IMPROVING SEPTIC TANK PERFORMANCE BY ENHANCING ANAEROBIC DIGESTION

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ABSTRACT

Septic tanks have been used for anaerobic treatment of raw sewage for well over one hundred years, and their basic design has not fundamentally changed over that time. On the other hand, there have been tremendous improvements in our understanding of anaerobic microorganisms and development of high-rate anaerobic treatment technologies particularly since the 1970's. However, this improved technical knowledge has not yet been applied to improving the century-old septic tank.

The Waterloo *'InnerTube™ Anaerobic Digester'* ('digester') was developed with consideration of modern understanding of anaerobic treatment systems. This new septic tank design directs the raw sewage into an initial smaller-diameter flexible pipe 'treatment tube' within any standard box-like tank without the need for dividing the septic tank into multiple compartments. The *InnerTube* pipe is kept warm in the septic tank water itself. The *InnerTube* includes design features that improve the treatment performance of septic tanks including: consistent and warmer initial temperature, creating a flow path that minimizes stagnant zones and elongates the flow pathway, directing the sewage through anaerobic microorganisms ('biomass') grown and retained in the tank, separating the liquids and solids retention times as is done in activated sludge, and elimination of the air space for better scum treatment.

Multi-year, third party testing of this new septic tank design has demonstrated improved sewage solids digestion over conventional septic tanks. The new design produces improved effluent quality especially with respect to increased total suspended solids (TSS) removal and decreased sludge and scum accumulation. Pump-outs are less frequent and the effluent is more amenable to subsequent aerobic treatment.

Keywords

Septic Tank, Anaerobic Digester, InnerTube, UASB, granulated sludge, biomass sludge

INTRODUCTION

Septic tanks are ubiquitous in the on-site treatment industry, and have been used for anaerobic treatment of raw sewage for well over one hundred years. The basic design of septic tanks has not fundamentally changed over the last century. Current septic tanks are typically multi-compartment and assumed to provide mainly physical treatment to separate solids and scum from the liquid, with some minor acknowledgement that slow-rate 'digestion' of the accumulated sludge occurs. Once the accumulations of both sludge and scum are excessive, the tank is then pumped out.

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What is interesting to note from the history of the septic tank is that the very early concepts developed in the late 1800's were observed to have little sludge accumulation in the tanks. Donald Cameron, who coined the term 'septic tank', noted in an 1896 paper that over a 6 month period only *"a thin layer of black earthy matter"* remained on the floor of his tank even while discharging an effluent that was *"clear and inoffensive, and not liable to any after-fermentation"* (Cameron, 1896). This early work demonstrated that septic tanks can provide biological treatment to liquefy the sewage solids, rather than just accumulate them.

There have been tremendous improvements in our understanding of anaerobic microorganisms and development of high-rate anaerobic treatment technologies particularly since the 1970's (Speece, 1996; Barber and Stuckey, 1999). However, modern technical knowledge has not yet been applied to improving the century-old septic tank.

Anaerobic digestion of sewage is a biological treatment process performed by several interacting groups of microorganisms, including those which perform 'hydrolysis' (the breakdown of particulate matter into soluble substances), 'fermentation' as in the production of cheese, yogurt, wine, and beer, and 'methanogenesis' which is the production of methane gas ('natural gas') from the liquefied sewage. Although anaerobic digestion of waste sludge is utilized at larger municipal sewage treatment plants, the anaerobic digestion technology also figures prominently in the initial treatment stage of most on-site septic systems – the septic tank.

Advantages of anaerobic digestion compared to suspended aerobic treatment are: lower energy use, potential energy recovery as methane gas, less sludge, lower nutrient requirements, higher organic loading rates, and being suitable for intermittent use like residences (e.g., Kraemer, 2017). Disadvantages include slow growth of methanogens, potential odours, greenhouse gas (methane) emissions if not captured, and potentially higher cBOD effluent values.

