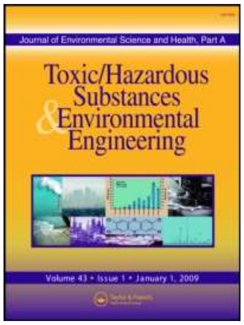

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Enzyme pretreatment of fats, oil and grease from restaurant waste to prolong septic soil treatment system effectiveness

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ABSTRACT
When a fast-food restaurant's wastewater containing fats, oil and grease (FOG) is discharged into a collection system, it builds up over time and clogs pipes. Similarly, when such wastewater flows into a septic soil treatment system, it adheres to the surface of inlet pipes, gravel/distribution media and soil, restricting the flow and eventually clogging the septic soil treatment system. In this study, an enzymatic pretreatment system was tested on wastewater from a fast-food restaurant to determine its effectiveness in preventing septic soil treatment system clogging. This system used aeration equipment, baffles and a one-time inoculum that excretes enzymes to reduce the molecular weight and number of double bonds associated with FOG. FOG containing triglycerides having lower molecular weights and fewer double bonds are less sticky. The enzymatic pretreatment system was found to cause these changes as verified by measuring the types of triglycerides (compounds in FOG) using liquid chromatography/mass spectrometry. A unique bench-scale septic soil treatment system (soil trench) was also used. Each contained six soil moisture sensors to enable the determination of moisture saturation trends among the five tested conditions: sanitary wastewater only, a combination of sanitary and kitchen wastewater, enzymatically pretreated sanitary and kitchen wastewater, kitchen wastewater, and enzymatically pretreated kitchen wastewater. For all influent types, a significant amount of FOG and other pollutants were removed, regardless of the initial concentrations. Moisture sensor readings showed differences among the tested conditions, indicating that septic soil treatment system clogging was delayed. Inspection of the influent pipe and gravel at the end of testing verified these differences as did the measurements of volatile solids.

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Enzyme pretreatment; fats oil grease; onsite wastewater; restaurant wastewater; septic drain field; septic soil treatment system; soil moisture sensor; soil trench

Introduction

Fats, oil and grease (FOG) come from animal meat, cooking oil, and dairy and petroleum products. The chemical structure of FOG is a triglyceride. Each triglyceride is composed of three fatty acids connected with glycerol, an alcohol with three carbons each bearing a hydroxyl group. A fatty acid has a long structure with usually 16 or 18 carbon atoms and potentially several double bonds. Higher molecular weight FOG containing a greater number of double bonds is less biodegradable and more cohesive (sticky). The cohesiveness of FOG results in the production of non-biodegradable grease balls.

There are two types of FOG. Yellow grease originates from fryer oil and other such concentrated sources. This FOG is only minimally contaminated with water, wastewater and solids and is usually recycled for animal feed or biofuels. Brown grease results from rinsing and washing dishes, sanitizing, mopping floors and washing rags. Unlike yellow grease, brown grease is contaminated and is typically discharged into the wastewater system, which results in collection system blockages as it builds up over time. When collection system pipes are clogged, raw sewage overflows into homes, streets, rivers and lawns, resulting in collection system back-up, potential exposure and property damage.

Removal of FOG from the collection system is expensive. In 2004, the U.S. EPA reported that there were 20,000 sanitary collection system overflows in the United States. Of these, 49% were related to FOG coming from restaurants, homes and industrial sources.[1] The New York Times stated that 62% of the 15,000 collection system backup complaints in New York City were related to FOG accumulation.[2] The United States spends $25 billion annually to manage FOG build up in collection systems.[3] Collection system issues caused by FOG cost $3.5 million and $4.65 million in San Francisco and New York City, respectively.[2,4] In London, 10 tons of congealed fat and household waste blocked and broke a collection system, resulting in a a repair cost of approximately $450,000.[5] From these cases, it is clear that the FOG being discharged into a collection system is of great concern all over the world.

Also important, but less documented, is the impact of FOG discharge into an onsite wastewater septic soil treatment system. FOG from fast food restaurants entering a septic soil treatment system adheres to the surface of inlet pipes, gravel

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surrounding the pipes and soil, restricting the flow and eventually clogging the system. FOG coagulates at a temperature below 60°C (140°F), and the typical temperature in a septic soil treatment system, at 61 cm (2 ft) below the surface, is from 3°C (37°F) to 20°C (68°F).[6] The average life of typical septic soil treatment system is 25–30 years.[7] However, the high strength of FOG in fast-food restaurant wastewater will prematurely age the septic soil treatment system. Wodalski reported that a septic drain field serving a large quick-serve restaurant was replaced three times in the first 5 years of business because of FOG.[8]

