percent digester sludge and liquid mix. This concentration was utilized in the remainder of the experiments.

Figures 3-5 are diagrams of a laboratory septic tank (25 X 14 X 13 cm) constructed from Plexiglass and plastic pipe. Four identical tanks were designed and built with a hydraulic capacity of 2.15 liters. Septic tank systems were needed characterize chemical effects on the likely recipient of these wastes.

Description of Experiments

Anaerobic digester contents, from the water pollution control plant for Roanoke, Virginia, provided initial biomass and trace nutrients for all experiments. Approximately 30 liters of primary digester contents was obtained for seed material. This sludge was stored at 20 degrees centigrade.

Preliminary Experiments

Aqua-Kem, the first chemical obtained, was studied to determine its effect on solids dewatering. Laboratory digesters were loaded with a wastewater mixture, 50 percent anaerobic sludge and 50 percent tap water, to which various

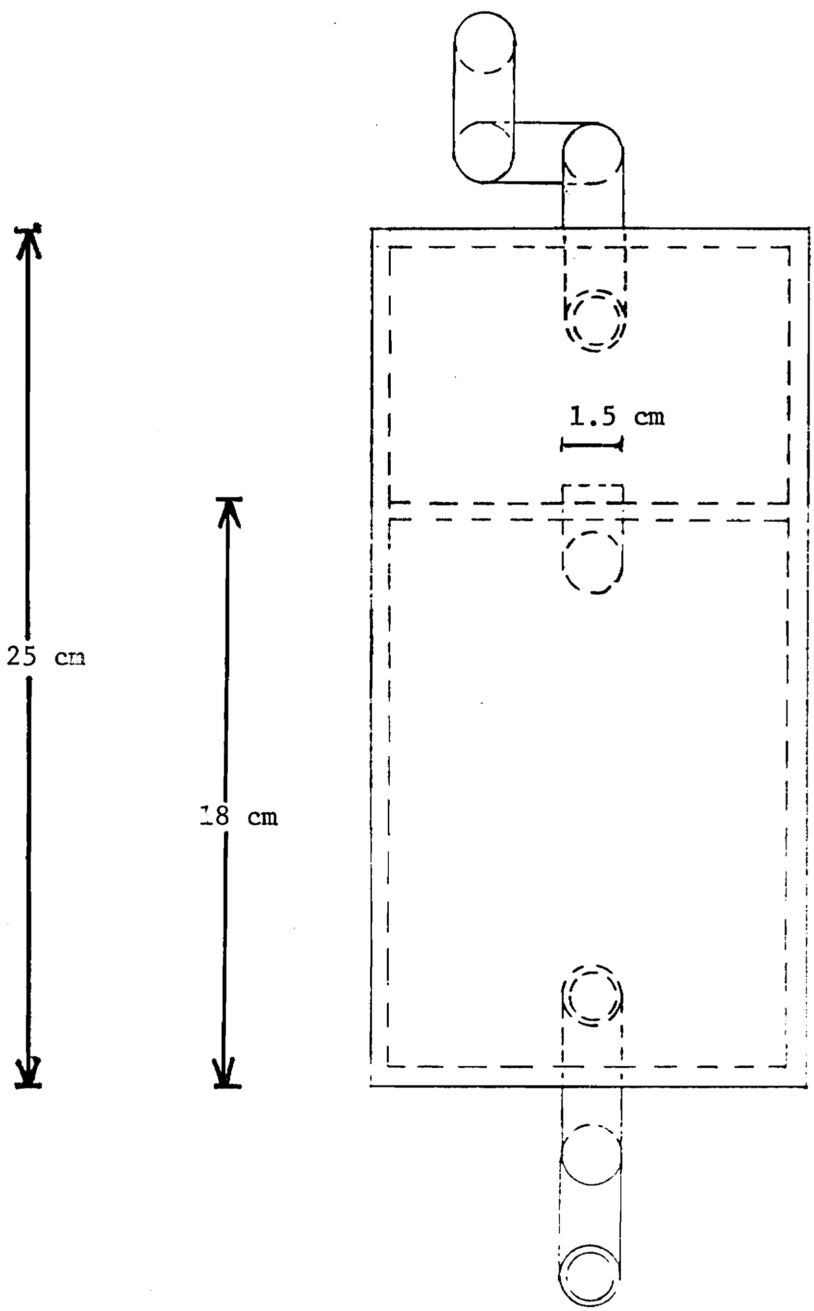

Figure 3. Detail of a Laboratory Scale Septic Tank, Top View.

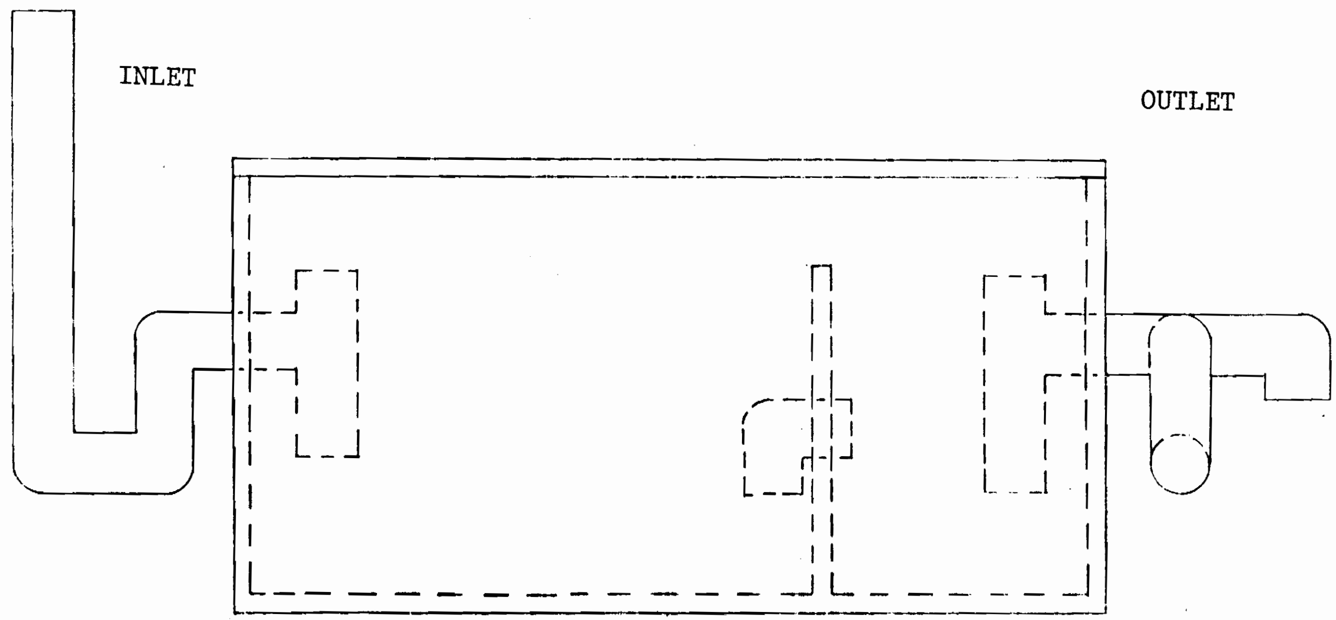

Figure 4. Detail of a Laboratory Scale Septic Tank, Side View.

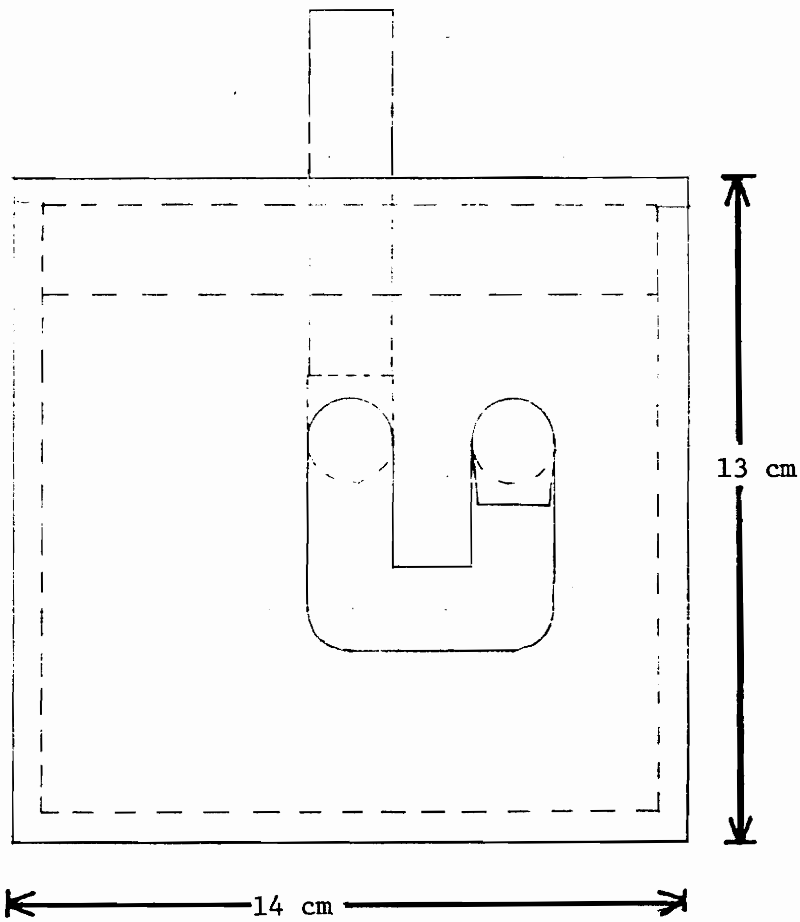

Figure 5. Detail of a Laboratory Scale Septic Tank, End View.

doses of Aqua-Kem were added. The batch digesters were operated at room temperature (approximately 25 degrees centigrade) for four days. The flasks were frequently gently swirled to mix the contents. The experimental procedure required sacrificing digesters. Each entire 300-mL digester volume was placed in the vacuum filtration device. The vacuum filtration apparatus consisted of a vacuum pump, 100-mL graduated cylinder, Buchner funnel, vacuum adapter collar, and 45 micron filter paper. The ratio of filtrate volume recovered in 60 seconds from the control divided by the volume of filtrate recovered in 60 seconds recovered from the dosed systems provided a comparison of the relative dewatering rate of the solids.

