Bioresource Technology 124 (2012) 52–58

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Use of Bio-Amp, a commercial bio-additive for the treatment of grease trap wastewater containing fat, oil, and grease

Hao L. Tang [1], Yuefeng F. Xie [2], Yen-Chih Chen *

Environmental Engineering Programs, Pennsylvania State Harrisburg, 777 West Harrisburg Pike, Middletown, PA 17057, USA

HIGHLIGHTS

- ▶ Grease trap wastewater was studied with and without Bio-Amp treatment.
- ▶ Bio-Amp can reduce FOG deposit formation and thus alleviate sewer line blockage.
- ▶ Bio-Amp can reduce COD and nutrients loadings to the treatment plant.
- ▶ Bio-Amp can increase rbCOD fractions and potentially enhance Bio-P removal.

ARTICLE INFO

Article history:
Received 21 June 2012
Received in revised form 31 July 2012
Accepted 2 August 2012
Available online 10 August 2012

Keywords:
Bio-additive
Bio-Amp
FOG
FOG deposit
Wastewater

ABSTRACT

This research investigated the application of Bio-Amp, a commercial bio-additive for the treatment of fat, oil, and grease (FOG) in a grease trap, and evaluated potential impacts of treated effluent on downstream collection system and treatment processes. Results show that after Bio-Amp treatment, FOG deposit formation was reduced by 40%, implicating a potential reduction of sewer line blockages. Chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP) and total fatty acids were reduced by 39%, 33%, 56%, and 59%, respectively, which represents an overall loading reduction of 9% COD, 5% TN and 40% TP received by the treatment plant from all the dining halls. On the other hand, readily biodegradable COD fractions significantly increased, which implies a potential improvement on Bio-P removal. Overall, the results showed that application of Bio-Amp in grease trap provides potential reduction of sewer line blockages, and can also alleviate downstream treatment burden.

1. Introduction

Fat, oil, and grease (FOG) have negative impacts on wastewater collection and treatment systems. Most blockages in wastewater collection systems can be traced back to FOG (Kizilaslan, 2007). The blockages can increase frequency of cleaning or replacement of piping systems, and cause unpleasant odors, sewage spills, manhole overflows, or sewage backups in homes and businesses (Canler et al., 2001). In addition, raw wastewater from restaurants and FOG-producing establishments with no pretreatment has high biological oxygen demand (BOD), oil and grease, and total suspended solids (TSS), which result in extra burdens to wastewater treatment plants. It is known that FOG has deleterious effects on biological wastewater treatment processes, as the formation of lipid films around the flocs reduces the oxygen transfer rate to the biomass (Becker et al., 1999) and FOG is also involved with filamentous bulking and foam production (Dueholm et al., 2000). Therefore, removal of FOG from raw wastewater is important.

Grease traps are commonly used by FOG-producing establishments to reduce FOG entering the collection systems and treatment utilities. Grease trap is normally a vault that is located at the exterior of a building. It allows wastewater to cool, and FOG to congeal and rise to the surface where FOG accumulates until the grease trap is cleaned. Because the efficiency of grease traps is relatively low (Chu and Ng, 2000; Chan, 2010), more effective approaches are needed to reduce FOG entering the collection system. Bio-Amp, a bio-additive from Eco Bionics (Irving, TX, USA), is a system that provides high amounts of 5 bacteria (*Pseudomonas fluorescens*, *Pseudomonas putida*, *Bacillus subtilis*, *Bacillus licheniformis*, and *Bacillus thuringiensis*) (Table 1) that are known to degrade FOG. These bacterial species produced an array of metabolic enzymes allowing the breakdown of FOG in wastewater (Wakelin and Forster, 1997). *Bacillus* are gram-positive bacteria that produce enzymes to breakdown fat into glycerol and fatty acids (Kunst et al., 1997; Roheim, 2003). *P. putida* and *P. fluorescens* are gram-negative bacteria that

* Corresponding author. Tel.: +1 717 948 6695; fax: +1 717 948 6580.
E-mail addresses: tang@psu.edu (H.L. Tang), yxx4@psu.edu (Y.F. Xie), yuc12@psu.edu (Y.-C. Chen).
[1] Tel.: +1 717 902 9518; fax: +1 717 948 6580.
[2] Tel.: +1 717 948 6415; fax: +1 717 948 6580.