In order to prevent collection system problems, FOG collection and/or treatment systems are required so that the discharge limit of 100 mg/L is not exceeded.[9] These systems can use physical or biological treatment techniques. The most common physical treatment technology is a grease trap. A grease trap interceptor uses baffles in a tank to trap floating FOG and separates it from the wastewater. The grease trap must be pumped when it is 25% full to prevent the loss of efficiency.[10] The filtration system, Zabel A300, developed by Polylok Inc. (Wallingford, CT), removes materials larger than 0.08 cm (1/32 inch) and reduces 50–98% of FOG from restaurant wastewater. This system is designed for flows of 0.05–0.1 L/s (1200–2400 gal/day), and the filter cartridge can be washed for reuse.[11] Big Dipper Internal Strainer, developed by Thermaco Inc. (Asheboro, NC, USA), consists of a baffle, skimming wheel, programmable timer, grease collection container and solids collection basket. The system can separate up to 98.6% of FOG using a skimming wheel. This unit is designed for a kitchen flow of 1.26–3.15 L/s (20–60 gal/min).[12] Ji et al. studied the effectiveness of electrocoagulation and electroflotation for removing FOG from restaurant wastewater. The reactor was connected to a battery and used an aluminum anode and stainless steel cathode. The optimal conditions of the system were determined to be an inter-electrode distance of 3.6 cm, a 34-min reaction time and a current density of 43 A/m^2. This resulted in a FOG removal efficiency of greater than 95%.[13] Kwiatkowsk et al. studied the ability of sonication to degrade FOG from Saga University kitchen wastewater. An ultrasonic power supply was used to produce 20 kHz frequency energy. Gas bubbles of air, oxygen, argon and ozone were produced using an ultrasound probe in a control reactor. Reactions were promoted with the gas bubbles causing a thermolysis of the water. The mass of free fatty acids was reduced by up to 65% by the argon bubbles and up to 42% by the ozone bubbles.[14]

An alternative to the grease trap is to pretreat wastewater containing FOG with enzymes. Several enzymes cleave long-chain fatty acids and double bonds in the triglycerides present in FOGs,[15] reducing its cohesiveness and increasing biodegradability. The use of enzymatic treatment in restaurants minimizes the cost of pumping, hauling and disposing of FOG. Several full-scale systems using an enzyme for pretreatment before discharge into a collection system or septic soil treatment system are commercially available. The Advanced Grease Interceptor System (AGIS) was developed by Sustainable Environmental Technologies (SET) (Mt. Morris, MI, USA). The system, installed in a 5,678 L (1,500 gal) underground modified septic tank adjacent to the restaurant, uses intermittent low-energy aeration, baffles and a one-time commercially available microbial inoculum that excretes enzymes to microbiologically break down FOG.[16] Aeration stimulates enzymatic activity [17] but does not degrade FOG and is a problem in an aeration tank because it forms viscous foam. Gerardi discussed that pretreatment or addition of bioaugmentation (enzyme) products is suggested in an aeration tank in order to degrade FOG.[18] More details will be provided on the AGIS system in the "Results" section. BIO-FLO, developed by NCH Waste Water (West Midlands, UK), uses a tablet containing multiple bacterial cultures that is commonly used for liquid odor control in a grease trap, drain pipe and septic tank.[19,20] The microbial culture is commercially produced by Bio-Systems International (Beloit, WI, USA). Each day, 32 g of tablets are added into the growth vessel. The vessel is then filled with water and spun for 24 h at room temperature to excrete the enzymes. Thereafter, the entire content of the vessel is discharged into the collection system. For one application, the FOG concentration of grease trap effluent was 281 mg/L. With BIO-FLO, the grease trap effluent decreased to 168 mg/L (40% reduction). The chemical oxygen demand, total nitrogen and total phosphorus were reduced by 39%, 33% and 56%, respectively.[21] Aerobic Bacterial Generator (ABG) was developed by SludgeHammer (Petoskey, MI, USA). The system is installed in an aerobic treatment tank and uses 0.07 kW blowers, diffusers, a 130.9 m^2 fixed film media and a bacterial pack. ABG stimulates the growth of bacteria and reduced COD, FOG, TP and TKN by 70%, 89%, 28% and 30%, respectively.[22] Application of ABG was also demonstrated for a septic soil treatment system.[23] Remediator Grease Treatment System, developed by Jay R. Smith Manufacturing Company (Montgomery, AL, USA), uses bacteria to break down FOG. Two units designed for flow rates of 1.26–4.73 L/s (20–75 gal/min) are used. The first is a solids interceptor, which can remove over 99% of suspended solids having a size larger than 2 mm. The second is a biological reactor that uses the microbial population, including *Bacillus*, *Pseudomonas*, *Arthrobacter* and *Micrococcus* bacteria, to break down over 99% of FOG.[24]

Materials and methods

Experimental methods assessing the impact of enzymatic pretreatment on fast-food restaurant wastewater included analyzing changes in the composition of FOG caused by pretreatment and designing and testing bench-scale septic soil treatment system with various wastewater influents to determine the impact of the enzymes.

Impact of enzymes on the characteristics of triglycerides

Liquid chromatography/mass spectrometry (LC/MS) was used to observe changes in the characteristics of triglycerides caused by enzymatic pretreatment. Fast food restaurant wastewaters with and without AGIS treatment were collected from a restaurant in mid-Michigan. This location was chosen as the project was funded, in part, by SET, and this AGIS unit has been operating continuously for over 12 years. Samples were stored in clean glass bottles. If the analysis was delayed for more than 4 h, the samples were adjusted to a pH below 2 with hydrochloric acid [25] and stored at 0–4°C. The analyses were then completed within 28 days.

