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 co

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

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'

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

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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