Digester gas production experiments required one liter of seed material diluted with an additional liter of tap water containing five grams of Bacto-Peptone. This produced a sufficient volume of feed material at a 50 percent sludge dilution to batch load six 300-mL digesters at one time. The feed solution contained 2.5 g/L Bacto-Peptone. This concentration was chosen because digesters loaded at this level produced significant quantities of gas in a four day period. Digesters were batch fed 300 mL of the feed mixture to which holding-tank additives were applied in doses ranging from 0 to 100 percent of the recommended dose for each product. Full strength concentrations of the chemicals were: 3.125 mL/L , 1.56 mL/L, respectively, for the liquid additives D-Odor-It, and Aqua-Kem; and 749 mg/L for Dri-Kem, the dry additive. The total gas volume produced over a four day period was measured for each digester. Relative biological gasification activity was calculated from this data. Relative biological gasification activity has been previously defined by Pearson et al. (12) as:

$$A = v/V \qquad (1)$$

where:

A = Relative biological gasification activity
v = volume of gas produced from the dosed digester
V = total volume of gas produced from an undosed control digester during the same time period.

Relative biological gasification activity is an indicator of anaerobic activity, and the inhibitory effects of a toxicant can be determined from calculations of this term (12).

Septic Tank Experiments

The septic tanks were loaded with one liter of anaerobically digested sludge to provide the initial anaerobic biomass. No additional biomass was added to the septic tank systems. Bacto-Peptone at 200 mg/L and tap water were used to construct synthetic wastewater in five liter batches. A similar synthetic wastewater feed was utilized in an activated sludge study. The four tanks were slug fed one liter of solution daily over a four hour period. The tanks were allowed to acclimate to the feed prior to chemical addition. Samples were collected for the analysis of effluent total suspended solids and chemical oxygen demand of the septic tank influent and effluent. These analysis were performed according to Standard Methods (17). One septic tank was chosen as the control. It received the synthetic wastewater only. Boat holding-tank additives were introduced into the synthetic feed for the three other laboratory septic tanks for two day periods, simulating a weekend, at 20, 50, and 100 percent of the product recommended dose. On each respective simulated weekend, the dosed septic tanks received an identical fraction of the recommended chemical dose. Each septic tank only received one deodorant product throughout the study. The research plan was to shock-load each dosed unit for two days to simulate heavy, weekend-use, then allow recovery over a longer period. The recover time was continued until it was obvious that either recovery or failure had occurred.

An additional experiment was performed at the 20 percent level to examine tank recovery from long term exposure to holding-tank additives. The tanks were exposed for 10 days to holding-tank chemicals. No additional feed was provided during this time period. Following the ten day no-feed period, the tanks were then fed on the daily schedule with Bacto-Peptone and the effluents sampled for COD.

IV. RESULTS AND DISCUSSION

The data presented are the results of laboratory studies investigating the effects of holding-tank chemical additives on anaerobic wastewater treatment. The anaerobic treatability of wastewater containing the chemical additives was investigated for batch digesters and septic tanks. Digester experiments were preliminary in nature. General physical effects of chemical and sludge dilutions were investigated. These preliminary experiments were followed by the septic-tank studies. Septic-tank treatment, however, was the major emphasis of the study because septic tanks are the likely recipient of such wastes.

Preliminary Experiments

Aqua-Kem's Effect on the Solids Filtering Rate

Figure 6 presents the results of the experiment to determine solids filterability as a function of Aqua-Kem dose. The dosages are percentages of the dose recommended for use in chemical toilets. As shown, the relative resistance to filtration increased with increasing chemical dose. The 100 percent datum point was destroyed in a laboratory accident. This preliminary experiment was not repeated. The filtration study was originally designed to

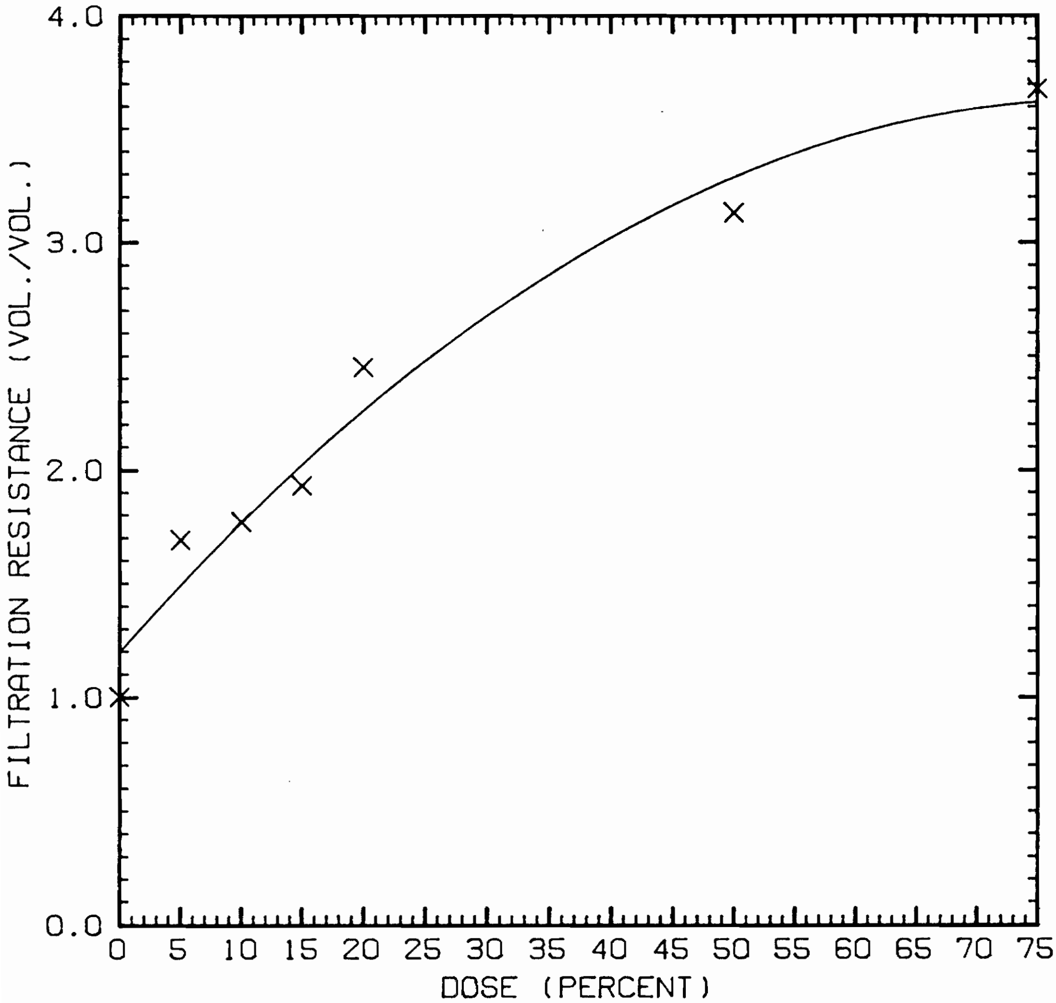

Figure 6. Relative Resistance to Filtration for Digester Solids as a Function of the Percentage of the Recommended Aqua-Kem Dose for Odor Control.

predict septic tank-drain field failure, which is caused by clogging of the soil pore spaces as a function of holding-tank chemical dose.

These results (Figure 6) indicated that anaerobic digesters dosed with Aqua-Kem produced a sludge that was increasingly difficult to dewater. Because septic tank drain fields receive settled wastewater from septic tanks, the solids dewatering experiment may be a better predictor of handling-problems associated with the disposal of septic tank sludge than of potential septic-tank drain-field problems. The most important feature of this experiment is, however, that it showed that these chemicals can adversely affect the physical characteristic of septic-tank solids (dewaterability) and, therefore, may affect septic-tank performance, and these effects can occur at doses as low as five percent of the recommended dose. Additional experiments were not undertaken for the other additives because solids handling was not an objective of this study.

Effects of Biomass Concentration

The anaerobic effect of biomass concentration on gas production from controls and the Aqua-Kem dosed systems is shown in Figure 7. It was thought that if full-strength digester sludge had been used, gas production might be so

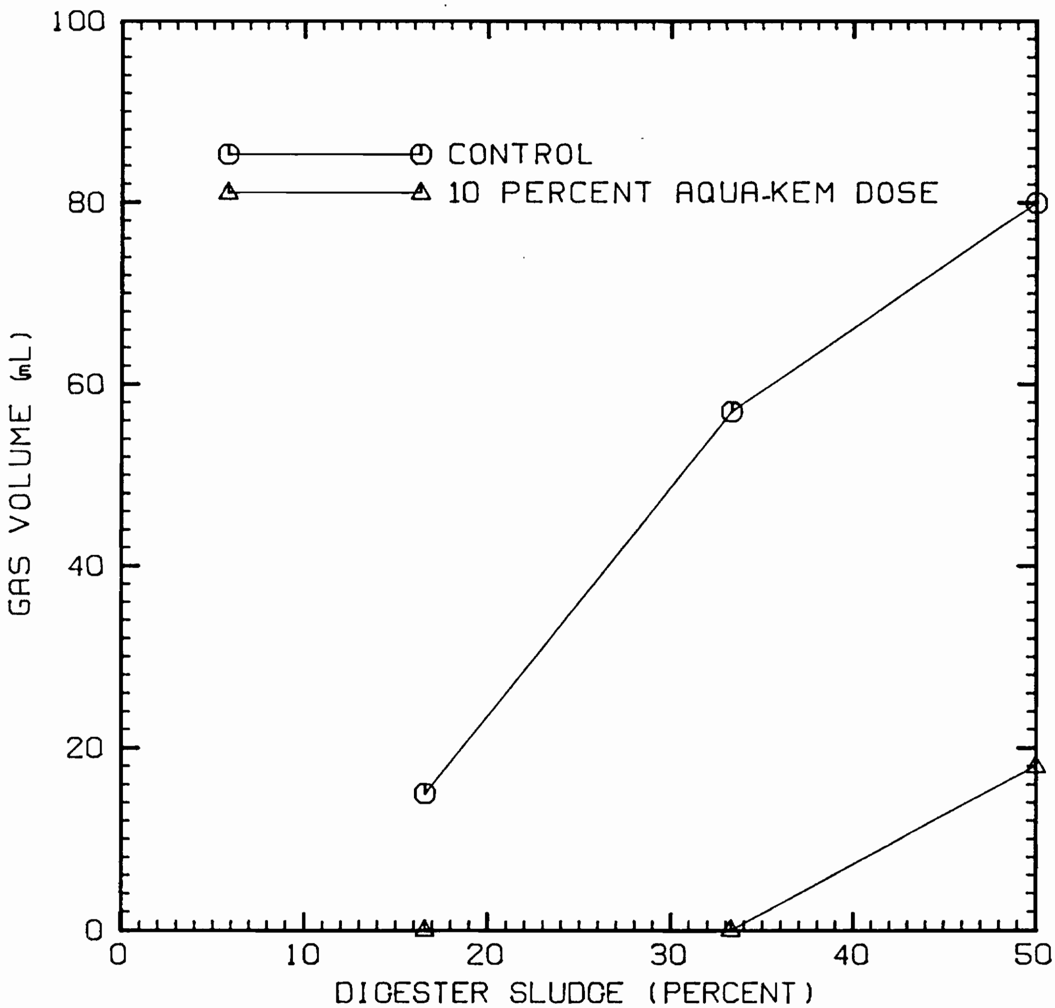

Figure 7. Determination of Gas Production as a Function of Digester Sludge Concentration.

