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COMPARING THE PERFORMANCE OF PRESCRIBED SEPTIC TANKS TO LONG, NARROW, FLOODED DESIGNS

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ABSTRACT

About 30% of all sewage generated in North America passes through septic tanks, but there is a lack of study to improve these important treatment vessels, and there is no performance-based standard. A survey of existing literature shows that septic tank effluent quality is improved in tanks designed for quiet, laminar fluid-flow and minimum ‘dead space’ such as in longer, narrower tanks. A correlation is suggested between formation of unwanted heavy scum and the presence of tank airspace where vegetative molds live and trap rising sludge particles. The presence of partitions with small orifices worsens effluent quality by setting up turbulent flow and short-circuiting between orifice and outlet, as seen in dye and surrogate solids testing.

Side-by-side testing at the Massachusetts Buzzards Bay Test Facility of a prescribed 1500 gallon single-compartment tank and a long, shallow, flooded tank with no airspace confirms that airspace and shorter flow length are not advantages in septic tank design. During normal testing conditions in the 14 month Study 1 dosed at 750 gpd, the flooded tank performed better in organics removal (~23% better cBOD removal in summer; ~6% in winter) and in solids removal (~30% better TSS in summer; ~18% in winter). Stress tests with heavy laundry detergent added lessened that differential. Over the first 7 winter months of ongoing Study 2 dosed at 660 gpd the flooded tank had both cBOD & TSS removal rates of 30-35% better than the prescribed tank. Solids accumulation was higher in the conventional tank (average 54%) compared to the flooded tank (25%) in both studies.

Septic tank design for thorough contact time and laminar flow can improve effluent quality, and perhaps lessen pumping out requirements. Prescriptive regulations and standards should be reviewed with treatment and maintenance considerations in mind.

KEYWORDS

Septic tank designs, purpose of airspace, laminar flow, scum formation, effective treatment design

INTRODUCTION

A hundred years ago, researchers experimented with designs and treatment performance of septic tanks because they were then important in treating municipal sewage in North America and Europe. Studies of performance criteria of septic tank designs in the last fifty years are generally lacking compared to studies on sand filters, treatment units, and soil disposal systems, even though 30% or so of all sewage generated now goes first through a septic tank. With an increasing importance of onsite treatment of sewage, the pre-treatment afforded by the septic tank should also be optimized. Standards and regulations typically prescribe the physical aspects for septic tank design, sometimes conflicting from place to place (e.g., partition or not, long or short travel distance, etc.). With the lack of firm empirical data to support many aspects of prescription, more comparative testing is required to provide a firmer basis for prescription in the absence of performance-based standards.

This paper reviews existing literature for aspects of septic tanks that should affect treatment, including length-width ratios, depth, presence of airspace and partitions, and reviews demonstrated empirical data of comparative performance. More recent third-party testing using biochemical performance parameters is reported, including solids accumulation and effluent quality from tanks of standard tank geometry and of a closed-conduit (‘flooded’), laminar flow design. The lack of an airspace results in much less scum formation, and a long, narrow geometry improves quality of effluent with respect to organics and solids.

HISTORICAL LITERATURE

Length to Width Aspects

The process of sedimentation to remove solids from suspension in wastewater is well described in standard engineering texts (e.g., Viessman and Hammer, 1985) and recognized in the review literature (e.g., Bounds, 1997). Differential flow velocities, causing unwanted higher-velocity plumes, increase in tanks with shorter, wider, or deeper aspects (e.g., Figure 1), especially with inlet and outlet ‘point sources’. Higher-velocity plumes through the partition orifices produce turbulent flow with eddies that suspend solids and allow untreated sewage to short-circuit directly to the outlet. This turbulence effect was also reported by Winneberger (1984) using dye as a tracer in a short, partitioned model tank (but no short-circuiting was seen in a long, meander model tank). To optimize separation of solids, the tank design should encourage a well-developed, quiet, laminar flow regime.

