Laboratory Scale Septic Tanks[1]

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ABSTRACT. Laboratory studies of on-site wastewater treatment systems require a dependable supply of septic tank effluent. The goal of this study was to produce a daily supply of septic tank effluent of approximately 140 mg/l BOD_5, 75 mg/l TSS, and 30 mg/l NH_3-N for use in laboratory studies. The laboratory tank had to be easy to operate, and emulate a septic tank by producing some fluctuation in effluent quality, have the ability to maintain sludge and scum layers, and operate with minimal maintenance. Nine replicates of laboratory septic tanks were developed and tested for twelve weeks. Tanks were constructed from 114 l cylindrical polyethylene containers with lids, a floating baffle, and discharge pipe. The tanks received a daily mixture of primary sludge, ammonium chloride, and tap water. The resulting septic tank effluent averaged 161 mg/l BOD_5, 75 mg/l TSS, and 25 mg/l NH_3-N.

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INTRODUCTION

More than 980,000 homes in Ohio and more than 25 million houses in the United States use septic tanks or cesspools as a step in wastewater treatment (Bureau of Census 1992). This represents about one fourth of the single family housing units in the United States. This number is growing steadily as approximately 350,000 new homes are built each year that are beyond the reach of public sewer systems (Anderson and others 1985). Most of these systems will use septic tanks as the first stage of treatment for household wastewater. As research efforts are undertaken to develop improved wastewater treatment systems for individual homes, investigators will need a representative supply of wastewater to conduct their experiments.

Studies have shown that septic tank effluent is highly variable in both quality and quantity. The US EPA (1980) has listed average values for septic tank effluent from more than 300 tanks reported by 5 investigators. BOD_5 (biochemical oxygen demand) values ranged from a low of 7 mg/l to a high of 480 mg/l. The average BOD_5 value for the 316 tanks reported was 142 mg/l. Total suspended solids (TSS) ranged from a low of 8 mg/l to a high of 695 mg/l. The average value for the 319 tanks was 77 mg/l. Canter and Knox (1985) reported ammonia levels in septic tank effluent. Ammonia levels in septic tank effluent ranged from less than 1 mg/l to 91 mg/l with an average value of 31 mg/l. Cagle and Johnson (1994) reported septic tank effluent characteristics for 85 tanks. The average levels were higher than those reported in earlier studies. Effluent characteristics from actual septic tanks are included in Table 1.

Laboratory studies to improve understanding and performance of septic systems require hundreds of gallons of septic tank effluent. Researchers have used two approaches to supply the necessary wastewater. Tapping into an existing sewer line and collecting actual wastewater was one method used. Mixing together laboratory reagents to create a synthetic wastewater was also applied. Jones and Taylor (1965) diverted raw sewage from a nearby trunk sewer line into a 1000 gallon septic tank. The average retention time in the tank was 48 hours. Miller and others (1994) collected sewage from the engineering building and stored it in a septic tank for use in laboratory experiments. Darby and others (1996) set up laboratory experiments at a wastewater treatment plant and diverted primary effluent. A synthetic wastewater composed of laboratory reagents was used in laboratory studies by Pell and Nyberg (1989) as listed in Table 2. A comparison of these four artificial septic tank effluents to average effluent values is presented in Table 1.

Previous investigators have constructed new plumbing connections and collected an uncontrolled source of wastewater to conduct laboratory studies or mixed a synthetic wastewater in the laboratory. The objective of this study was to bring together the elements of both approaches. The aim was to develop a procedure to mix easily stored wastewater components to emulate septic tank effluent. The wastewater source would not rely on new or direct connections to sewers. In this way, experiments could be carried out nearly anywhere, even some distance from a wastewater source. Ease of operation and the ability to operate with minimal maintenance were also factors to keep labor costs to a minimum.

MATERIALS AND METHODS

Primary sludge from a local wastewater treatment plant (Southerly Wastewater Treatment Plant, Columbus, OH) was chosen as the main ingredient in the preparation of artificial septic tank effluent. The sludge was stored in a refrigerator for up to one month at 4° C until use. A dilution experiment was conducted to estimate the sludge dilution necessary to approximate the BOD_5 and total suspended solids content of septic tank effluent. In the dilution experiment, portions of the sludge were diluted with tap water to make final ratios of 1:40, 1:50, 1:60, 1:70, and 1:80 by volume. These dilutions were mixed in beakers with magnetic stirrers, then allowed to settle for 24 hours. The BOD_5, TSS, and

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TABLE 1

Characteristics of actual and laboratory septic tank effluent in mg/l.