0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.08.012

Table 1
Bio-Amp bacteria composition.[a]

Genus species	Class	Enzymes/food
Pseudomonas fluorescens	Aerobic	Lipase Multiple enzyme systems
Pseudomonas putida	Aerobic	Lipase Multiple enzyme systems
Bacillus subtilis	Aerobic	Protease Amylase
Bacillus licheniformis	Facultatively anaerobic	Protease Amylase Cellulose
Bacillus thuringiensis	Facultatively anaerobic	Protease Amylase Lipase

[a] Schutz (2008).

can further break down fatty acids, and oxidize unsaturated fatty acids (Auerbach et al., 2000; Roheim, 2003). The Bio-Amp was proven successful in grease pretreatment for Derry Township Wastewater Treatment Plant (Hershey, PA, USA), allowing the utility to take in grease wastes from the region without upsetting downstream treatment processes (Schutz, 2008). The Bio-Amp application takes advantage of FOG's biodegradability and has a potential to be used in combination with grease traps for pretreatment of FOG-containing wastewater.

However, after FOG is biologically converted to glycerol and fatty acids by Bio-Amp, there is a concern that these soluble organics may enter the aqueous phase, resulting in increased chemical oxygen demand (COD) and nutrient levels in wastewater entering the treatment plants. Furthermore, it was recently shown that calcium may be released from biologically induced concrete corrosion (O'Connell et al., 2010; Bielefeldt et al., 2010), and FOG deposits, which display adhesive, grainy and sandstone-like texture, can be formed as a result of a saponification reaction between fatty acids and calcium ions and lead to undesirable sewer line blockages (He et al., 2011). Keener et al. (2008) investigated major metals in FOG deposits and found that calcium is the primary metal present and is the highest-contributing metal of FOG deposits. On the other hand, it has been noted by He et al. (2011) that no more increase of FOG deposit formation can be observed if no more fatty acids are available to continue the reaction with calcium. The principal fatty acids in domestic wastewater are the saturated myristic (C14:0), palmitic (C16:0), and stearic acids (C18:0), and the unsaturated oleic (C18:1) and linoleic acids (C18:2) (Novak and Carlson, 1970). Control of these fatty acids is expected to alleviate the sewer line blockage problems. Therefore, there is a need to explore how the application of Bio-Amp will affect the formation of FOG deposits. It is also important to analyze the degradation byproducts of Bio-Amp application and evaluate these byproducts' impact on downstream biological treatment systems. This project addresses these issues in a field application of Bio-Amp at an operating grease trap, prior to the disposal of the FOG at a local wastewater treatment plant. While the producers of BioAmp have studied its behavior on FOG in grease traps, no one has published an extensive study of the generation of byproducts and changes in nutrient content of treated wastewater as a result of Bio-Amp application. The information is especially lacking on the potential impact of these byproducts to the downstream collection system and wastewater treatment processes.

The objectives of this research were (1) to examine the change of FOG deposit formation that is responsible for sewer line blockages after the application of Bio-Amp to the grease trap; and (2) to investigate the change of COD, total nitrogen (TN), total phosphorus (TP), readily biodegradable COD (rbCOD), and fatty acids in Bio-Amp treated grease trap wastewater and their potential impact on downstream biological wastewater treatment processes.