great that gas collector capacities might be exceeded. Excess sludge dilution, on the other hand, might make variations in gas production due to holding-tank additives undetectable because the volumes would be quite small. It is obvious from Fig. 7 that, as was expected, gas production increased with sludge content for the control systems. Batch digesters that received 10 percent of the recommended Aqua-Kem dose did not produce gas at sludge concentrations of 16 and 33 percent by volume. Gas production in the control was four times greater than that in the dosed system for the digesters loaded with the feed mixture containing 50 percent sludge by volume. Similar volumes of gas were produced from the control and the dosed system at sludge concentrations of 16 and 50 percent, respectively. On the basis of these data, the 50 percent sludge concentration was selected for use in further gas-production experiments.

Anaerobic Biological Gasification

The impact of holding-tank chemicals on gas production was determined. Gas production was measured in a series of laboratory, batch digesters that had been dosed with varying concentrations of holding-tank chemicals. It was expected that holding-tank additives would inhibit anaerobic gasification at full-strength because this is one of the major ways by which the chemicals serve to control odor (1, 2).

Figure 8 presents the results of the anaerobic-gasification activity study for batch digesters exposed to the three holding-tank chemicals. Initial experiments were performed with digesters shock dosed with Aqua-Kem at dosages equal to 50, 75 and 100 percent of the recommended dose. It is obvious from Fig. 8 that this range of chemical dosage severely inhibited gas production. Later experiments were completed for lower chemical dosages for all three additives. It can be seen that activity, as measured by gas production, decreased with increased chemical dose. The data are in agreement with previous studies with formaldehyde (7, 12), and indicate that there is a potential for the additives to upset septic-tank, treatment systems. Aqua-Kem, which contains formaldehyde as its odor control ingredient, suppressed the anaerobic gasification activity more than 80 percent at 20 percent of the recommended dose. The depression of gas production by the other two holding tank additives was not as severe. Reductions of 10 and 25 percent in gas production were evident from similar (20 percent recommended dose) concentrations of the other products, which are methanol- and paraformaldehyde-based (D-Odor-It, and Dri-Kem, respectively).

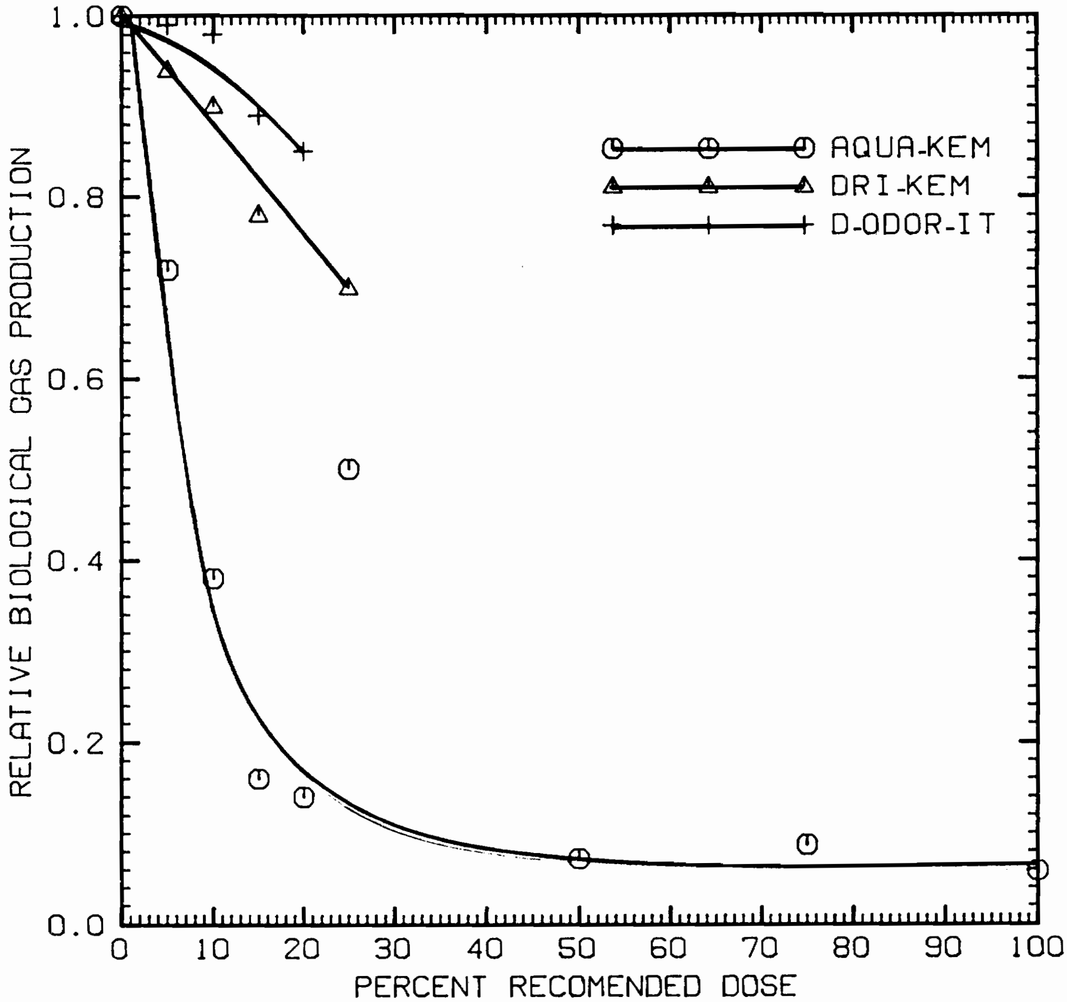

Figure 8. Effect of Chemical Addition on Digester Gas Production.

Septic Tank Experiments

The remaining figures detail laboratory septic-tank performance in response to varying chemical dosages. Figures 9-11 show data for effluent TSS as a function of operational time of the septic tanks. Figures 12-16 present a comparison of influent and effluent COD concentrations for the laboratory septic tanks. The start-up period was defined as the period prior to day three. Day three to day 35 delineated the operating period. Recovery periods were defined as the period of time starting two days after chemical dosage and ending at the next addition of holding-tank chemicals. The change in COD across the system was the result of both degradation and dilution.

Effects On Septic Tank Effluent Total Suspended Solids

For the operating period after initial start-up, the average effluent TSS concentration from the control was 19.5-mg/L with a standard deviation of 9.6-mg/L. The system treated with D-Odor-It had an average effluent TSS concentration of 23.6-mg/L. The lowest average effluent TSS concentration, 17.8-mg/L, was observed in the effluent from the system dosed with Dri-Kem. The Aqua-Kem dosed septic tank had the highest average concentration (23.5-mg/L). The mean values were statistically not different at the 95 percent confidence level. Only one chemical, D-

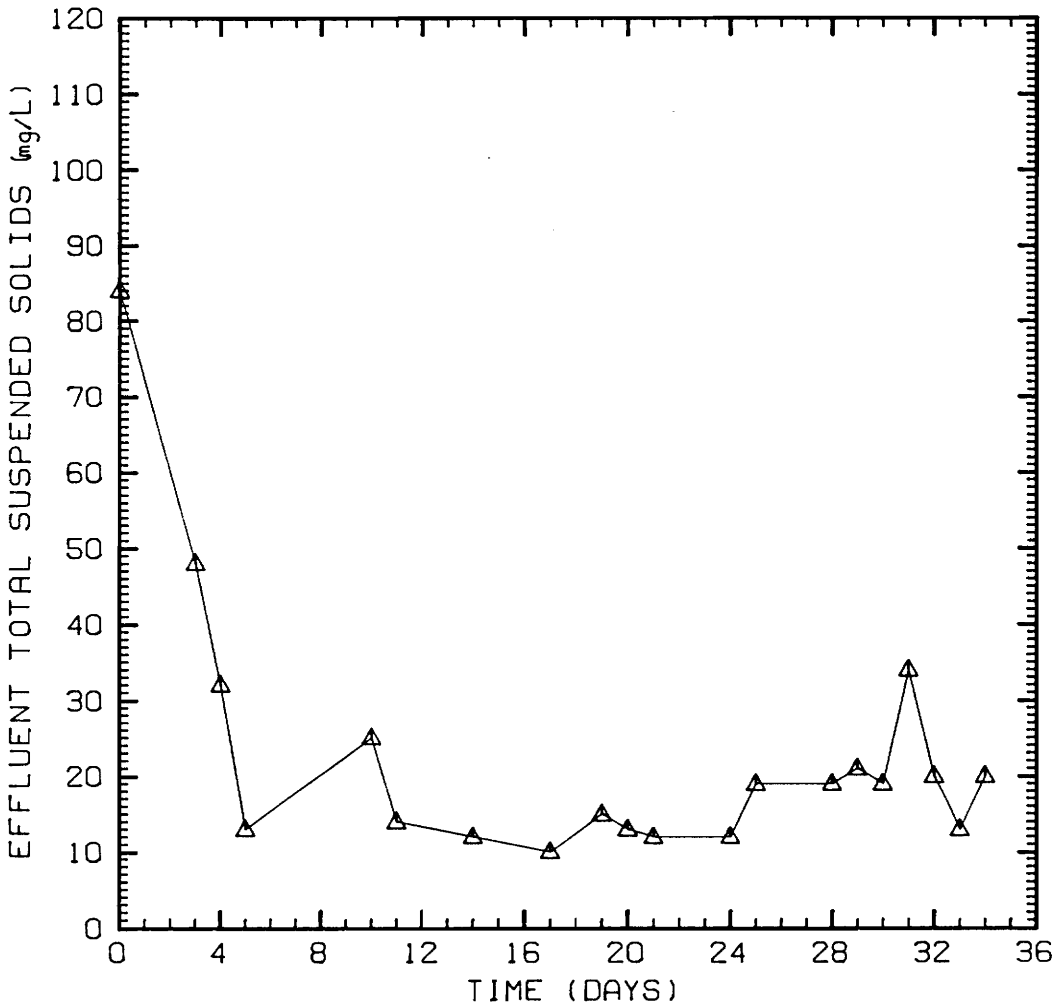

Figure 9. Effluent TSS Over Time for the Control Septic Tank.