This paper will document the basics of anaerobic microbiology and describe why directing sewage flow and inducing a more methanogenic anaerobic environment improves treatment, especially important with higher strength sewage due to water conservation. A new technology, the *'InnerTube'* anaerobic digester, will be used to demonstrate the usefulness of improved septic tank design.

BASICS OF ANAEROBIC DIGESTION RELEVANT TO SEPTIC TANK DESIGN

The following section discusses anaerobic digestion processes and designs relevant to the septic tank treatment technology. This information is adapted from Speece (1996), Barber and Stuckey (1999), Metcalf and Eddy (2003), Hulshoff Pol et al. (2004) and Kraemer (2017).

Biologic Reactions: Complex organic matter is converted in an initial 'fermentation' stage by 'hydrolysis' reactions to simple organics, followed by 'acidogenesis' to volatile fatty acids, then 'acetogenesis' to either acetic acid or hydrogen gas. These end products are then converted via 'methanogenesis' to methane gas. It is important to note that methanogenesis is facilitated by specialized microorganisms which are separate from those conducting the earlier reactions, grow slower, and are more sensitive to extremes of pH, toxicants, ammonium, and sulfide.

Benefits are that the metabolic reactions are low energy, and the waste product (i.e. methane) contains energy that can be recovered when there is sufficient quantity. Less biomass is produced and therefore less waste sludge to be disposed of. In summary, compared to aerobic activity that produces 50% sludge and 50% waste heat, methanogens produce 10% sludge and 90% methane. Typical daily loading rates into high rate anaerobic reactors are 3.2 – 32 kg chemical oxygen demand (COD) per m^3 of digester tank, compared to 0.5 – 3.2 kg/m^3/day in aerobic tanks.

Well-performing methanogenic microorganisms prefer a pH of 6.5 – 8.2, and sufficient nutrients (nitrogen, phosphorus and sulfur) and trace metals (iron, cobalt, nickel and zinc), and time to acclimatize to any toxicants in the sewage. Solids retention is integral to the process, as is good contact between the sewage and the sludge[3]. In larger plants, solid and liquid retention times can be changed to suit the sewage constituents – soluble and simple versus particulate and complex, carbohydrates versus starches and proteins. For on-site systems, the process would necessarily be fixed at the design stage. Warmer temperatures increase the rate of microbial growth and hasten digestion of sewage constituents – ideally a warm and stable temperature range is optimum. However, research over the last two decades has looked at improving anaerobic treatment at low temperatures (McKeown et al., 2012).

Anaerobic Reactor Types: Anaerobic lagoons, unmixed sludge digesters and conventional septic tanks are examples of 'low rate' reactors, characterized by separated solids and hydraulic zones with no purposed intermixing. Septic tanks are the standard technology used as pre-treatment for residential leach fields but are not designed specifically for treatment purposes (e.g., Winneberger, 1984; Jowett, 2009). For instance, the double-compartment septic tank, as in Ontario's building code, allows unacceptable short-circuiting of raw sewage directly to the outlet (Figure 1). The prescribed orifices in the partition wall produce turbulent flow and allow suspension of sewage particles to the outlet pipe; this is a poor design for retention and digestion of sewage solids.

Because the box-like tank has hydraulically stagnant zones in the sides and corners of the tank, undigested solids accumulate, but do not digest, as they are distanced from the flow of the sewage within the tank. This is an undesirable accumulation of solids and is distinct from the beneficial accumulation of biomass solids within a flow stream, discussed below. The existence of the air space required in most septic tanks encourages scum formation when sludge particles float to the surface, and hydraulic short-circuiting through open-conduit flow (Winneberger, 1984; Lay et al., 2005).

[3] Distinction should be made among (a) raw sewage solids that need to be digested by microbes, (b) digested solids that are the result of anaerobic digestion, and (c) actual biomass solids or sludge composed of beneficial microbial accumulations.