2. Methods

2.1. The Bio-Amp and grease trap system

Fig. 1 shows the schematic diagram of the Bio-Amp and grease trap system in use for the pretreatment of restaurant wastewater from a student dining hall at The Pennsylvania State University (University Park, PA, USA). The Bio-Amp unit is located inside the building. It has a dimension of 45.7 cm $\times$ 74.9 cm $\times$ 23.5 cm (width $\times$ height $\times$ depth). When the unit was in operation, 32 g of Bio-Amp pellets, which were a blend of nutrients and the five *Pseudomonas* and *Bacillus* strains, were automatically added into the growth vessel containing water, allowing bacteria to grow for 24 h at room temperature and neutral pH. At the end of the 24 h period, the entire contents of the vessel, which contained approximately 3×10^{13} viable cells as analyzed by plate count with nutrient agar, were applied to the grease trap where the temperature of raw wastewater was 22 ± 2 °C and the pH was 7.2 ± 0.2. After that, the entire process started over again. The operations were controlled by a programmable digital control unit. The Bio-Amp unit was operated for three consecutive months from October to December 2011. The grease trap with a capacity of 7500 L is located at the exterior of the building. It has baffles inside to retain the wastewater for the grease to congeal and rise to the surface. Accumulated grease was pumped out and disposed, which happened once in November 2011 during the experimental period.

2.2. Sample collection

Grease trap effluents were collected from the manhole downstream of the grease trap using an auto-sampler. Samples were collected monthly from September 2011 through February 2012. Because the Bio-Amp unit was in operation from October through December 2011, samples collected in these 3 months were under the influence of Bio-Amp. The collected samples were acidified, chilled, and transported to laboratory for analysis.

2.3. Sample analysis

The collected grease trap effluents were filtered through glass fiber filters (Pall Corporation, Ann Arbor, MI, USA) to remove suspended solids. The filtered samples were then diluted for the FOG deposit formation test based on methods described by He et al. (2011). The resulting CODs after dilution were approximately 1000 mg/L. A jar test apparatus (PB-900 Programmable Jar Tester, Phipps & Birds, Richmond, VA, USA) was used to perform the test. The pH was adjusted to 7 using a 1 mol/L NaOH solution. In each beaker, 500 mL of diluted and pH-adjusted grease trap effluent wastewater was dosed with a $CaCl_2$ stock solution (40 g/L) to give a final calcium concentration of 750 mg/L. The mixing speed was set at 20 rpm and the reaction process lasted 10 days. On Day 10, the solution in each beaker was filtered again to analyze FOG deposits, which was determined as TSS using Standard Method 2540D (APHA, 1998).

COD, TN and TP were analyzed using Hach vials (Cat. No. 21259-15, 27141-00 and 27426-45) and a spectrophotometer (Hach Company, Loveland, CO, USA). An aerobic batch method described by Ekama et al. (1986) was used to determine rbCOD in this research. In short, the diluted grease trap effluents were aerated rapidly to raise the oxygen level to approximately 6–8 mg/L. Then a measured volume of activated sludge mixed liquor was added to each reactor, which resulted in a food to microorganism (F/M) ratio of