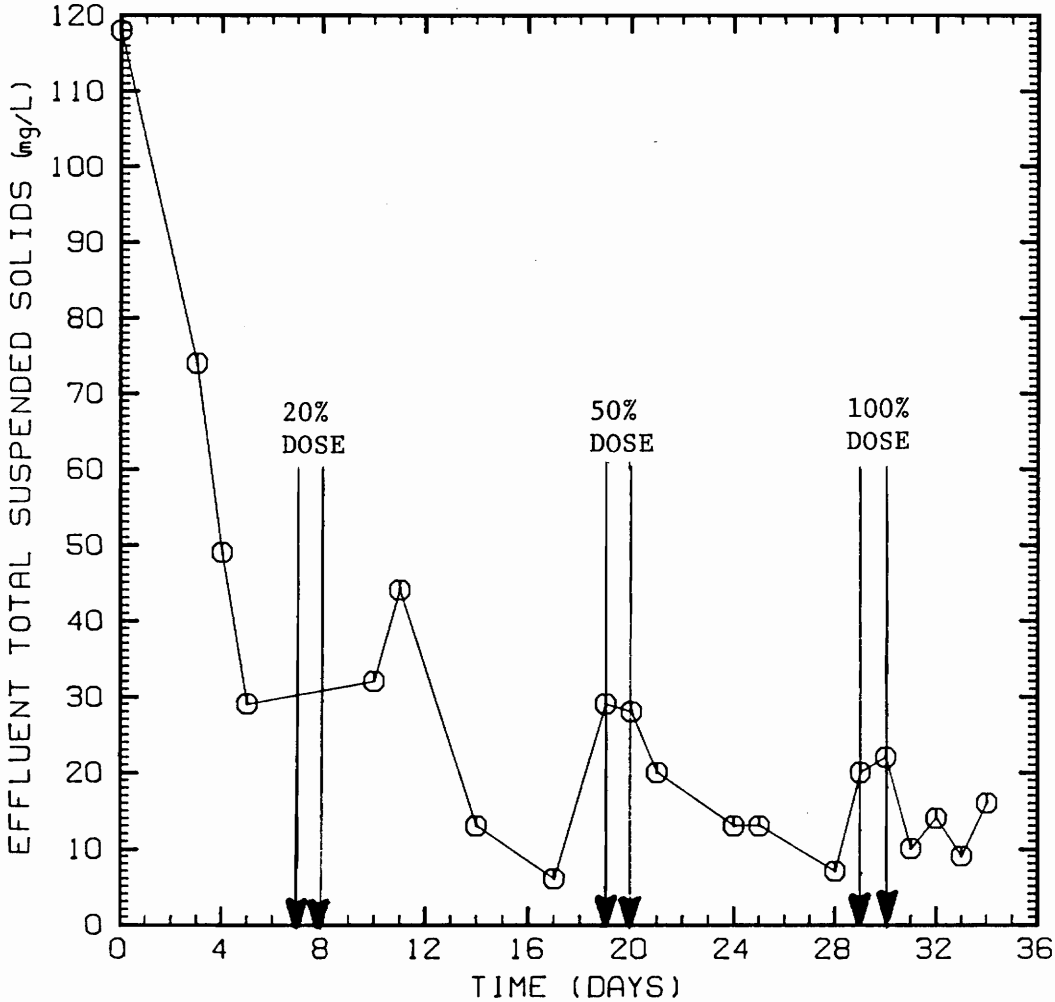

Figure 10. Effluent TSS Over Time for The D-Odor-It Dosed Septic Tank. Dose Percentage is the Percentage of the Dosage Recommended for Odor Control in a Chemical Toilet.

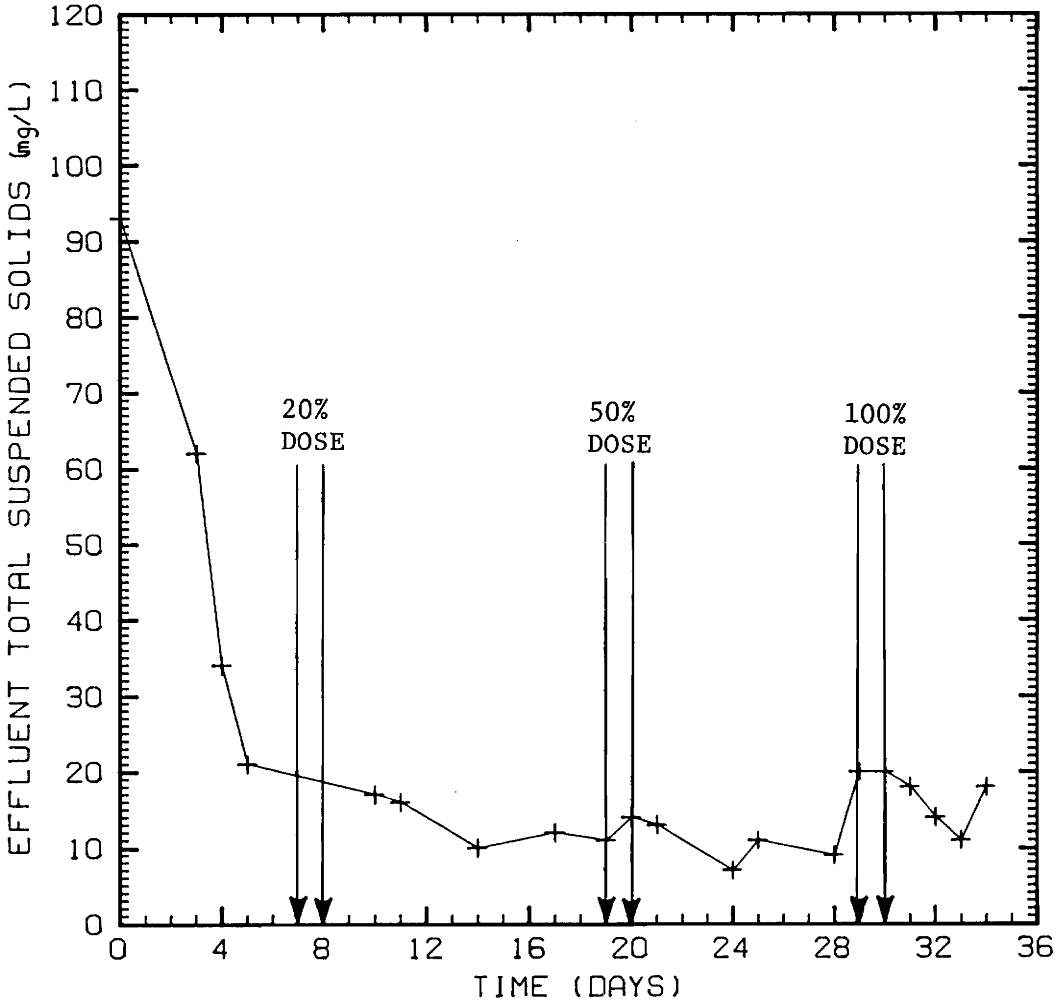

Figure 11. Effluent TSS Over Time for the Dri-Kem Dosed Septic Tank. Dose Percentage is the Percentage of the Dosage Recommended for Odor Control in a Chemical Toilet.