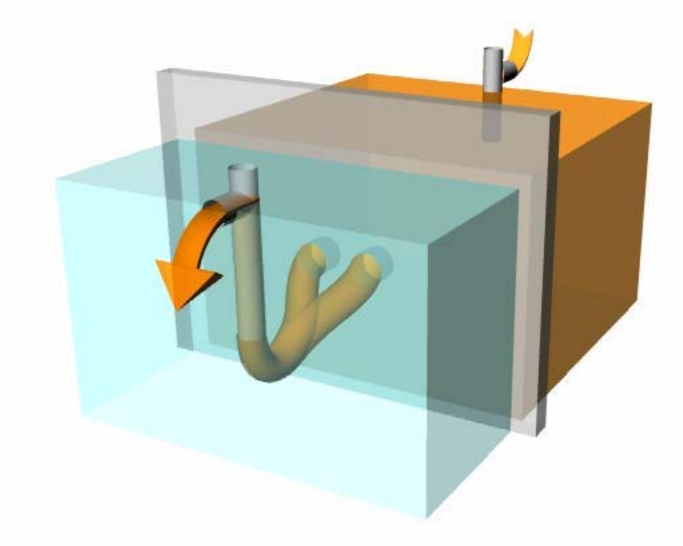

Figure 1. Short-circuiting of sewage from inlet to outlet due to open conduit flow and location and size of partition wall orifices.

Closed conduit flow results when the airspace is removed in a long, flooded tank (Figure 2), which in turn prevents hydraulic short-circuiting and reduces scum production (Lay et al., 2005). In a long-term comparison study with a standard box-like tank, the flooded tank in Figure 2 had 50% less solids accumulation and performed 21% and 24% better in cBOD and TSS removal respectively (Jowett, 2009).

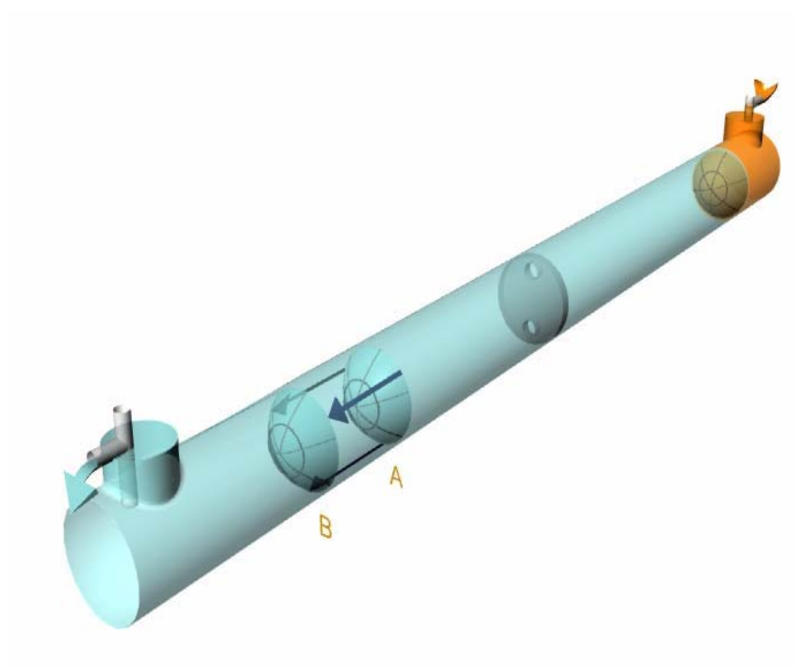

Figure 2. Closed conduit flow in a long, flooded tank improves digester performance.

'High rate' anaerobic digestion technologies include:

- anaerobic filters with high surface area internal attachment means (Speece, 1996);
- upflow anaerobic sludge blanket (UASB) with granular biomass sludge particles acting as attachment means (Lettinga et al., 1983);
- expanded granular sludge blanket (EGSB) like the UASB but with higher upflow velocity; and
- anaerobic baffled reactor, basically a septic tank with multiple baffles directing flow in a continuous upflow and down flow meander which ensures the sewage contacts active biomass (Barber and Stuckey, 1999).