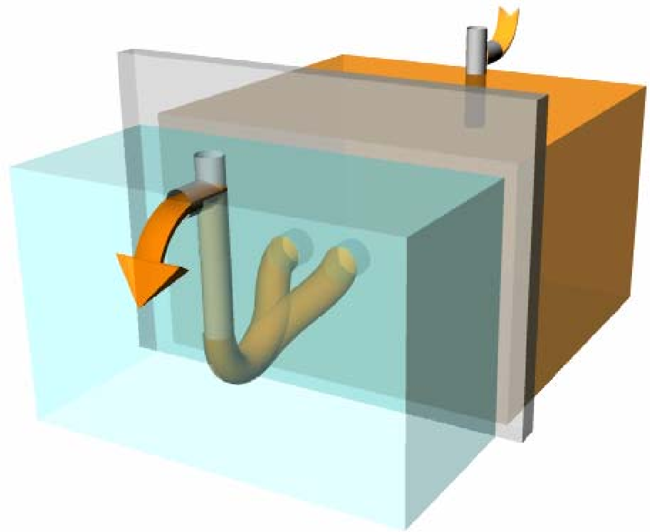

Figure 1 - Conventional 1200 gallon Ontario CSA septic tank with 2:1 compartments and 6” central orifices in partition during 5% and 10% volume dosing (Lay et al., 2005), showing upwelling into airspace above the invert of the outlet pipe, and the resulting visible 'untreated sewage' plume formed directly from inlet, through partition orifices, to outlet.

Early designers such as Metcalf (1901, in Winneberger, p. 50) valued long septic tanks to produce “sedimentation by slow flow through long tanks”. However, as Winneberger (p. 50) states, “…the value of long tanks became forgotten” and “probably because of construction convenience, short, stubby tanks became common”. Many designs (e.g., CSA B66) specify a deep tank of typically ≥4 feet and allow a short distance of ≥4 feet (in total) between the inlet and outlet. Where there is a transverse partition, the partition openings and the outlet may be only 16 inches apart and at a similar depth. Is this good design in a septic tank?

Entrained sludge particles settle out along the flow path, and are captured when they reach the floor or upper scum layer of the tank. The horizontal distance required for settling out increases with smaller particle size and with greater depth (e.g., Novotny et al., 1989). A longer, shallower tank will therefore capture more sludge, and finer sludge, than a shorter, deeper, box tank, in accord with summaries by Winneberger (1984, p. 54) and Seabloom et al. (2004, p. 31) to this effect. The septic tank prescription in Britain (BS 6297, 1990) recommends a maximum of 39 inches depth, and with a 4 foot width the length would be typically 13 feet long.

Reducing the amount of unused, ‘dead’ space that is common in wider, box tanks has an advantage other than better solids removal. Dunbar (1907, reported in Winneberger, p. 92) carried out experiments on decomposition of organic matter in septic tanks and found that “decomposition is quicker in a tank of 12-hour capacity than one of 2-hour capacity, but very much quicker than in a septic tank in which the sewage is stagnant”. Tank design to ensure flow paths to remove waste products from around organic matter, such as the meat used in Dunbar’s experiment, is therefore more important than just increasing the tank size without regard to flow pathways.

Partition Studies

Modern tank designs (e.g., CSA B66) typically prescribe relatively deep, wide tanks, always with airspaces, and optional transverse partitions to keep solids from exiting the tank. Lehmann et al. (1928) and Bendixen et al. (1950) compared performance benefits of different shapes and sizes of tanks. The latter compared partitioned tanks but for only 2 months, and since they had also been inoculated for quick start-up, firm conclusions about the benefits of partitions are difficult to support. Seabloom et al. (1982, reported in Seabloom et al., 2004) concluded the single compartment tank had 17% better BOD and 69% TSS removal than a partitioned tank. Rock and Boyer's (1995) two-year study showed that a transverse partition with a 4-inch orifice (their Tank 6) had a deleterious effect on treatment (23% worse BOD and 14% worse TSS) compared to otherwise identical single-compartment Tank 2. Only with a much larger and wider partition opening in Tank 3 did effluent quality improve by 11% BOD and 7% TSS over single-compartment Tank 2.