A 1 L sample of wastewater was extracted using the Xenosep solid-phase extraction method (EPA Method 1664A). The extract was dried and weighed in an aluminum dish that was washed three times with approximately 3 mL of hexane (≥95%), acetone (≥99.5%) and methanol (≥99%), in sequence, and dried in a pre-heated oven with a temperature of 103°C. The extracted FOG was dissolved in isobutyl alcohol (≥99.9%) and diluted for analysis using LC/MS. LC/MS was conducted at the Michigan State University Mass Spectrometry Facility using the Xevo G2-S QT with an Acquity UPLC BEH C18 1. 1.7 μm – 2.1 × 50 mm column. MassLynx V4.1 software was used to set up a method and analyze the samples.

Bench-scale septic soil treatment system design and performance

In order to observe the impact of enzyme pretreated fast-food restaurant wastewater on a septic soil treatment system, bench-scale septic soil treatment systems (trenches), including soil moisture sensors embedded within the soil, were designed. The wastewater flowed into the trench by gravity and exited through an outlet structure along the length of the trench, parallel to the inlet distribution pipe that allowed the determination of how far the influent progressed along the length of the trench. This outlet was designed by incorporating a sloped floor perpendicular to the distribution pipe that channeled water through three 5.08 cm (2 in) diameter pipes equally spaced along the length of the trench. Each pipe drained a third of the trench as a short vertical wall that extended 5.1 cm (2 in) up from the floor produce three equal outlet segments.

All dimensions of the trenches were based on the Michigan criteria for subsurface sewage dispersal, which are calculated from the hydraulic loading.[26] The width of the trench was 0.61 m (2 ft), selected to accommodate one inlet pipe. A typical septic soil treatment system has multiple inlet pipes with a maximum separation of 91 cm (36 in) between the pipes. Its length was 0.74 m (4 ft). The loading required for the soil used in this research, sandy loam, is 10.2 L/day/m^2 (0.25 gal/day/ft^2) [26] resulting in a flow rate of 7.57 L/day (2 gal/day) and an empty bed contact time (EBCT) of 60 days. Figure 1 shows the profile of each trench. The soil profile simulated an actual installation as scaling mass transfer characteristics with depth is not feasible. The first layer of soil, before wastewater entered, contained 22.9 cm (9 inch) of top soil. Wastewater was distributed in the next layer, having a 7.6 cm (3 inch) depth of gravel followed by the inlet pipes and then 15.2 cm (6 inch) of gravel. The depth of the sandy loam that served as the treatment media was 60.9 cm (2 ft). Gravel, sandy loams, top soils, gravels and 6A stones were ordered from Carl Schlegel, Inc., in Lansing, Michigan.

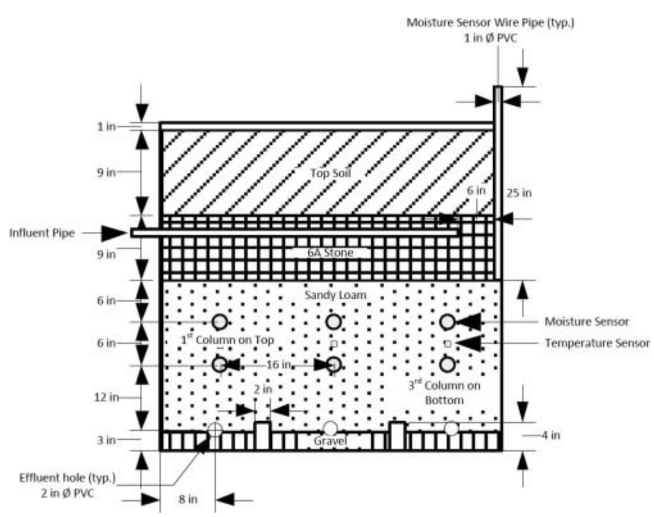

Figure 1. Profile view of a trench.

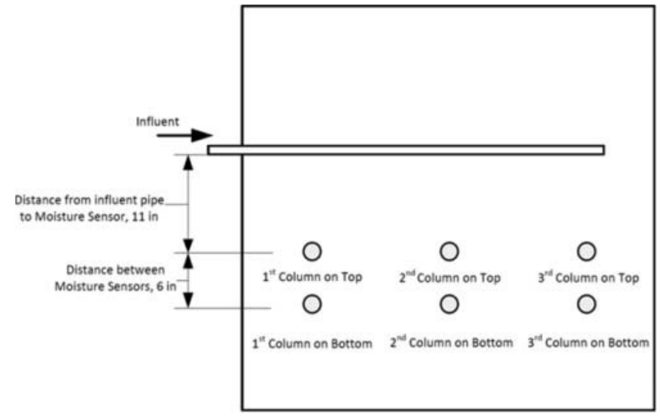

Figure 2. Schematic of moisture sensor locations (circles) for each trench (not to scale).

The walls of each trench were Plexiglas, and their corners were primed and glued. Each wall was supported with a wooden frame, and all seams were caulked. The inside of the trenches was lined with heavy-duty plastic sheeting by Blue Hawk Inc. (Mooresville, NC, USA).