The higher rate systems are not necessarily higher maintenance though, and some of their features can be adapted to the passive and low-temperature conditions found in on-site systems.

Biomass Separation and Retention: An interesting aspect of several high-rate anaerobic digestion technologies, such as the UASB, EGSB and sometimes also the anaerobic filter, is the formation of 'granular sludge' biomass and its involvement in the process. Granular sludge is composed of intertwined microbial masses that are structured and layered, with a dense pellet-like shape of 0.5 to 3.0 mm diameter. When raw sewage is placed in a tank and directed upwards in the tank at a particular velocity, the granular sludge forms and becomes suspended in the liquid and improves rates of biological sewage treatment.

These plug flow reactors improve treatment with better growth kinetics, little short-circuiting, and are smaller in size. Biomass formed must be retained so a high biomass inventory is needed with high solids retention time (SRT). This is the same design feature found in aerobic activated sludge where the biomass providing treatment is separated from the liquid flow. The separation and retention of biomass within the tank allows for the liquid to flow quickly through the treatment system while the biomass solids are retained for a long time thereby ensuring their continued growth and desired sewage treatment.

Importantly, it is desirable that the sewage *flows through the retained biomass* rather than keeping the liquids and solids separated. This allows both soluble and solid organics to be digested at the same time. This concept is non-intuitive as the normal septic tank is thought of as having separate spaces for sludge in the bottom and liquid in the middle, whereas these plug flow reactors are designed to have the sludge and liquid in the same space, though at different flow rates, to improve treatment.

The ideal reactor encourages methanogenesis with warmer and stable temperatures, but also directs flow of sewage through the accumulated biomass solids formed in the reactor – physical design of the reactor is the foremost aspect to accomplish these flow characteristics.

As will be described below, it is the contacting of sewage liquid and solid contaminants with active biomass that improves treatment performance and degradation of sewage solids, instead of merely settling them in the bottom of the septic tank. Removing the air space to sludge connection enhances scum management (e.g., Lay et al., 2005). Improvement can also be made by protracted physical contact between potential scum solids and microbial biomass while the solids are still emulsified in the liquid, so that they are digested to liquid and gases without forming a scum layer in the top of the septic tank.

CONFIGURING A BETTER SEPTIC TANK

Following the above discussion, improvements over conventional septic tank design would incorporate features of; flooded tank, closed-conduit flow, removal of airspace, avoidance of 'dead' or stagnant space by directed flow, warm fully-anaerobic digestion, and use of 'high-rate' design features such as granular sludge. The system would still have to compete in the marketplace with the standard septic tanks and therefore cost increases must be minimized.

The *'InnerTube Digester'* has been developed to address these improvements, and although the presence of granular sludge is still being investigated, the presence of coarse microbial biomass particles within the pipe is verified. The addition of a long, confined tube to receive raw sewage within an existing standard tank (Figure 3) provides the characteristics listed above to improve anaerobic digestion. Sewage is directed through the tube from the inlet to the outlet, the end of which is preferably distant from the tank effluent pipe to increase overall retention time in the tank.

The pipe has a volume of about 10% of the tank volume, which with a tank design capacity of 2 days peak flow capacity, provides an HRT of 5 hours or so in the pipe. However, with water conservation measures now so prevalent, this can increase to 20 hours or more on average. More importantly, the SRT in the pipe can be 'indefinite' if the flow of influent sewage is not strong enough to flush out the beneficial microbial sludge within the pipe.

Biomass particles are grown and retained in the pipe, which allows water to flow past and through this sludge 'blanket', with solids being retained longer than the water flowing through the tube. This means the solids retention time is longer than the hydraulic retention time, a key feature of high-rate anaerobic treatment technologies described earlier. The lack of airspace in the tube allows a greater degree of methanogenic microbial activity to digest solids and precludes solid scum formation. The sewage TSS is only in the direct path of the incoming sewage, with no hydraulic 'dead' spaces where sludge would accumulate without decomposition. This configuration allows a passive and more thorough anaerobic digestion as described earlier, without a large increase in cost.