Short-Circuiting Comparison

Lay et al. (2005) determined the effect of tank design on short-circuiting of raw sewage from inlet to outlet, using expanded clay particles as tracers. Tanks were dosed at 5% and 10% of their volume with a particulate-water mixture, at flow rates simulating a bathtub emptying, and effluent screened for short-circuited particulates. The 1200 gallon partitioned, airspace tank with two 6-inch orifices (Figure 1) short-circuited far more than the 1200 gallon flooded tank with no airspace and a long, narrow, shallow aspect designed for laminar flow (Figure 2).

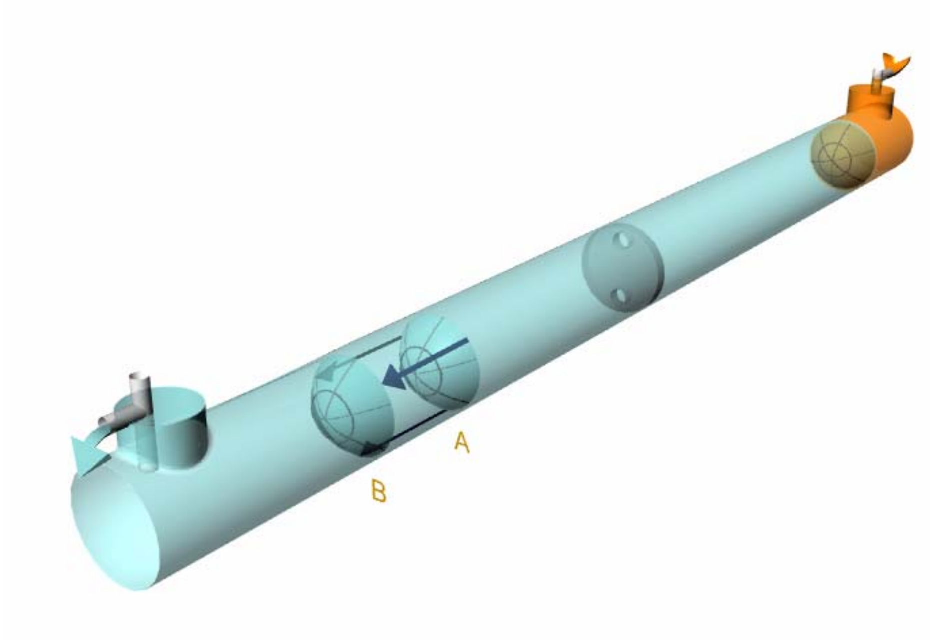

Figure 2 - Closed-conduit flow tank during 10% volume dosing of 120 gallons with 'untreated

sewage' contained near inlet, and only 'old' treated sewage exiting tank. Parabolic discs depict relative flow velocities over cross-section of tank, and movement of water from disc A to disc B during 10% dosing.

Forming Scum & Sludge

"Floating scum storage" sounds reasonable as a purpose for an airspace, but how does this contribute to the intended tank function. Again Winneberger; "it is a common misconception that…lighter solids…rise to surface and form a layer of scum". Rather, surface scum is related to amount of gases evolved, because sludge particles are carried up by gas bubbles and become scum when trapped by mold at the airspace; otherwise, they sink again to remain as sludge (Metcalf and Eddy, 1930, p. 526).

Only with an airspace present can vegetative molds take hold and accelerate the trapping of rising sludge (Metcalf and Eddy, 1930, p. 526), matting them together into a "tough, floating mass". In comparison to sludge, this leathery scum is more difficult to pump out, and digestion of solids is greatly retarded in the scum (Metcalf and Eddy, 1930, p. 526). Because the formed scum can be denser than water, it can overturn and sink, causing re-suspension and out-flow of sludge (Max Weiss, pers. comm., 2004). Removing the airspace from the conventional tank should then result in relatively more sludge and less crusty scum.

SIDE-BY-SIDE SEPTIC TANK PERFORMANCE

Manufacture and Preparation

With this literature review and testing with surrogates in mind, and a lack of performance based standards, a side-by-side test protocol was developed to compare a long, narrow, shallow tank design with no airspace with a conventional prescription tank to see if performance assumptions based on the literature would be valid.