Six Campbell Scientific (Logan, UT, USA) soil moisture sensors (model CS616) were placed at two depths and three locations along the length of the trench (Fig. 2). All soil moisture sensor wires exited through a 2.5 cm (1 inch) PVC pipe. A Campbell Scientific CR1000 data logger recorded all data. Three temperature sensors were placed in each column in the sandy loam layer. The data were downloaded to a dedicated computer.

Impact of wastewaters with/without enzyme pretreatment on clogging

Each trench received only one of the following feedstocks:

1. Sanitary wastewater (sanitary)—control that does not cause premature aging of the septic soil treatment system.
2. Sanitary wastewater mixed with kitchen wastewater without enzymatic pretreatment (sanitary/kitchen)—simulates condition for a typical restaurant. Assumed to clog a septic soil treatment system causing its premature aging.
3. Sanitary wastewater mixed with kitchen wastewater treated with enzymatic pretreatment (sanitary/treated kitchen)—typical test condition.
4. Kitchen wastewater without enzymatic pretreatment (kitchen)—extreme condition that is expected to rapidly clog the septic soil treatment system.
5. Kitchen wastewater treated with enzymatic pretreatment (treated kitchen)—high loading test condition.

The sanitary wastewater originated from a small cluster wastewater treatment system serving 25 homes in Dimondale, Michigan. Each house has a septic tank that emptied into a force main, which transports the waste to an advanced treatment unit. Samples were collected from the centralized septic tank where the wastewaters from all the homes were combined before being further treated. Because this wastewater was biologically active, the samples were stored at 0–4°C.

Enzymatically pretreated kitchen wastewater was collected from a restaurant in Mid-Michigan, where an AGIS has been operating for over 12 years and discharging to a municipal collection system. Wastewater without enzymatic pretreatment could not be directly collected because there was not a sampling port and a buffer tank to provide a representative sample. Consequently, this wastewater was formulated by mixing the individual wastewater sources together. Sources included water from a dishwasher, sink, and floor cleaning and towel washing machine.

Trench influent was fed three times a day at approximately 9:30 am, 1:30 pm and 8:30 pm to simulate the cleaning schedule at a typical fast-food restaurant. Feedstocks were pumped into the inlet pipe using a Masterflex pump. Experimentation lasted for 505 days for all trenches except for the one receiving the kitchen feedstock, which was run for 362 days due to changes in the experimental design.

The temperature was measured manually three times a day using simple thermocouples. Readings from the soil moisture sensors were monitored automatically using the CR1000 data logger. The data were saved monthly in a spreadsheet. Volatile solids (VS) analysis was conducted on the soil to provide a rough, relative estimate of the amount of microbial activity. Soil samples were collected and stored in plastic bags at 4°C for up to 24 h and analyzed using EPA Method 1684. Samples for VS measurements were conducted on the day after the trench operation was discontinued. The analysis methods of trench influent and effluent wastewater parameters are shown in Table 1. All analyses were conducted with HACH Company (Loveland, CO, USA) analytical methods.

The parameters in Table 1 were compared with an one-way ANOVA (significance level of 0.05) using the software SAS 9.4.

Results and discussion

The 'Results' section discusses the impact of enzymes on the characteristics of triglycerides, bench-scale septic soil treatment system design and the impact of wastewaters with and without enzyme pretreatment on the septic soil treatment system.

Table 1. Wastewater analytical parameters.

Parameter	HACH method	U.S. EPA method	Reference
Chemical oxygen demand (COD)	8000	40 CFR 136.3.	
Biological oxygen demand (BOD_5)	8043	SM 5210 B	
Fats, oil and grease (FOG)	10300	EPA 1664A	
Total phosphate (TP)	8190	EPA 365.1, 365.3	[27]
Total nitrogen (TN)	10208	N/A	
Ammonia	10205	EPA 350.1, 351.1, 351.2	
Nitrate	10206	40 CFR 141	

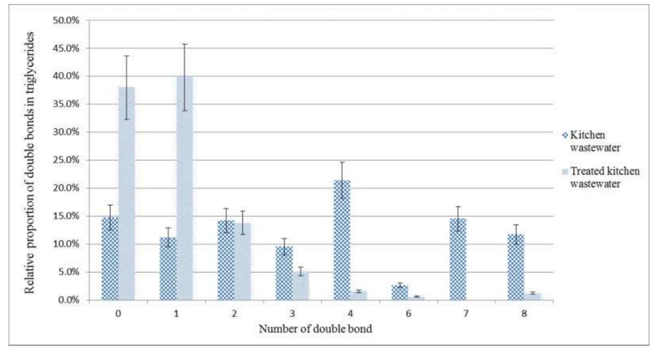

Figure 3. Relative proportion of double bonds in triglycerides from kitchen wastewater and treated kitchen wastewater.