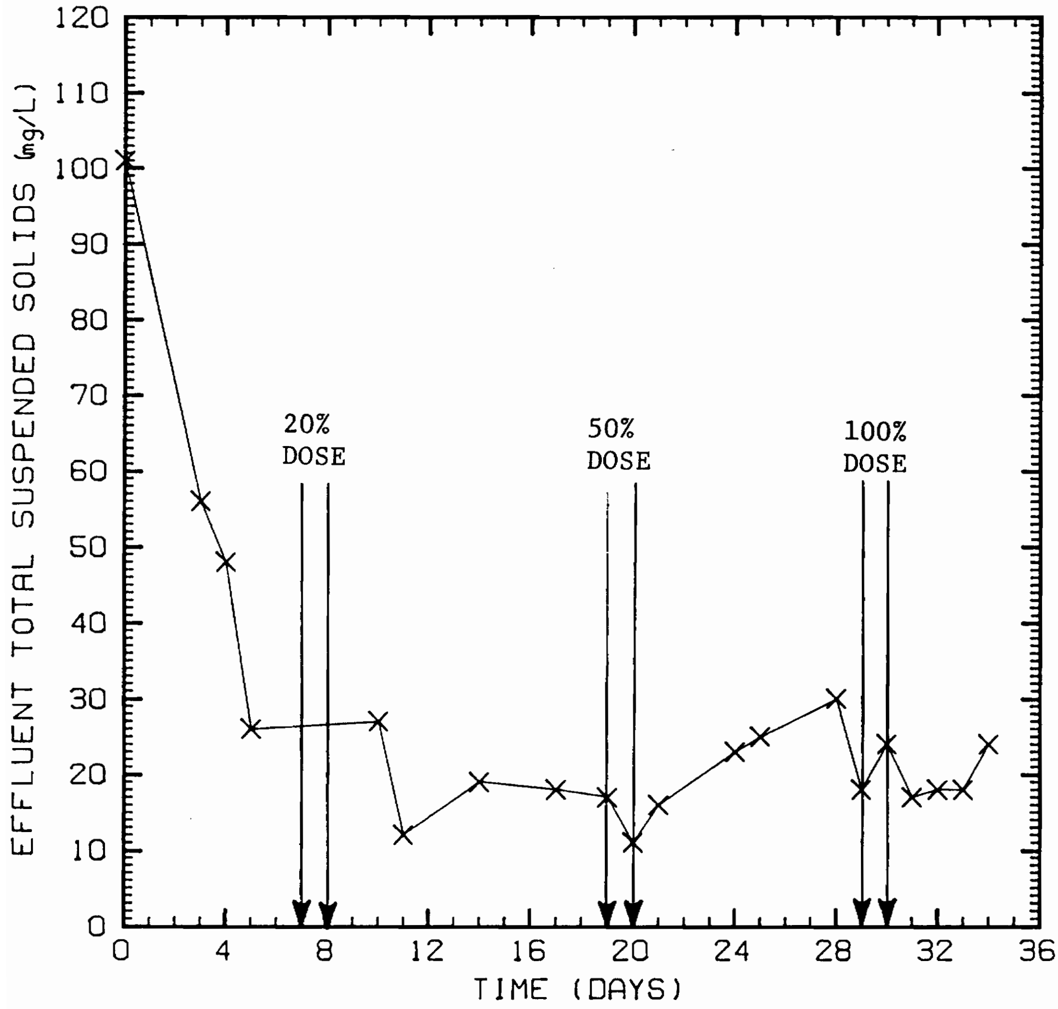

Figure 12. Effluent TSS Over Time for the Aqua-Kem Dosed Septic Tank. Dose Percentage is the Percentage of the Dosage Recommended for Odor Control in a Chemical Toilet.

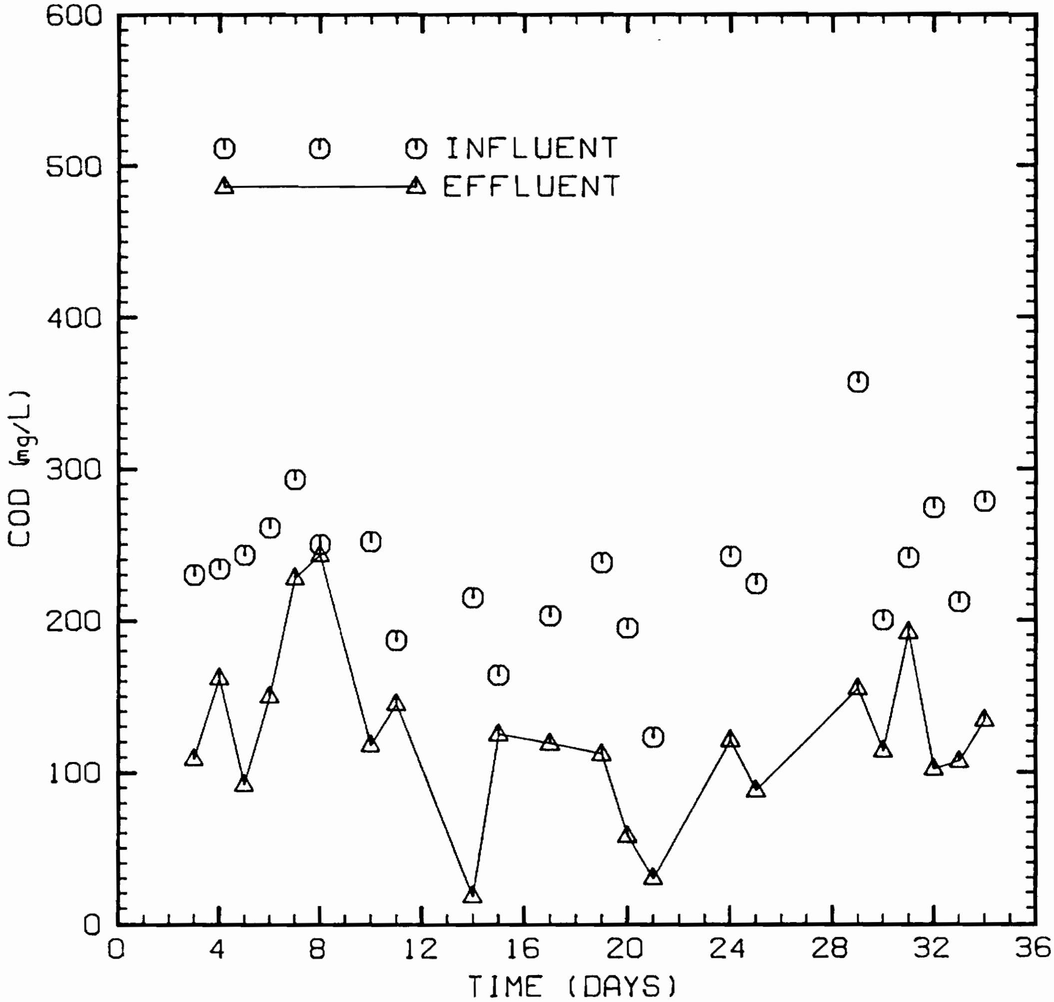

Figure 13. Influent and Effluent COD Concentrations Over Time for the Control Septic Tank.

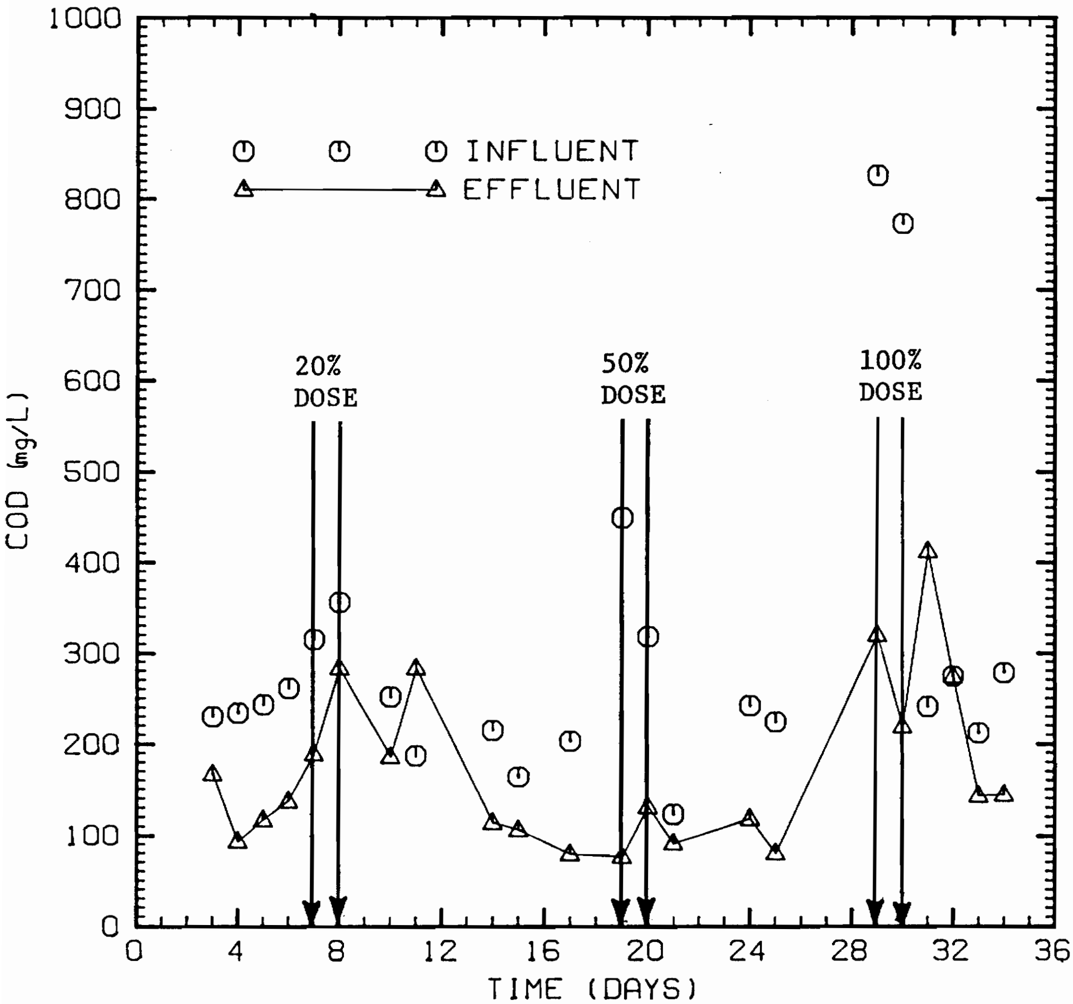

Figure 14. Influent and Effluent COD Concentrations Over Time for the D-Odor-It Dosed Septic Tank.