A closed-conduit, laminar flow septic tank was constructed by Armtec in Ontario from 30-inch diameter, extruded high-density polyethylene pipe (Figure 3). A 30-inch diameter riser was welded onto each of two 20-foot long tanks to form the inlet and outlet, and a 6 inch inspection port welded onto the opposing end, and the two tanks were connected by two 6-inch diameter connecting pipes on the end plates. The connecting pipes were set in the middle base and top of the end plates to allow sludge and scum to migrate between tanks and not act as a partition. The tank was sized at 1500 gallons to match the existing conventional tanks at the Massachusetts Alternative Septic System Test Center (MASSTC) (www.buzzardsbay.org/etimain.htm) on Cape Cod, a facility supported by EPA and accredited by NSF, and where the present biochemical testing was carried out.

The conventional septic tank was thoroughly pumped out and filled with fresh water. The unused test tank was leak-tested with fresh water, and testing began with both tanks filled with fresh water.

Dosing Rates and Sampling Methods

While there is no set standard for dosing septic tanks, hydrolysis and fermentation reactions are typically fully functional within 48 hours, prompting some jurisdictions (e.g., Ontario) to size septic tanks at twice the daily design flow. Bounds (1994) suggests that the ‘clear zone’ between sludge and scum layers should be 0.25 to 1.0 times the daily flow, and that a conventional tank has maximum solids capacity of ~58% of its effective volume (((0.75x225gal)+410gal)/1000; p.61). Assuming design flow being twice average flow, and half the tank being ‘clear zone’ at pump-out time, Bounds’ preferred tank would also be conservatively sized at twice the daily design flow.

The 1500 gallon tanks in Study 1 (from April 2005 to August 2006) were dosed at half their effective tank capacity (750 gallons) each day to simulate the full design flow every day. Dosing of 50 gallons was carried out 15 times per day (updated to 30 times per day) using the standard NSF diurnal variation of 35% 6-9 a.m., 25% 11 a.m.- 2 p.m., and 40% 5-8 p.m. (NSF International, 2005). Ongoing Study 2 was carried out at 660 gpd loading beginning in November 2006 and is reported here to June 5 2007.

On sampling day, a cumulative sample of 15 or 30 aliquots was taken from the distribution box after each septic tank a few minutes after the tank is dosed by pump. Samples were sent off-site for laboratory analysis of TSS, cBOD, COD, fecal coliform, and FOG. Standard quality assurance measures scrutinize the analyses, and analyses are accepted by the facility staff or requests made to the laboratory for verification. Results were tabulated by MASSTC staff.

Every 2-3 months, 2-4 sludge and scum thickness measurements were taken through the 24-inch diameter inlet and outlet ports of the standard tank F3, and the volume percentage of the flat-bottomed tank calculated assuming gradation between the two ports. Scum is measured by a simple angled wire, and a ‘sludge judge’ is used for sludge (Crites and Tchobanoglous, 1998).

In each of the inlet and outlet risers of the test tank, two measurements are taken along the deepest center-axis, below the inlet or outlet tee and at the point where the sewage enters or exits the submerged zone. Measurements are also taken at the inspection ports at the end of the inlet segment and the beginning of the outlet segment (see Figure 3). Each of the four depth measurements are then used to calculate the percentage of the circular cross-sectional area of the submerged tank segment that the sludge and scum represents, and averaged to determine volume percentage. The volume of the 7-8 inch thick scum layer in the inlet riser and above the submerged zone (no scum was present in the outlet riser or inspection ports) is calculated and added to the submerged volume percentage.