Characteristics*	BOD_5	COD	TSS	Total Nitrogen	Ammonia
Average of actual septic tank studies US EPA 1980	142	296	77	42	–
Average of actual septic tank studies Canter and Knox 1985	138	327	49	45	31
Average of actual septic tank studies Cagle and Johnson 1994	181	–	133	–	65
Connection to sewer line Jones and Taylor 1965	63	–	40	–	–
Collecting sewage from research building Miller and others 1994	15-30	–	–	–	–
Diverted primary effluent from wastewater treatment plant Darby and others 1996	75	144	29	11	–
Synthetic wastewater Pell and Nyberg 1989	–	700	–	114	0.12

*BOD_5 is biochemical oxygen demand; COD is chemical oxygen demand; TSS is total suspended solids.

NH_3-N of the supernatant were determined for each dilution using Standard Methods (Clesceri and others 1989).

Septic Tank Effluent "Recipe"

Primary sludge was diluted to meet the target values of 140 mg/l BOD_5 and 75 mg/l TSS for septic tank effluent. From locally available primary sludge, a dilution of 1:68 primary sludge to tap water was needed to achieve the target values for BOD_5 and total suspended solids.

TABLE 2

Composition of the stock solution (concentrated 50 times) of synthetic wastewater (Pell and Nyberg 1989).

Component	Amount
$NaHCO_3$	26.25 g
Casein hydrolysate	26.25 g
Meat extract	17.50 g
Urea	4.55 g
NaCl	1.05 g
$CaCl_2$	0.53 g
$MgSO_4 \times 7 H_2O$	0.35 g
Tap water up to	1000 ml

Supernatant from a 1:68 dilution was also analyzed for ammonia nitrogen. The ammonia nitrogen level of 8.0 mg/l was well below the target level of 30 mg/l. A 0.363 M ammonium chloride solution was added at 4.4 ml/l to increase the ammonia concentration.

Laboratory Septic Tanks

Nine laboratory septic tanks were constructed from a 114 l (30 gallon) cylindrical polyethylene containers with an inside diameter of 52 cm (20 inches). The tanks had loosely fitting polyethylene lids. A hole drilled into the center of each lid allowed for introduction of tap-water into the tank. A drawing of a laboratory septic tank is given as Figure 1. All the septic tanks had 2.54 cm openings in the bottom center and on the side near the bottom. These openings were fitted with 2.54 cm PVC couplings. The center opening was used for draining sludge from the tanks when necessary, and for emptying the tanks at the end of an experiment. The opening was equipped with a 2.54 cm PVC ball valve and was connected to a drain that led to the building sewer.

A sidewall opening of the tanks, located 3.8 cm above the base, was used for draining effluent. This opening was also fitted with 1.6-cm female threaded joints. A pipe extended inside to the center of each tank and elbowed upward to a height of 25 cm from the bottom of the tank to form an outlet baffle. Effluent entered the vertical pipe radially through 4 cm slots cut

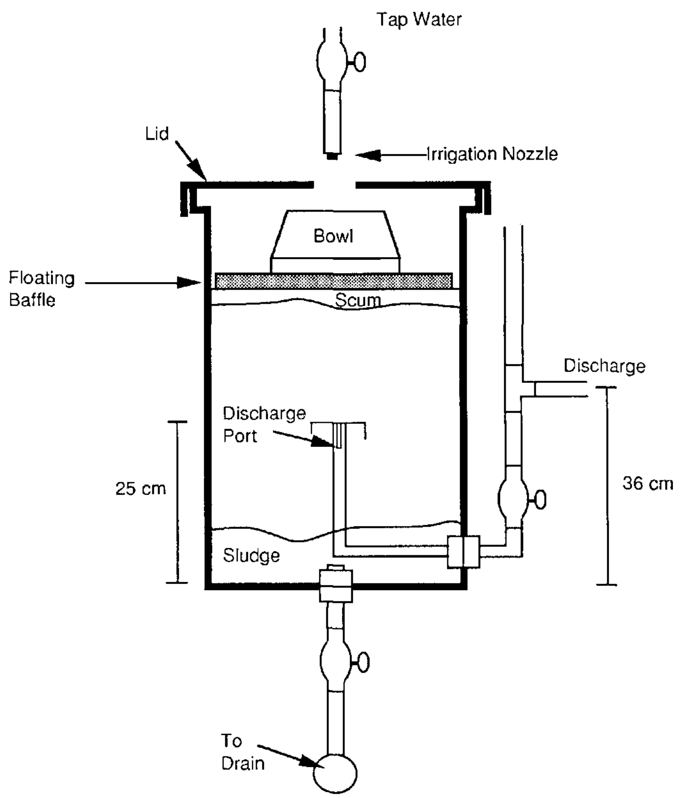

FIGURE 1. Laboratory septic tank assembly.

at the top of the pipe. The top half of a plastic petri dish was glued to the top of the pipe to prevent the flow of effluent and scum into the pipe from above. The 4 slot openings extended from 21 to 25 cm above the bottom of the tank.