Impact of enzymes on the characteristics of triglycerides

The proportion of double bonds in triglycerides from the kitchen feedstock was compared to that in the treated kitchen feedstock (Fig. 3). Three replications were conducted for each sample, and the error bars represent the standard deviation. Figure 3 shows that the relative proportions of single bonds and one double bonds in the triglycerides within the treated kitchen wastewater were statistically significantly higher from 15% to 38% and 11% to 40%, respectively, than in the non-treated wastewater (ANOVA, P-value < 0.001, $\alpha = 0.05$). Results showed that treatment of the kitchen wastewater with enzymes reduced the number of triglycerides with equal or greater than four double bonds by 44% by (ANOVA, P-value < 0.001, a D 0.05). Therefore, results show that enzyme treatment reduced the cohesiveness of FOG and increased its biodegradability.

Bench-scale septic soil treatment system design and performance

Removal of constituents, including COD, BOD_5, FOG, TP, TN, ammonia and nitrate, were measured to determine the effectiveness of each trench. Table 2 shows that the trench receiving sanitary wastewater had influent and effluent characteristics typical of an actual septic soil treatment system, demonstrating the utility of the trenches to simulate field conditions. Average COD, FOG, TP, TN, ammonia and nitrate of simulated septic soil treatment system were similar to typical values of an actual septic soil treatment system. Average BOD_5 effluent of

Table 2. Comparison of performance between simulated sanitary septic soil treatment system and typical field-scale system.

	Simulated septic soil treatment system (sanitary)		Typical septic soil treatment system		
Parameter	Influent	Effluent	Influent	Effluent	Reference
COD (mg/L)	119.8	29.3	99–445	N/A	[28–31]
BOD_5 (mg/L)	102.6	28.0	32–217	0–17	[30–34]
TP (mg/L-P)	6.8	2.6	4.5–30	0.01–4.9	[29–32,34]
FOG (mg/L)	10.9	2.6	6–15	N/A	[29,30]
TN (mg/L-N)	42.9	42.3	25–63.4	48	[29,30,33,34]
Ammonia (mg/L-N)	27.3	0.1	20–60	0.03	[27,31]
Nitrate (mg/L-N)	1.9	39.1	0–10	40–42	[28,30–32]

Table 3. Performance of septic soil treatment system for each trench.

Parameter		Sanitary		Sanitary/kitchen		Sanitary/treated kitchen		Kitchen		Treated kitchen	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
COD (mg/L)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	119.8	29.3	703.9	59.9	740.6	47.5	2615.4	152.9	2903.8	133.4
	Std.	22.4	7.0	110.7	19.0	132.3	19.5	268.2	40.9	256.3	35.6
BOD_5 (mg/L)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	102.6	28.0	327.9	42.4	406.6	38.3	1120.3	118.5	1267.9	84.3
	Std.	24.8	9.9	50.1	24.9	95.6	16.7	325.4	43.0	359.1	25.1
FOG (mg/L)	n	15	12	15	12	15	12	15	12	15	12
	Avg.	10.9	2.6	180.3	32.0	184.3	6.5	588.7	48.7	605.0	27.3
	Std.	3.0	1.7	19.2	4.6	29.3	3.5	19.6	9.5	31.6	6.5
TP (mg/L-P)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	6.8	2.7	7.8	2.6	7.8	2.6	7.1	2.2	7.7	1.0
	Std.	0.4	0.7	0.9	0.9	0.8	0.7	2.5	0.5	1.2	0.4
TN (mg/L-N)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	42.9	42.3	46.1	28.8	42.7	38.8	45.4	39.0	54.7	14.6
	Std.	5.5	5.7	6.0	5.1	6.5	4.4	10.8	10.5	11.4	2.1
Ammonia (mg/L-N)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	27.3	0.1	36.9	0.4	32.1	0.5	35.7	0.3	42.4	6.9
	Std.	6.1	0.2	6.0	0.6	5.8	0.7	7.7	0.4	8.9	2.9
Nitrate (mg/L-N)	n	20	20	20	20	20	20	20	20	20	20
	Avg.	1.9	39.1	2.4	22.7	3.1	30.7	1.9	38.4	2.6	9.4
	Std.	4.7	4.1	2.6	3.5	1.9	3.3	1.3	10.3	1.4	4.0

simulated septic soil treatment system was higher than the typical value of an actual septic soil treatment system, for unknown reasons.

Table 3 shows the performance of the trench for each wastewater feedstock. All bench-scale trenches removed significant amounts of COD, regardless of the initial concentrations. The effluent levels of the trench receiving kitchen and treated kitchen wastewater were higher than the trench receiving sanitary/kitchen and sanitary/treated kitchen wastewater likely due to the high initial concentration. All bench-scale trenches removed significant amount of BOD_5, regardless of the initial concentrations. BOD_5 concentrations are lower than COD concentration because a substantial amount of FOG is not biologically degradable. All bench-scale trenches reduced the FOG concentration significantly, regardless of the initial concentration. The removal rate for the trench receiving sanitary/treated kitchen and treated kitchen wastewater was statistically higher (ANOVA, P-value<0.0001, $\alpha = 0.05$) than the trench receiving sanitary/kitchen and kitchen wastewater. This is hypothesized to have occurred because the FOG in the sanitary/treated kitchen and treated kitchen wastewater became more biodegradable after enzymatic treatment. All bench-scale trenches reduced TP concentrations significantly. The trench receiving treated kitchen wastewater had a statistically lower effluent TP (ANOVA, P-value < 0.0001, $\alpha = 0.05$) than the other trenches, hypothesized to be due to the heavy amount of biomat formation (to be discussed later in the manuscript).[35] All bench-scale trenches decreased ammonia concentrations significantly and, as expected, the nitrate level in all trenches increased. The effluent level of nitrate for sanitary/kitchen was statically lower (ANOVA, P-value<0.001, $\alpha = 0.05$) than sanitary/treated kitchen wastewater. Also, the sanitary/kitchen and treated kitchen trenches had statistical better nitrate removal rates (ANOVA, P-value<0.0001, $\alpha = 0.05$) than sanitary/treated kitchen and kitchen wastewater, respectively. The soil in the trenches receiving treated kitchen and sanitary/kitchen wastewater was saturated and, consequently, anaerobic conditioned for enhancing the denitrification process.