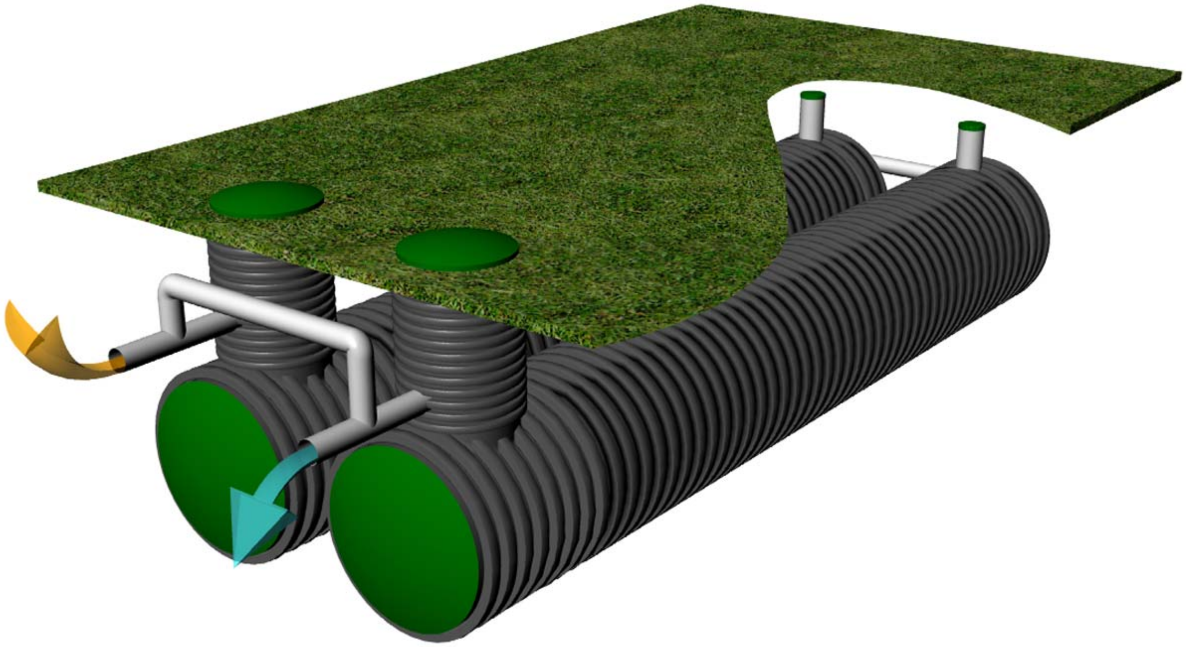

Figure 3 - 'Flooded' or closed-conduit flow tank of 1500 gallons capacity tested side-by-side with 1500 gallon conventional single-compartment tank at Buzzards Bay test facility. Water level is 3 inches up into risers, controlled by the outlet invert (blue arrow). Submerged or flooded flow between the inlet (brown) and outlet risers acts to restrict hydraulic short-circuiting and form of scum.

Analytical Results of Effluent

Study 1 was carried out from April 2005 to August 2006 and conformed to the CSA B66 test protocol by dosing the tanks at NSF-40 diurnal rates at half the tank capacity per day or 750 gpd, and included the 'wash day' and 'working parent' stress tests (NSF International, 2005). In the first 3 months of operation, the conventional tank had accumulated 52% solids, mainly as sludge to confirm that testing simulated long-term performance of a mature tank. In comparison, the test tank had 15% solids, and scum only in the inlet airspace after 3 months of operation. Combining the main performance parameters of cBOD and TSS, effluent from the prescribed tank contained ~18% more contaminants than the flooded tank when both were dosed at the same high rate (Table 1).

Table 1 – Study 1 average septic tank effluent analyses of performance parameters conducted at MASSTC in Massachusetts over the first 14 months of the 16-month test period dosed at 750 gpd (± 10%) at NSF-type diurnal rates, not including two NSF-type stress tests of Table 2. A3 site is 1500-gallon, long 'flooded' tank of Figure 3; F3 site is 1500-gallon, single-compartment conventional tank.

Study 1 – 750 gpd April 2005 – July 2006	**cBOD mg/L**	**COD mg/L**	**TSS mg/L**	**FOG mg/L**	**Fecals* cfu/100mL**
Number of QA/QC samples	41	39	41	39	40
A3 Flooded Tank average	157.7	313.9	43.2	22.4	2.98e6

F3 Conventional Tank average	178.2	344.1	53.0	23.7	3.10e6
A3/F3 T_{inf}≥15°C** (n=15)	0.81	0.92	0.77	0.89	0.85
A3/F3 T_{inf}<15°C** (n=26)	0.94	0.91	0.85	0.92	0.97

*geometric mean in cfu/100mL; **normal diurnal flows not including stress tests in summer