On the outside of the tank, the discharge line turned upward to a 2.54 cm ball valve located 20 cm from the tank bottom. Beyond the valve, the line continued upward to a point 36 cm from the tank bottom. At that point, it split to a T with an open pipe extending straight up to the height of the septic tank and the other pipe continuing away from the tank horizontally. The vertical pipe was open to the atmosphere to prevent suction forming within the line. It was also a point of entrance in the case of a clogged line.

Other features of the septic tanks seen in Figure 1 included a floating baffle, a mixing bowl, and a tap water inlet line equipped with a spray nozzle. The 50 cm diameter floating baffles made of extruded polystyrene, divided the tanks into two compartments. The upper compartments were accessed daily for adding and mixing ingredients and the lower compartments formed relatively undisturbed areas that functioned as anaerobic zones.

Mixing bowls were placed on top of each floating baffle to hold the daily addition of primary sludge and ammonium chloride. The bowls, 25.4 cm in diameter at the base and tapering to a 21.6 cm diameter at the top, were very stable.

The tap water inlet line was a 1.25 cm PVC pipe, which extended to a point 15 cm above each septic tank lid. The line was equipped with irrigation nozzles mounted above each tank. The nozzles directed 1.5 mm streams of water into the center of each mixing bowl. These gentle streams of water facilitated the mixing action for the ingredients that were added to the bowl.

Laboratory Septic Tank Operation

Starting with full laboratory septic tanks, the discharge valves on the side of each tank were opened to allow the septic tank effluent to flow out of the tank. As effluent emptied from the septic tanks, the floating baffle-mixing bowl assemblies moved down in each tank following the liquid level. The discharge stopped when the liquid level fell to the highest point in the external pipe system. The stop position for the floating baffles allowed for the accumulation of scum. The position of the outlet above the tank bottom allowed the accumulation of sludge in the tanks that was not removed at each discharge cycle.

The discharge valves to each septic tank were then closed, the tank lids removed, and 500 ml of primary sludge and 250 ml of 0.363 M ammonium chloride solution (in tap water) were manually poured into each mixing bowl for the next cycle. The tank lids were replaced and the valves to the water inlet line at the top of each tank were opened. Tap water, flowing through the irrigation nozzles, formed a fine stream which flowed, through the hole in each tank lid, into the mixing bowls, mixing with the contents and carrying the mixture over the side of the bowls. The solution then flowed across the surface of each polystyrene baffle to the edge and slowly entered the septic portion of each tank. As a result of this slow and low energy refilling process, the sludge layer received minimal disturbance and septic conditions were maintained at the bottom of the tanks. The tap water remained on until the tank had refilled to the upper level (approximately 22 minutes to refill 56.8 l). The mixture was allowed to settle in the tanks, undisturbed until the next loading cycle (approximately 23 hours later), and the cycle was repeated.

RESULTS

BOD_5, TSS, and NH_3-N content of the septic tank effluents from 9 laboratory septic tanks were measured over a 12 week period (Fig. 2). BOD_5, TSS, and NH_3-N fluctuated as expected from week to week about or near the target values of 140 mg/l BOD_5, 75 mg/l TSS, and 30 mg/l NH_3-N. Table 3 presents the BOD_5, TSS, and NH_3-N content and variability in the effluent from the septic tanks.

None of the laboratory septic tanks clogged during the entire experimental period. The 9 tanks formed visible sludge and scum layers. After 60 days of operating the thickness of the scum layer was estimated by removing the floating baffle and opening a hole through the scum layer to the effluent below. The average thickness of the scum layers at that time was 4 cm. During the last 2 weeks the sludge layers were thick enough that occasionally sludge solids were released with the effluent during discharge.