Impact of wastewaters with/without enzyme pretreatment on clogging

Figure 4a shows the average daily moisture content from the trench receiving sanitary wastewater for each sensor. The average value was calculated from measurements made every 10 min. Results show a relatively constant to very slight increase in water content with time at all locations. The highest moisture content was found at the first top location, and the lowest was at the third bottom location (Fig. 2). This indicates that very little water flowed across the length of the trench. Figure 4b shows the daily moisture content from the trench receiving treated kitchen wastewater. This trench had the highest moisture level of all the conditions but also the largest biodegradable organic loading (Table 3).

To gain a better perspective on the change in moisture content, monthly plots of the 10-min moisture contents values were produced over a 24-h period beginning on the 254th day of operation for all the trenches except the kitchen trench, which was on the 88th day of operation. These plots could not be routinely produced due to memory limitations of the CR1000 data logger. Figure 5a shows the volumetric moisture level of the trench that received sanitary wastewater. Only the first bottom location was affected during feed periods over the 505 days of operation. The other locations showed consistent moisture contents. Figure 5b and c shows the 10-min moisture level of the trenches that received sanitary/kitchen and sanitary/treated kitchen, respectively. Both the graphs show higher moisture levels than those for the sanitary wastewater trench. The soil moisture levels at each location were greater for the sanitary/kitchen trench, although both showed similar COD and FOG removal rates. The slope of moisture content in the trench receiving sanitary/kitchen was gradually increasing,

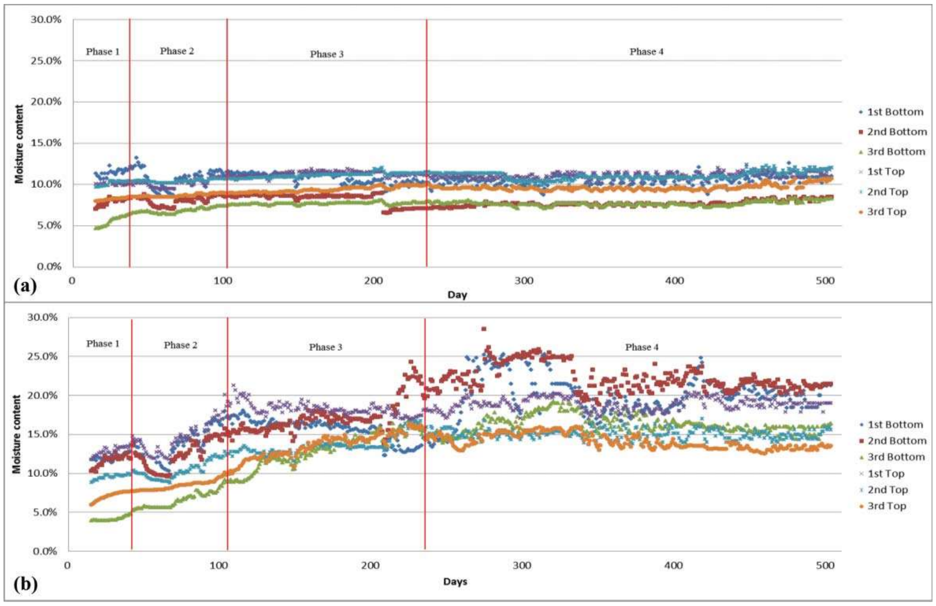

Figure 4. Daily moisture levels in the trench receiving (a) sanitary wastewater and (b) treated kitchen wastewater.

Figure 5. Moisture content of trench receiving (a) sanitary wastewater, (b) sanitary/kitchen wastewater, (c) sanitary/treated kitchen wastewater, (d) kitchen wastewater, and (e) treated kitchen wastewater – 10 min segments.