During the warm months when the influent sewage temperatures were 15-22°C (June to end of November), the flooded tank performed ~27% better in cBOD (23%) and TSS (30%) removal, and during the cold months (December to end of May) when sewage was down to 6°C, the flooded tank was ~12% better (6% cBOD, 18% TSS). The higher quality effluent suggests that a long, flooded tank is a better anaerobic digestion vessel as well as a better sedimentation vessel. Effluent quality improves with respect to the conventional tank in warmer weather, but is still substantially better in winter conditions, especially with respect to TSS removal. It is suggested that insulation and proximity to the source would increase sewage temperature and thus improve treatment in the septic tank.

At the end of the initial 14-month testing of normal NSF-style diurnal dosing, two NSF-style stress tests were performed to conform to the CSA B66 equivalency test protocol (Table 2), the wash day and working parent stress tests that involve laundry loads to the normal flow rate (NSF International, 2005). The differential in treatment is not as great as during normal operation described above. The tests are one week in duration, and both have laundry detergent added which could act as a source of organics (cBOD) and to emulsify oils (FOG) and carry them through the tank.

Table 2 – Study 1 average septic tank effluent analyses of performance parameters during two NSF-40 style stress tests (‘wash day’ and ‘working parent’) in July-August 2006.

Study 1 – 750 gpd July – August 2006	**cBOD mg/L**	**COD mg/L**	**TSS mg/L**	**FOG mg/L**	**Fecals* cfu/100mL**
Number of QA/QC samples	11	11	11	11	11
A3 Flooded Tank average	144.5	266.4	35.5	16.3	3.79e5
F3 Conventional Tank average	141.8	287.3	44.7	15.0	9.23e5
A3/F3 T_{inf}≥15°C (n=11)	1.0	0.93	0.80	1.1	0.41

*geometric mean in cfu/100mL

During Study 1, grab samples of tank contents were taken along the pathway of both tanks to determine trends during the anaerobic treatment process and effluent maturity indicated by production of volatile fatty acids (VFA) and solubilization ratios of dissolved versus total elements such as phosphate ion versus total phosphorus and ammonium versus TKN (Jeremy Kraemer, pers. comm., 2005), shown in Tables 3, 4, 5 and 6.

This part of the study is not comprehensive, but in general the VFA component increases between inlet and outlet, as do alkalinity and solubilization parameters. The performance parameters of cBOD, TSS, COD generally decrease as expected between inlet and outlet as the sewage is being treated.

Table 3 - Sampling along flow path in A3 and F3 tanks on June 28, 2005 during Study 1.

June 28, 2005 – 750 gpd	**cBOD mg/L**	**TSS mg/L**	**Alkalinity mg/L**
A3-1 inlet riser 10”	370	670	150
A3-2 end first segment	280	85	150
A3-3 start second segment	240	69	170
A3-4 outlet riser 10”	270	47	180
F3-1 inlet end 14”	320	130	180
F3-2 outlet end 14”	650	80	220

Table 4 - Sampling along flow path in A3 and F3 tanks on August 29, 2005 during Study 1.

August 29, 2005 – A3 1500 gpd; F3 750 gpd	**cBOD mg/L**	**COD* mg/L**	**TSS mg/L**
A3-1 inlet riser 14”	120	440	130
A3-2 end first segment	180	450	110
A3-3 start second segment	210	390	83
A3-4 outlet riser 108”	170	360	63
F3-1 inlet end 14”	140	530	160
F3-2 outlet end 14”	150	480	88

*COD is unfiltered (solid and soluble COD)

Table 5 - Sampling along flow path using volatile fatty acids (VFA) in A3 and F3 tanks on March 1, 2006 during Study 1.

March 1, 2006 – 750 gpd	**cBOD mg/L**	**TSS mg/L**	**Alkalinity mg/L**	**VFA mg/L**	**T°C**
A3-1 inlet riser 10”	290	110	160	18	6.9
A3-2 end first segment	270	210	160	36	7.0
A3-3 start second segment	220	93	170	34	7.0
A3-4 outlet riser 10”	140	88	170	19	6.5
F3-1 inlet end 14”	-	-	-	19	7.1
F3-2 outlet end 14”	-	-	-	16	7.2

Table 6 - Sampling along flow path in A3 and F3 tanks on February 8, 2006 during Study 1.