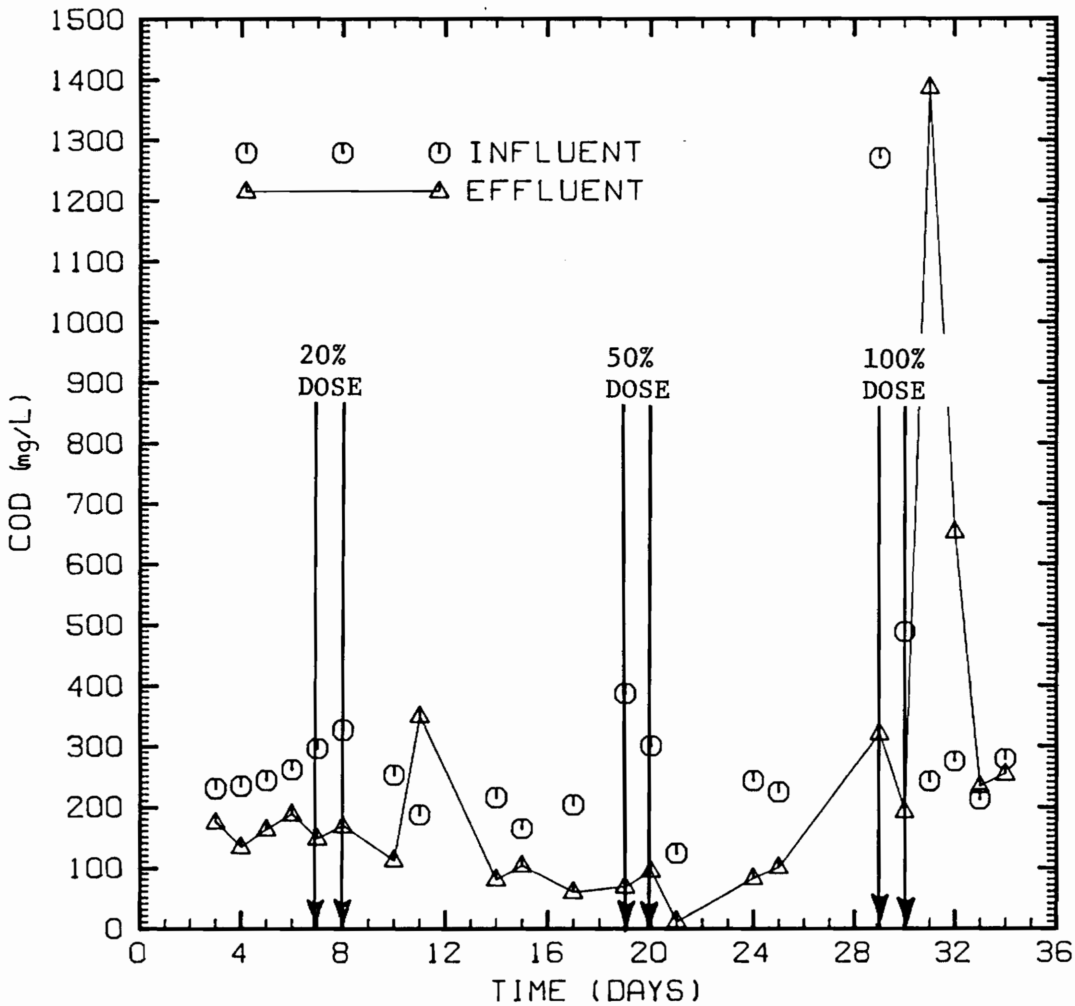

Figure 15. Influent and Effluent COD Concentrations Over Time for the Dri-Kem Dosed Septic Tank.

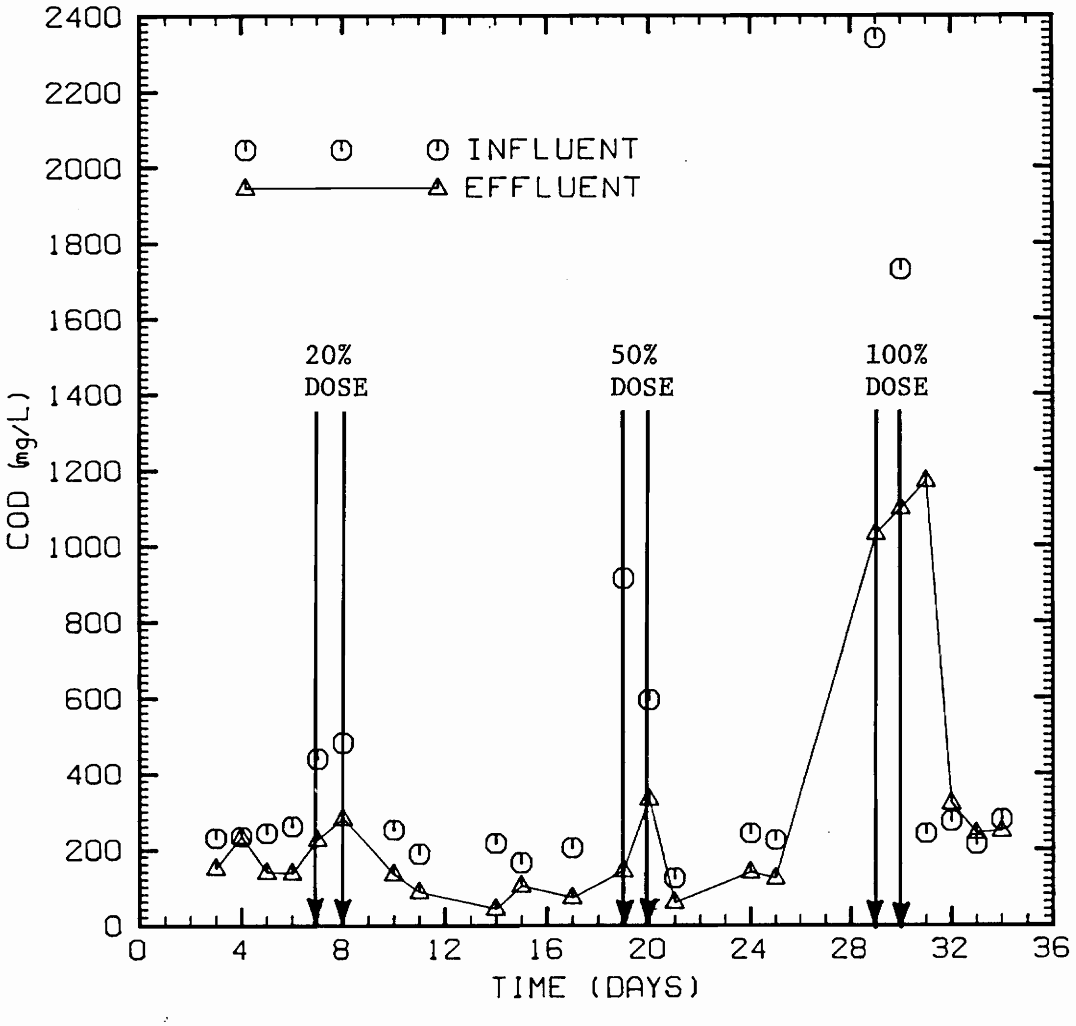

Figure 16. Influent and Effluent COD Concentrations Over Time for the Aqua-Kem Dosed Septic Tank.

Odor-It, appeared to influence effluent total suspended solids concentration (Figure 10). Effluent TSS increased slightly during and immediately after chemical dosing at doses of 20 and 50 percent. The magnitude of the increase declined after each chemical addition. The decreased response may be due to better flocculation resulting from increased biological growth.

COD Effects

It is obvious from Figures 14-16 that the holding-tank chemicals were high in COD. In the control system the average influent COD concentration was 233 mg/L and decreased to an average effluent COD concentration of 124 mg/L, an average removal rate of 46.8 percent. The average removal rates during the entire operating period were 43.2, 23.8, and 38.6 percent in units dosed with D-Odor-It, Dri-Kem, and Aqua-Kem, respectively; The average COD removal rates were 45.3, 44.8, and 56.3 percent, respectively, for the period prior to receiving wastewater containing the respective full strength deodorants. Average effluent COD concentrations during this operating period were 141, 127, and 131 mg/L for D-Odor-It, Dri-Kem, and Aqua-Kem dosed systems, respectively. The similarity between these previous values and the corresponding control system average effluent COD concentration (124 mg/L) indicated that the systems were able to treat wastewater containing holding tank chemicals up to 50 percent of the recommended concentration. Recovery was within two days when both the 20 and 50 percent doses were applied.

Figures 17-19 show the average effluent COD concentrations for the recovery periods, after chemical additions. D-Odor-It and Dri-Kem had average effluent COD concentrations of 146 and 148 mg/L, respectively, for the 20 percent dose recovery period. The Aqua-Kem dosed system effluent COD concentration, 75 mg/L, was the lowest of the dosed systems for this time period.

The health of the D-Odor-It and Dri-Kem systems generally improved after the systems were shock loaded with 50 percent of the recommended holding tank chemical dose. Each of these systems produced the highest quality effluent at this time (Fig. 17, 18). The chemicals may have stimulated biological degradation or additional biomass growth which improved COD removal. Average effluent COD concentrations, for the recovery period following dosing at the 50 percent level, were 105, 99, 91, and 131 mg/L, for the control and septic tanks receiving D-Odor-It, Dri-Kem, and Aqua-Kem feeds, respectively.

A different picture emerges from the examination of the effects of full-strength holding-tank chemicals on the average effluent COD concentrations. The fully-dosed systems had effluent COD concentrations 1.2, 2.0, and 2.0

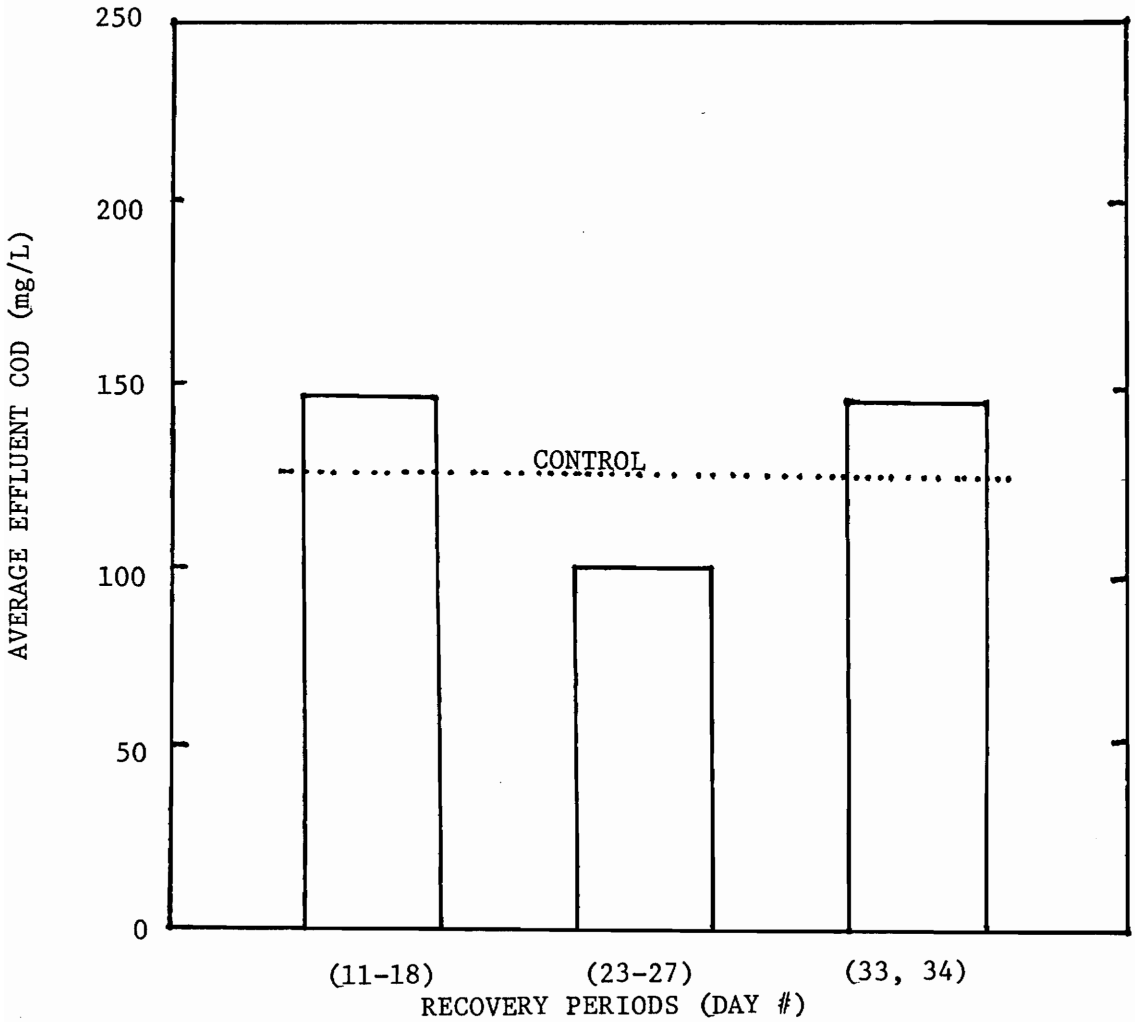

Figure 17. Average Effluent COD Concentrations for the Recovery Periods After D-Odor-It Additions.