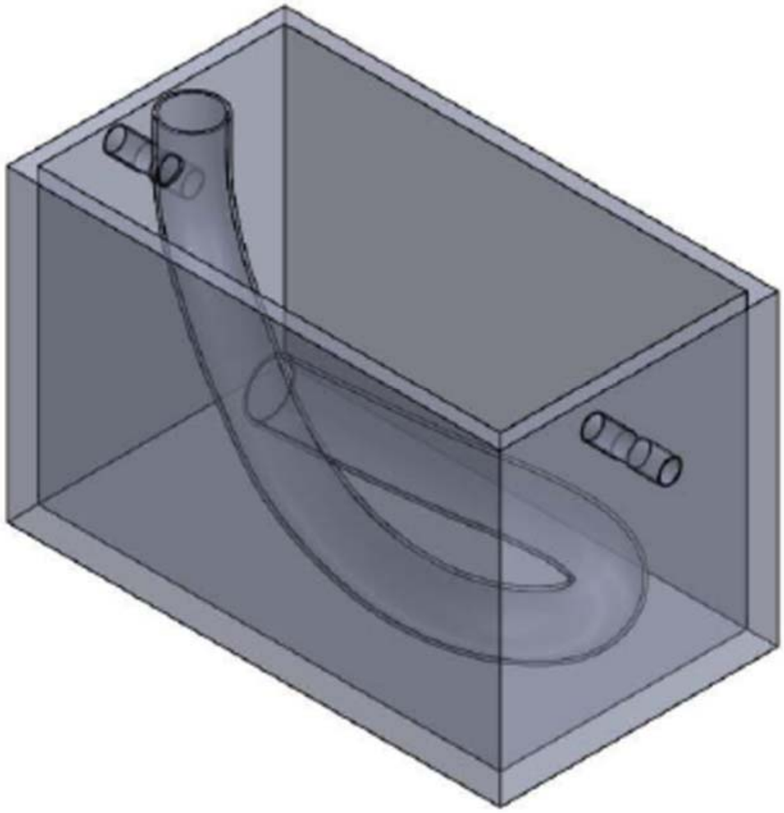

Figure 3. The *InnerTube* technology converts a box-like septic tank into a more efficient treatment system, modeled after the upflow anaerobic sludge blanket process.

Temperature Stability
When standard septic tanks are tightly packed into surrounding soil, the loss of heat through the sidewalls and ceiling can be substantial, as evidenced by melting of snow above a tank. The deeper body of water in a tank allows convection currents to form more readily than inside the shallow depth of the *InnerTube* pipe. Fewer convection currents result in less heat loss by advection.

The digester tank is buried in soil but the *InnerTube* pipe itself is not in contact with the outer walls, and is therefore insulated from this loss of heat. In addition, the warm sewage entering the *InnerTube* pipe has its heat content confined to the pipe and not diluted with the rest of the tank contents, which are cooler. The combination of the pipe inside an otherwise standard septic tank provides a warmer environment in which sewage sludge can be digested. The warmer environment is important, as documented in Pussayanavin et al. (2015), because it facilitates increased methanogenic activity, increases microbial diversity and activity resulting in better digestion of sludge and less frequent pump-outs than at cooler temperatures.

Comparative Performance at BNQ Test Facility
Side by side testing at the Bureau de Normalisation de Quebec (BNQ) test facility in Quebec showed that the new digester performed substantially better in solids digestion than a standard

septic tank of the same size and same sewage flow of 1500 L/day. Communal residential sewage was dosed equally to the two tanks (each of nominal 3000 L capacity) from early September 2015 to mid-February 2016. The normal NSF-style morning-noon-night dosing sequence with the NSF-style stress tests was used during the first half of the testing period, while the second half of the testing period followed a 'working parent' NSF-style morning-night sequence from Monday to Friday with the normal sequence on weekends. The same volume of sewage was dosed each day regardless of the sequence. In total, 805,500 L of raw sewage was dosed to each tank over 537 consecutive days, containing 160 kg BOD, 207 kg TSS, and 39 kg TKN.