February 8, 2006 – 750 gpd	**VFA mg/L**	**COD* mg/L**	**Alkalinity mg/L**	**$NH_{3,4}$-N/TKN mg/L**	**PO_4-N/TP mg/L**
A3-1 inlet riser 14”	34	150	170	0.74	0.65
A3-2 end first segment	40	170	175	0.69	0.57
A3-3 start second segment	46	120	190	0.67	0.62
A3-4 outlet riser 108”	51	120	195	0.76	0.75

F3-1 inlet end 14”	48	110	190	0.72	0.73
F3-2 outlet end 14”	80	110	190	0.72	0.71

*COD is filtered (soluble COD)

A second period of comparative testing using normal NSF-style flows was started in November 2006 and is continuing. The flow was decreased to 660 gpd to dose treatment units following the A3 septic tank.

Table 7 – Ongoing Study 2 average septic tank effluent analyses of performance parameters conducted over first 7-months dosed at 660 gpd. Influent sewage values were BOD = 178 mg/L, cBOD = 154 mg/L, TSS = 145 mg/L, fecals = 2.86e6 cfu/100mL, pH = 7.4. Temperatures of influent raw sewage varied between 7.2 and 16.8°C to June 5, 2007.

Study 2 - 660 gpd Nov. 2006 – June 2007	**cBOD mg/L**	**TSS mg/L**	**Fecals* cfu/100mL**	**pH**
Number of QA/QC samples	26	26	26	26
A3 Flooded Tank	131	28	1.33e6	7.00
F3 Conventional Single Compartment	175	37	1.27e6	6.82
A3/F3 $T_{inf} \geq 15°C$ (n=1)	-	-	-	-
A3/F3 $T_{inf} < 15°C$ (n=25)	0.78	0.75	1.05	-

*geometric mean in cfu/100mL

Measurements of Sludge and Scum

With the high 750 gpd rate of sewage dosing, sludge and scum accumulated quickly in the conventional tank with 52% solids within 3 months of operation and 64% within 6 months of Study 1, versus 14% and 30% for the flooded tank (Figures 4 & 5). With the lower 660 gpd rate in Study 2, solids accumulation were ~62% in the conventional tank after 8 months of operation, including 14” dense scum, versus ~35% solids in the flooded tank with no scum.

The fact that less solids accumulation and better quality effluent resulted from the flooded tank (~45-55% less solids, and with 20-30% better cBOD & TSS values in Studies 1 & 2) suggests that the flooded tank is a better fermentation vessel degrading organic matter, and not just a better sedimentation vessel. The flooded tank had no scum and very little sludge halfway along the pathway, with scum only in the inlet riser, confirming the relation between air space and scum formation reported in Dunbar (1907) and Metcalf and Eddy (1930).

When the tank was pumped by a commercial pumper near the end of Study 1, the comments were “It looks like 8 years of sludge buildup” in conventional tank F3, and flooded tank A3 “had a standard maintenance look” which is “3-4 years buildup” (MASSTC, 2006).