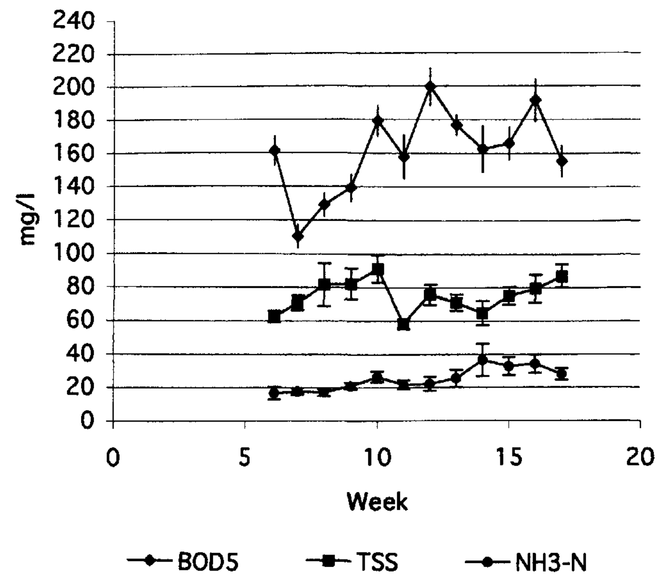

FIGURE 2. Average effluent values for 9 laboratory septic tanks. Weekly samples were collected over a 12 week period.

DISCUSSION

Septic tank effluent was emulated for laboratory use by mixing primary sludge, ammonium chloride, and tap water. Tap water to primary sludge ratios in preliminary dilution experiments revealed approximate dilution factors to meet BOD_5 and suspended solids targets. Primary sludge was readily obtained from a local wastewater treatment plant and was stored in a refrigerator for use in daily preparation of septic tank effluent. Tap water was needed to dilute the sludge. No sewer connections were required so the septic tanks could be easily moved and situated to meet experimental needs.

TABLE 3

Summary of effluent characteristics for septic tanks.

Weeks Reported	12
Number of Samples	108
BOD_5	
Average of all Samples (mg/l)	161
Standard Deviation (mg/l)	26.2
Coefficient of Variation	0.163
Minimum Value (mg/l)	102
Maximum Value (mg/l)	216
TSS	
Average of all Samples (mg/l)	75
Standard Deviation (mg/l)	11.8
Coefficient of Variation	0.158
Minimum Value (mg/l)	54.0
Maximum Value (mg/l)	111
NH_3-N	
Average of all Samples (mg/l)	25
Standard Deviation (mg/l)	7.9
Coefficient of Variation	0.316
Minimum Value (mg/l)	12.5
Maximum Value (mg/l)	46.7

Commercially available plastic tanks were readily fitted with baffles and a drain to operate as laboratory septic tanks. A mixing bowl in the tank on top of a floating baffle allowed for easy preparation of the septic tank effluent. The floating baffle and vertical pipe worked well to maintain sludge and scum layers emulating the operation of actual septic tanks. No clogging problems were experienced and the tanks were easy to drain at the end of an experiment.

The maintenance of sludge and scum layers in laboratory septic tanks is important in emulating natural conditions. A scum layer contributes to the anaerobic conditions within a tank. Organic compounds released from the decomposition processes in the sludge layer should make the effluent from these laboratory septic tanks more like that of a field septic tank. However, as sludge accumulated some was drawn out with the effluent. By making regular observations of the sludge depth through the side of translucent plastic tanks, sludge can be drained periodically through the bottom drain of each tank to avoid discharges of excess solids.

Through a series of dilutions of primary sludge and tap water, a "recipe" for septic tank effluent can be easily developed. In these experiments, the target average total suspended solids of 75 mg/l was achieved. The average BOD_5 of 161 mg/l was higher than predicted by the dilution experiment and exceeded the target of 140 mg/l. Some BOD_5 may be released from the decomposing sludge that remains in the tank. However, this value is in the range of actual septic tanks and for research purposes would represent a slightly higher than normal loading by 15%. The average BOD_5 value obtained from the laboratory septic tanks was a closer approximation to the target value than those obtained from sewage diverted from nearby sewer lines reported by Jones and Taylor (1965) at 63 mg/l BOD_5, Miller and others (1994) at 15 to 30 mg/l BOD_5, and Darby and others (1996) at 75 mg/l BOD_5.

Supplemental ammonia was needed to bring ammonia levels close to the desired target level of 30 mg/l. By adding 250 ml of 0.363 M ammonium chloride to the diluted sludge, an average of 25 mg/l was achieved in the laboratory septic tanks. Some of the ammonia may have been adsorbed by the sludge and scum that is retained in the tank. A slight adjustment to the "recipe" will be needed in future experiments.

To meet the need for hundreds of gallons of wastewater to conduct research, lightweight plastic tanks can easily be fitted with outlets, valves, and baffles to emulate septic tanks. Primary sludge can be obtained from a nearby wastewater treatment plant and through a series of dilutions, analyzing for BOD_5, total suspended solids, and ammonia nitrogen, a simple recipe can be derived for experimental use. A supply of sludge can be stored in refrigerators for daily use throughout experiments. The only plumbing connections required are a source of tap water to dilute the sludge.

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