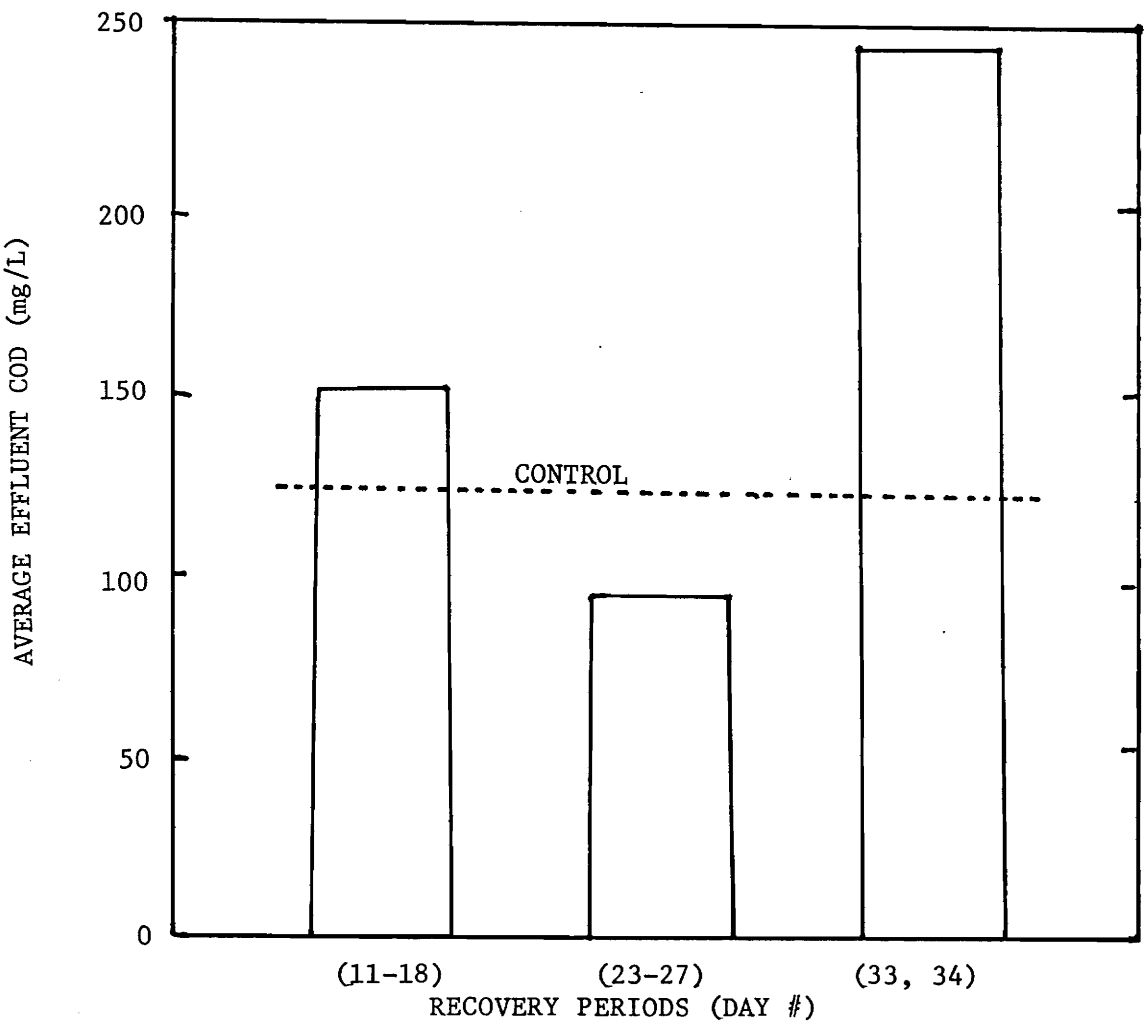

Figure 18. Average Effluent COD Concentrations for the Recovery Periods After Dri-Kem Additions.

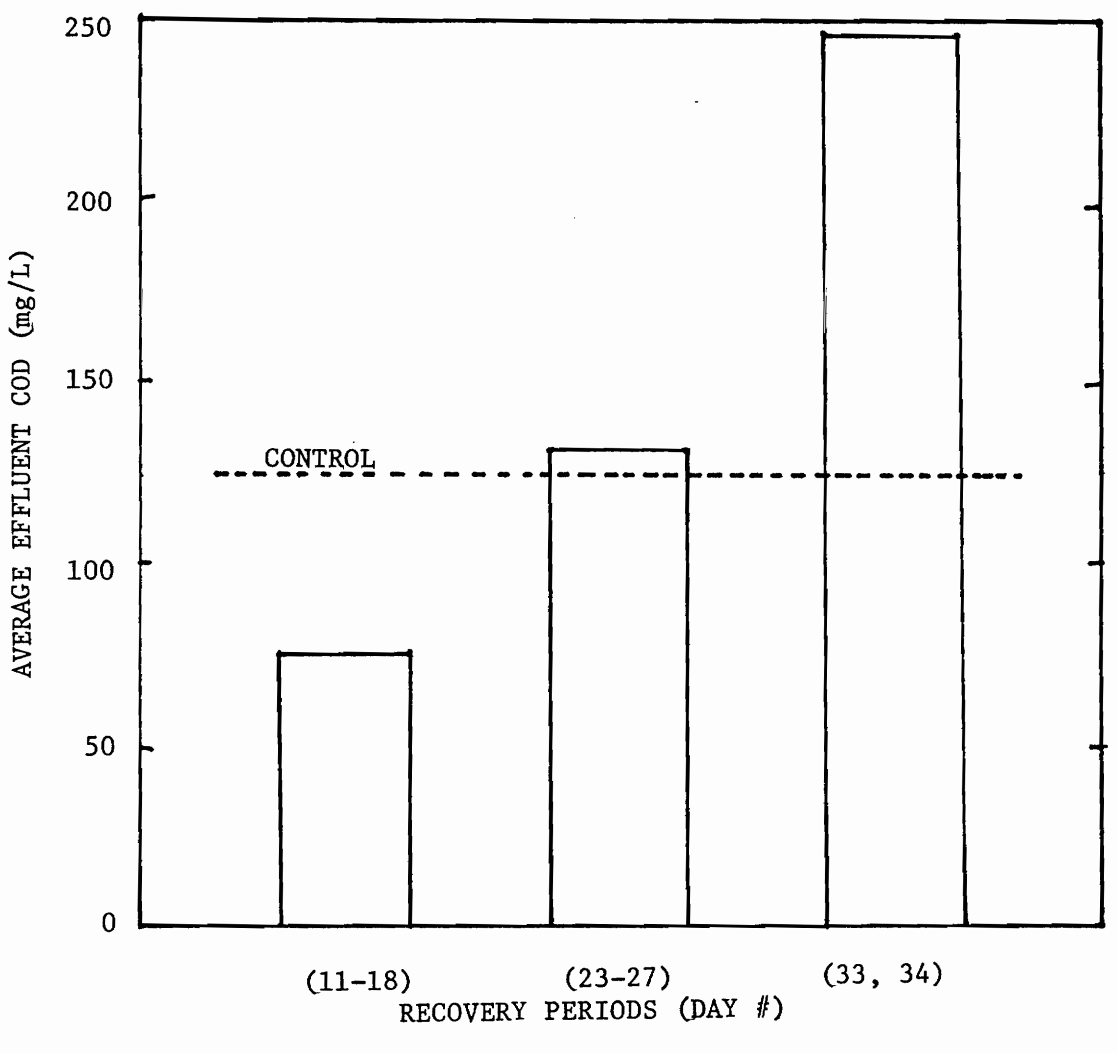

Figure 19. Average Effluent COD Concentrations for the Recovery Periods After Aqua-Kem Additions.

times the average effluent COD concentration from the control data base of 124 mg/L COD, respectively for D-Odor-It, Dri-Kem, and Aqua-Kem. Additionally, the data indicates, after exposure to full-strength Aqua-Kem and Dri-Kem holding-tank deodorant chemicals, influent COD concentrations were passed through the system after a two day delay with no biological degradation, a result expected from previous studies on formaldehyde inhibition of aerobic and anaerobic treatment systems (7, 12, 13). Figures 15 and 16 exhibit signs of treatment failure after full-strength chemical dosing. The influent and effluent COD concentrations were nearly equal on days 33 and 34. Inadequate septic-tank operation is likely to lead to system failure (1, 2, 11-14). The high organic content of septic tank effluent under heavy loading conditions would require additional drain field area to prevent excessive bio-mat growth and clogging of the system (1, 2, 11-14). The observed decrease in septic tank performance after exposure to full-strength deodorant chemicals coupled with expected drain field failure suggests that system failure could be expected to result at full holding tank chemical doses.