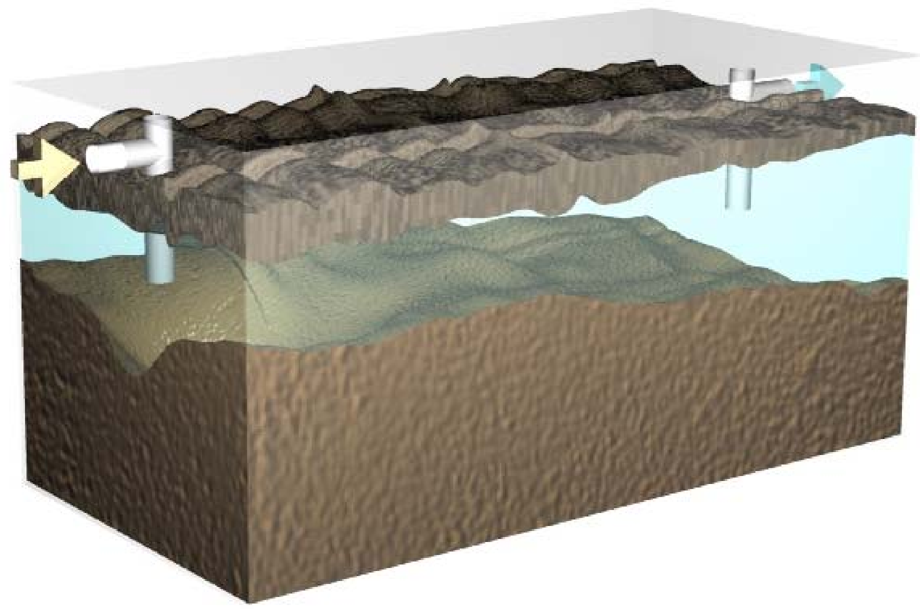

Figure 4 - Conventional tank F3 with 64% solids after 6 months of 750 gpd dosing in Study 1. Note heavy scum formation at airspace.

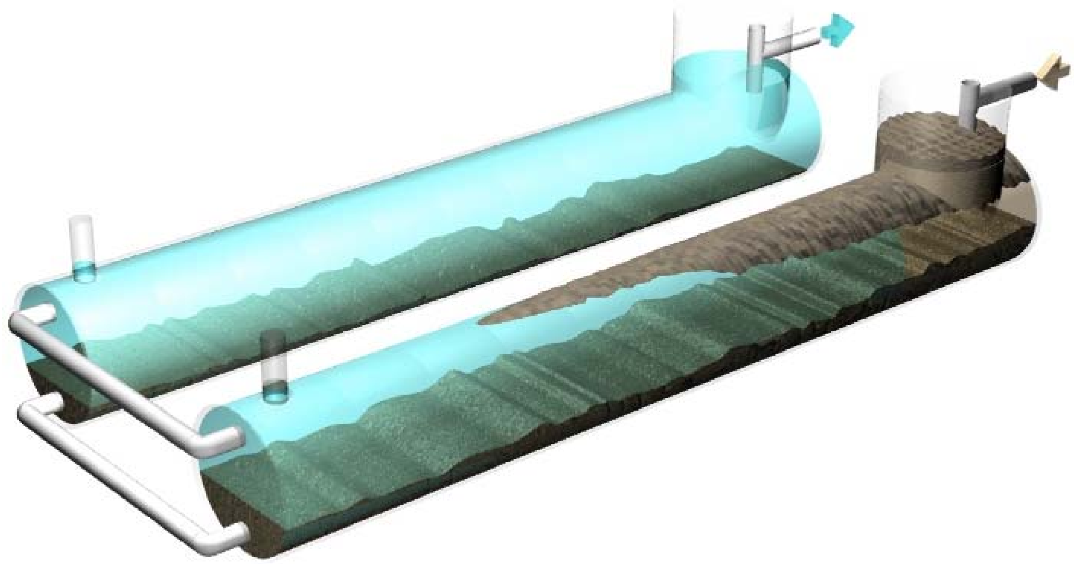

Figure 5 - 'Flooded' tank A3 with 30% solids after 6 months operation in Study 1 (included 5 months of 750 gpd dosing and 1 month at 1500 gpd not included in analytical results) . Note lack of scum in flooded section of tank.

CONCLUSIONS

Removing the airspace to induce closed-conduit flow in a long, narrow, shallow tank results in substantially less scum and sludge formation and higher quality effluent compared to a conventional box-like tank with airspace. In one study, the treatment differential is greater with sewage temperatures of ≥15°C, but is still substantial down to 6°C, especially with respect to solids separation. In the ongoing second study at slightly less loading, the winter removal differential was higher at 30-35% for cBOD and TSS. Scum forms only in the inlet riser where airspace is present, confirming the correlation of airspace and scum formation. The higher quality effluent compared to a standard tank suggests that the flooded tank is a better anaerobic digestion vessel as well as a better sedimentation vessel. Standards organizations and regulators need to review existing prescribed designs which may limit the treatment capabilities of the important septic tank.

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