Solids Accumulation: Within 5 months of operation (including a severely harsh winter), the conventional septic tank had accumulated 33" of sludge in the first compartment compared to 11" in the first compartment of the *InnerTube* digester tank (taken where the *InnerTube* pipe exits into the tank). After 8 months the septic tank had accumulated solids from floor to airspace, solid enough to support a metal rod standing up in it (Figure 4a). The digester tank under the same conditions had no scum in the inlet or outlet area and only a minor amount of sludge, not sufficient to warrant a pump-out (Figure 4b).

Figure 4a. After 8 months of BNQ testing, the septic tank is completely full of solids.

Figure 4b. In comparison, the *InnerTube* digester has insufficient solids to pump out and effectively no scum layer.

At Day = 540 or 10 months after its first pump-out, the septic tank had again accumulated 22” of sludge or 45% by volume, enough to require a second pump-out (Figure 5a). By contrast, even after 18 months of continuous peak flow operation at 1500 L/day and without any prior pump-out, the *InnerTube* tank still has no scum and only 14” of sludge in the tank and does not require a pump-out (Figure 5b).

Figure 5a. In 10 months after its first pump-out, the septic tank is completely full of solids.

Figure 5b. The digester still has insufficient solids to warrant a pump out, after 18 months of continuous peak flow.

Performance Improvement: In the first 8-month period, although only 3 samples were taken, the *InnerTube* digester effluent was 7.4% better in cBOD, 30.1% better in TSS, and 9.2% better in fecal coliforms than the septic tank effluent. This suggests that the *InnerTube* digester may produce an improved effluent with respect to suspended solids removal, even while digesting far more solids. The actual cBOD removal is not expected to be much better, because the digested solids will themselves produce additional dissolved cBOD (sugars, fatty acids, etc.), adding to the cBOD value, though at the same time making it an easier, more 'labile' effluent to treat than cBOD bound up in larger molecules in solid form.

Performance at MASSTC Test Facility

At the Massachusetts Alternative Septic System Test Center (MASSTC) at the Otis Air Force Base, Cape Cod MA a 1500 US gallon *InnerTube* digester has been continuously tested for 3.5 years (and is on-going). The tank contains 15 feet of 12" diameter *InnerTube* pipe into which raw sewage is directed (Figure 6). The tank has no effluent filter.

Figure 6. Raw sewage is directed through the *InnerTube* pipe before entering the greater tank volume.

By Day 1293, the inlet area of the tank above the outlet of the *InnerTube* pipe contained scum, and likely the intervening space was largely filled with scum and sludge (Figure 7).

Figure 7. After 3.5 years of continuous dosing scum and sludge have accumulated at the tank inlet.

However, over the test period, no scum at all appeared in the outlet end of the single-compartment tank (e.g., Figure 8), and after 1293 days, there was only 6” of sludge in the outlet end. The *InnerTube* tank does not need pumping out even after receiving 1.38 million litres of sewage.

Figure 8. After 3.5 years of continuous dosing no scum has formed at the tank outlet and sludge depth is 6”.

The average cBOD and TSS values of the *InnerTube* tank effluent were 101 mg/L and 51 mg/L, representing removal rates of 47% and 75% respectively, from the BOD and TSS sewage values. This is very good performance for primary treatment, especially for TSS removal, similar to the BNQ case.

CONCLUSIONS

More thorough treatment of sewage is obtained in modified septic tanks with consistent and warmer temperature, utilization of more tank space, and removing the air space. Utilizing the produced biomass in the septic treatment process appears to be an easy improvement suitable for on-site systems. ‘Plug flow’ reactors like the *InnerTube* tank described in this paper direct liquid sewage through accumulated biomass solids to obtain a more thorough anaerobic digestion of sewage solids resulting in fewer pump-outs.

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