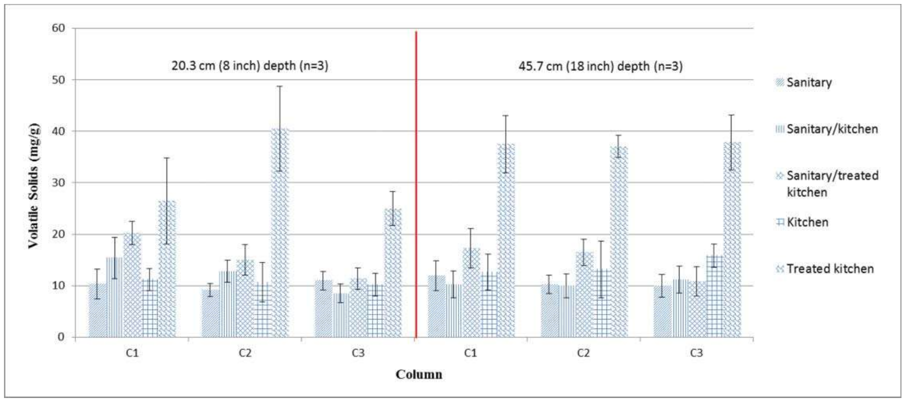

Figure 6. VS of sanitary, sanitary/kitchen, sanitary/treated kitchen, kitchen, treated kitchen trenches at depths of 20.3 cm (8 inch) and 45.7 cm (18 inch) from the top of the sandy loam at the columns within the trench (Fig. 2).

whereas the slope for the sanitary/treated kitchen is constant. More affected locations and higher peaks of moisture levels are hypothesized to cause the premature aging of the septic soil treatment system. Figure 5d and e shows the moisture levels of the trenches that received kitchen and treated kitchen wastewater, respectively. The trench receiving kitchen and treated kitchen wastewater showed higher moisture levels than the sanitary wastewater trench. However, there are clear differences between the trenches. Water started to become apparent at the soil surface on day 242 of operation. This was at first surprising but was later found to occur when the inlet pipe becomes clogged with FOG, which is discussed in the next subsections.

At the end of the experiment, when feeding to the trenches was discontinued, soil samples were collected to to measure VS. In each trench, three replicates were collected from each column at depths of 20.3 cm (8 inch) and 45.7 cm (18 inch). Data are shown in Figure 6, with the error bars representing the standard deviations. The VS in the trench that received treated kitchen is statistically higher than that in the trench receiving kitchen wastewater (ANOVA, P-value<0.001, $\alpha = 0.05$). The VS in the trench receiving sanitary/treated kitchen wastewater is statistically higher than that in the trenches receiving sanitary and sanitary/kitchen wastewater (ANOVA, P-value $= 0.0025$, $\alpha = 0.05$). VS levels for the trenches that received sanitary and sanitary/kitchen wastewater were not statistically different except for location C1 at a depth of 20.3 cm (8 inch). These results indicate that there is a greater microorganism population in enzyme-pretreated wastewater.

Visual observations of gravel in the trenches, influent pipes and treatment soils was made when the system was disassembled. Figure 7a shows the clean condition of the inlet pipe from the sanitary trench after 505 days of operation. Since sanitary wastewater contains a relatively low concentrations of FOG and COD, when compared to fast-food restaurant wastewater, it did not cause physical clogging. Figure 7b shows the condition of the inlet pipe in the sanitary/kitchen trench after 505 days of operation. Some FOG residues adhered on both the inner and outer sides of the pipe. This solids accumulation has

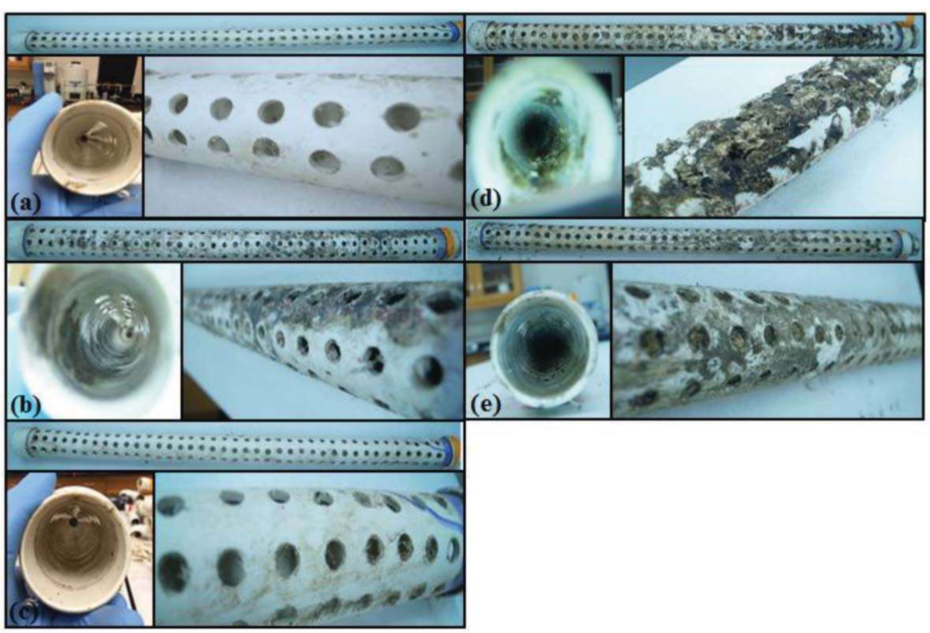

Figure 7. Inlet pipe condition in the (a) sanitary trench after 505 days of operation, (b) sanitary/kitchen trench after 505 days of operation, (c) sanitary/treated kitchen trench after 505 days of operation, (d) kitchen trench after 337 days of operation, and (e) kitchen trench after 505 days of operation.