Extended Exposure

Figure 20 indicates that the septic-tank treatment systems recovered favorably from long term exposure to the

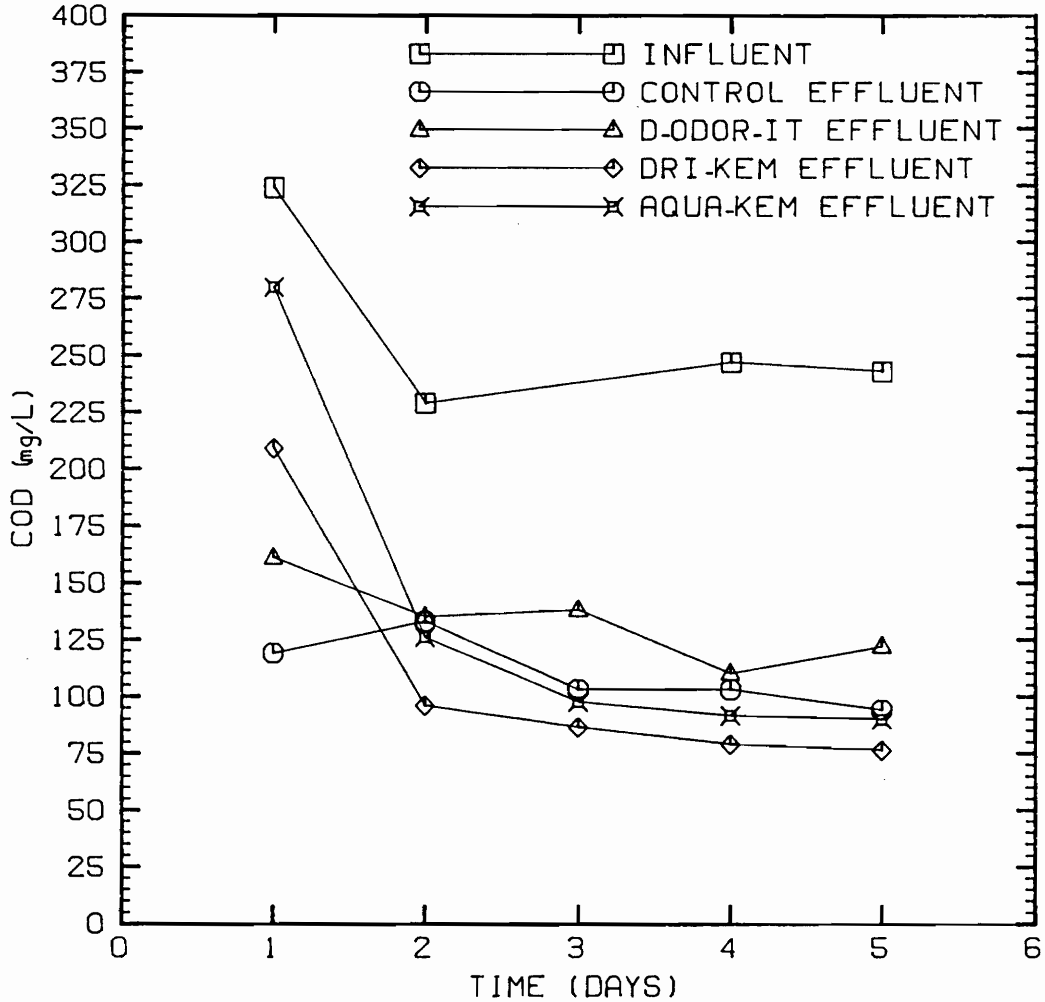

Figure 20. Effluent COD Following Exposure to Holding Tank Chemicals at 20 Percent of the Full-Strength Dose in Chemical Toilets For Ten Days.

additives at 20 percent of the recommended concentration. This type of exposure would potentially result from a high use period, a holiday weekend, followed by a period of low marina use.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the preliminary batch digester experiments and the septic tank experiments, the following conclusions were derived from this study.

1. Decreased digester gas production indicated the boat holding-tank chemicals inhibited anaerobic activity.
2. Digester solids filtration rates were adversely affected by Aqua-Kem.
3. Mean septic-tank effluent total suspended solids were not statistically different for the control and the dosed systems.
4. COD removals were inhibited in septic tanks receiving wastewater containing full-strength concentrations of the chemicals. Septic tanks shock loaded with the formaldehyde and paraformaldehyde holding tank additives, Aqua-Kem and Dri-Kem, at full strength did not recover.
5. The chemicals did not adversely affect septic-tank performance at the 20 and 50 percent concentrations.

Recommendations

Marina operators should provide dilution capacity in their septic-tank treatment systems to prevent potential problems. Assuming that boat sewage-holding tanks contain full-strength odor-control chemicals, marinas should provide 5 liters of septic-tank volume for each liter of boat wastewater accepted each day. A dilution factor of four would provide dilution volume to reduce the strength of the wastewater by one-half and a two day hydraulic detention period. The recommended dilution factor of five provides for this and an additional safety factor to allow for additional sludge accumulation and storage volume.

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IV. APPENDIX

Table A-1. Digester Sludge Resistance to Vacuum Filtration as a function of Aqua-Kem Dose.

Sample	Aqua-Kem Conc. (mL/L)	% Dose	Relative Resistance
1	0	0	1
2	0.08	5	1.69
3	0.16	10	1.77
4	0.23	15	1.93
5	0.31	20	2.45
6	0.39	25	5.15
7	0.78	50	3.13
8	1.17	75	3.68

Table A-2. Anaerobic Gas Production From Digesters Treating Bacto-Peptone or Bacto-Peptone and Aqua-Kem Dosed Synthetic Wastewaters.

Wastewater	Volume of Gas Produced (mL)	
	Control	Aqua-Kem
Sludge Concentration (Percent by Volume)		
16.6	15	0
33.3	57	0
50	80	18

Table A-3. Biological Activity as a Function of Holding Tank Chemical Dose.

	Relative Biological Gas Production		
Chemical	Aqua-Kem	Dri-Kem	D-Odor-It
% Dose			
0	1	1	1
2.5			.95
5	.72	.94	.99
10	.38	.90	.98
15	.16	.78	.89
20	.14		.85
25	.5	.70	
50	.072		
75	.087		
100	.058		

Table A-4. Average Daily Septic Tank Effluent Suspended Solids Data.

Tank	Total Suspended Solids (mg/L)			
	D-Odor-It A	Control B	Dri-Kem C	Aqua-Kem D
Day				
0	118	84	93	101
3	74	48	62	56
4	49	32	34	48
5	29	13	21	26
10	32	25	17	27
11	44	14	16	12
14	13	12	10	19
17	6	10	12	18
19	29	15	11	17
20	28	13	14	11
21	20	12	13	16
24	13	12	7	23
25	13	19	11	25
28	7	19	9	30
29	20	21	20	18
30	22	19	20	24
31	10	34	18	17
32	14	20	14	18
33	9	13	11	18
34	16	20	18	24

Table A-5. Average Daily Septic Tank Influent Chemical Oxygen Demand.

Tank	Chemical Oxygen Demand (mg/L) D-Odor-It A	Control B	Dri-Kem C	Aqua-Kem D
Day				
3	230	230	230	230
4	234	234	234	234
5	243	243	243	243
6	261	261	261	261
7	315	293	296	439
8	356	250	326	481
10	252	252	252	252
11	187	187	187	187
14	215	215	215	215
15	164	164	164	164
17	203	203	203	203
19	449	238	386	913
20	318	195	300	593
21	123	123	123	123
24	242	242	242	242
25	224	224	224	224
29	826	357	1270	2340
30	773	200	488	1730
31	241	241	241	241
32	274	274	274	274
33	212	212	212	212
34	278	278	278	278
Average	301	233	302	458

Table A-6. Average Daily Septic Tank Effluent Chemical Oxygen Demand.

	Chemical Oxygen Demand (mg/L)			
Tank	D-Odor-It A	Control B	Dri-Kem C	Aqua-Kem D
Day				
3	167	109	175	150
4	93	162	134	232
5	117	92	163	139
6	137	150	188	137
7	189	228	148	225
8	283	243	168	282
10	186	118	112	134
11	283	145	349	86
14	114	18	80	41
15	106	125	103	103
17	79	119	59	71
19	76	112	68	143
20	131	58	94	332
21	91	30	11	58
24	118	121	82	139
25	80	88	100	123
29	320	155	320	1030
30	219	114	192	1097
31	412	192	1387	1170
32	274	102	652	320
33	143	107	233	242
34	144	134	253	247
Average	171	124	231	296

Table A-7. Septic Tank Recovery Data.

Day	Chemical Oxygen Demand (mg/L)				
	Influent	Control	D-Odor-It	Dri-Kem	Aqua-Kem
1	324	119	161	209	280
2	229	133	135	96	126
3		103	138	86	98
4	247	103	110	79	92
5	243	94	122	76	90

VITA

Born June 17, 1964, in Virginia Beach, Virginia, Mr. Howard has made Virginia his home for most of his life. He has spent some time in South Carolina and Tennessee. He plans to make his new home in Oak Ridge, TN. For much of the past six years, Sam has been a "towny", resident of Blacksburg, Virginia. He and Robert, his brother, have often been asked; "Are you just visiting?" at social events. It is obvious that he doesn't fit the stereotype of a college student; often dressed in leather motorcycle riding gear, he rides a red Kawasaki 550 GPZ and a Honda CM 450 E.

Sam's professional career spans many trades and reflects his adaptability and varied interests. He prepared for a career in electronics by attending both Peninsula Vo-Tech North and Denbigh High Schools in Newport News, Virginia. However, he found himself the recipient of a Virginia Electric and Power Co. scholarship to study Nuclear Reactor Operations as the result of test taken in Richmond to become an instrument technician. Square, alias given to Sam by his loving Father, has been employed as: an Unlicensed Reactor Operator, Surry Nuclear Power Station; a Painter and an Electrician, Newport News Shipbuilding; and a Health Physics Technician, Virginia Tech.

Thanks to a stimulating program at Memphis State University, Sambo found academia rewarding. He sought the challenge of a B.S. in Nuclear Science from Virginia Tech. After serving first as President and then Vice-President of the Tech chapter of the American Nuclear Society, Sam's Mother was surprised to learn that in August, 1986, her son had: 1. completed his undergraduate degree, 2. declined a lucrative position with a "Beltway Bandit", and 3. enrolled for the fall quarter as a graduate student in Environmental Engineering at Virginia Tech. Two short years later he could be found hard at work completing this thesis.

Samuel C Howard