the potential to ultimately clog the pipe. Figure 7c shows the inlet pipe from the sanitary/treated kitchen trench. There is minimum evidence of FOG or biomat accumulation on both the inner and outer sides of the pipe. Result shows that enzyme treatment degraded the cohesiveness of the triglycerides so that FOG will not physically clog the pipe. Figure 7d shows the condition of the inlet pipe in the kitchen trench. The pipe is plugged with FOG resulting in wastewater back-up within the pipe and in the soil. The feedstock very slowly progressed downward though the column, hence the reason for the low and relatively constant soil moisture levels, as previously discussed (Fig. 5d). Figure 7e shows the inlet pipe from the treated kitchen wastewater trench. Approximately half of the effluent holes were clogged with a layer of biomat, but physical plugging from FOG was not observed. The COD concentrations of both kitchen and treated kitchen wastewater were approximately 30 times higher than those of sanitary wastewater. Enzymatic pretreatment transformed the FOG so that it was more biodegradable, causing the extensive biomat growth. To manage this large biodegradable, organic load, the sizing of the septic soil treatment system should be designed based on organic loading, not on the standard hydraulic loading used.

Conclusion

LC/MS analysis showed that enzyme treatment affected the characteristics of the triglycerides composing the FOG. Specifically, the number of double bonds and the molecular weight of the individual components of the FOG were reduced.

Bench-scale trenches with embedded soil moisture sensors for monitoring clogging proved to be a unique, effective method to research the impact of diverse feedstocks. Their performance in removing typical wastewater constituents during experimentation with typical sanitary feedstocks generally closely correlated to that found in the literature. Sizing the trenches based on hydraulic loading effectively removed a significant amount of COD, BOD_5 and FOG, regardless of their initial concentrations. Daily readings from the moisture sensors were not sensitive enough to detect water flow through the septic soil treatment system to distinguish between feedstocks. Ten-minute segment readings showed substantial changes in moisture levels, including an increase at each feeding and a slow decrease thereafter. Moisture levels in the trenches receiving sanitary wastewater (serving as a control) and the sanitary wastewater mixed with kitchen wastewater that was enzymatically pretreated were not substantially elevated. The trench receiving the sanitary wastewater and untreated kitchen wastewater showed signs of premature aging based on the elevated moisture and increasing levels with time. The trench receiving only untreated kitchen wastewater had a constant level of moisture due to the clogged inlet pipe. However, the trench receiving only enzymatic treated kitchen wastewater had the highest level of moisture due to the formation of a biomat. VS levels in the trench receiving sanitary wastewater were consistently low. The trench receiving sanitary/treated kitchen wastewater showed higher VS levels than the trench receiving sanitary/kitchen wastewater. The VS levels of trench receiving kitchen wastewater showed no significant changes in different trench locations, whereas significant VS levels in different trench location were found in the trench receiving treated kitchen wastewater. These results indicate that there is a greater microorganism population in enzyme pretreated wastewater. Inlet pipes from the trenches receiving sanitary wastewater and sanitary/treated kitchen wastewater were found to be relatively clean. The inlet pipe receiving the sanitary/kitchen wastewater showed signs of clogging because of FOG accumulation, and the inlet pipe receiving kitchen wastewater was clogged. However, the inlet pipe receiving treated kitchen wastewater was also partially clogged, but this was caused by the extensive biomat growth.

Overall, results from the laboratory trenches show that pretreatment of restaurant wastewater using an in situ enzyme-producing bacteria (enzyme generator) will delay clogging, and consequently, premature septic soil treatment system aging. This research verified that the enzyme treatment helps the FOG to become more biodegradable, which reduces the risk of physical clogging. The resulting increase in the biodegradable organic load may increase the growth of the biomat. However, if the septic soil treatment system is clogged by a biomat, feeding can be discontinued to allow the biomat to degrade, which should occur after several months.[34,36] However, if it is clogged by the accumulation of FOG, it will be difficult to recover. Designing the septic soil treatment system based on organic loading, instead of the standard hydraulic loading, is recommended when pretreating with enzymes. Alternatively, constructing two separate septic soil treatment systems, one for operation and another one where the biomat is degrading, may also be an option.

Based on this research, recommendations for the future studies are as follows:

1. Repeating this research using different soil types.
2. Precipitation and snow can affect the performance of a septic soil treatment system because its efficiency decreases when there is an increase in the hydraulic loading. Simulation including precipitation is suggested.
3. Bench-scale septic soil treatment system performed similar as a typical septic soil treatment system during the 505 days of operation. However, a field demonstration for a longer period of operation is recommended. Field demonstrations are more realistic as temperatures are affected by season and precipitation influences are included.
4. As moisture content sensors showed the potential clogging of a trench, installing oxygen sensors in addition to moisture content sensors is suggested in order to show the potential clogging by a biomat.
5. Microbial community analysis is suggested in order to understand the impact of different characteristics of wastewater with/without enzyme pretreatment on the microbial community in a septic soil treatment system.

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