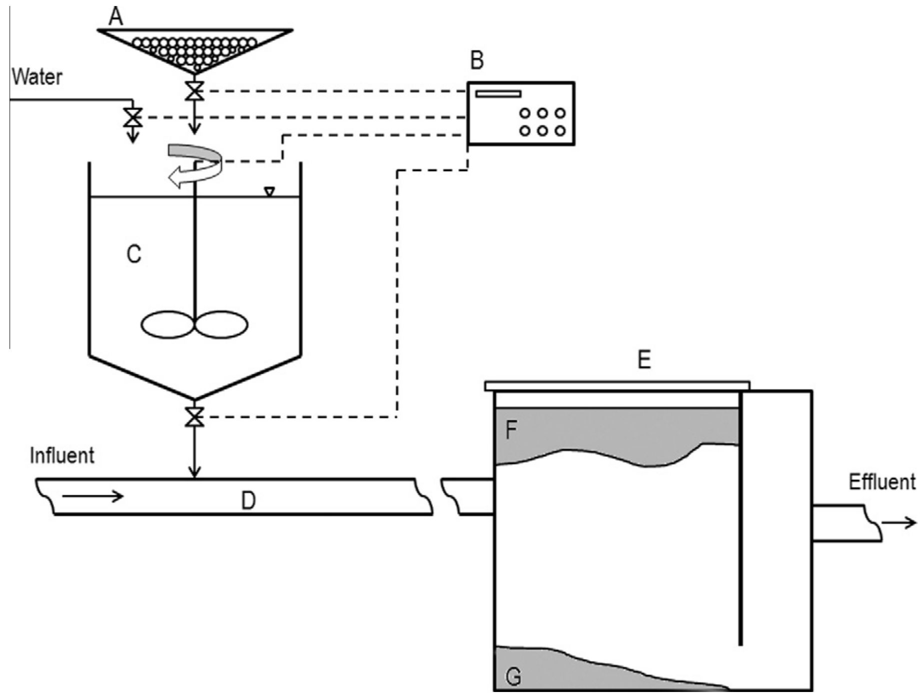

Fig. 1. Schematic diagram of the Bio-Amp and grease trap system. A: Bio-Amp pellets; B: digital control unit; C: reaction vessel; D: sewer pipe; E: grease trap; F: accumulated FOG; G: accumulated solids.

approximately 0.6. The remaining DO was recorded over time by a rapid response DO probe and a data acquisition device from Vernier Software & Technology (Beaverton, OR, USA) until the DO was reduced to approximately 3 mg/L. For each sample, the oxygen utilization rate (OUR) response was plotted over time and the rbCOD concentration was estimated based on measuring the area under the OUR curve indicating the mass of oxygen utilized for the oxidation of rbCOD.

2.4. Fatty acid analysis

The analyzed short-chain fatty acids or volatile fatty acids (VFAs) were the sum of fatty acids with aliphatic tails of equal or greater than 2 carbons and less than 8 carbons. The preparation of volatile fatty acid (VFA) samples for gas chromatography (GC) determination was based on Manni and Caron's procedure (Manni and Caron, 1995; Siedlecka et al., 2008). In short, each 1-mL aliquot of the acidified FOG sample was shaken along with 1 mL of diethyl ether for approximately 30 s. The supernatant ether phase was transferred to a GC vial. A series of VFA standards diluted from a stock mixture (Volatile fatty acid standard mix, Matreya, Pleasant Gap, PA, USA) were prepared in the same manner as described above. Calibration curves for determination of retention times and recoveries were obtained using aqueous solutions of nine acids: acetic, propionic, isobutyric, *n*-butyric, isovaleric, *n*-valeric, isocaproic, *n*-caproic, and heptanoic, in the concentration from 0 up to 1302 mg/L. A GC with flame ionization detector (FID) system (Model: Hewlett–Packard 6890) was used with a DB-23 capillary column (30 m $\times$ 0.2 mm i.d. column coated with a 0.25 μm film) for VFA analyses. The carrier gas was helium at a flow-rate of 30 mL/min. The detector base and injector port temperatures were set at 170 °C. The oven settings consisted a 5-min isothermal period at 30 °C, followed by a 10 °C/min temperature ramp to 130 °C, and a final hold at 130 °C for 5 min. The total analysis time was 20 min.

The analyzed long chain fatty acids were the sum of fatty acids with aliphatic tails of equal or greater than 8 carbons and less than 23 carbons. Extraction of long chain fatty acids from the FOG samples requires pre-derivatization, which converts fatty acids to fatty acid methyl esters (FAMEs) before GC analysis. Preparation of FAMEs for GC determination was based on AOCS Ce 2-66 (AOCS, 2004). In short, tridecanoin (C13:0) in ethanol was used as an internal standard and was pre-added to all samples. One milliliter of 0.5 mol/L NaOH in methanol was added to 1 mL sample, and the sample tubes were heated for 10 min at 85 °C in a water bath. After cooling, 1 mL of 14% boron trifluoride in methanol was added to each tube. The tubes were recapped, vortexed, and returned to the water bath for another 10 min. After cooling, 1 mL of water followed by 1 mL of hexane was added, respectively. The tubes were vortexed at top speed for 30 s, and the supernatant hexane phase was transferred to a GC vial. A series of FAME standards diluted from a stock mixture (Kel Fir Fame 5 standard mix, Matreya, Pleasant Gap, PA, USA) were prepared in the same manner as described above. Calibration curves for determination of retention times and recoveries were obtained using aqueous solutions of 19 FAME components in the concentration from 0 up to 155 μg/mL. A GC-FID (Model: Agilent 6890) system was used with a DB-23 capillary column (30 m $\times$ 0.2 mm i.d. column coated with a 0.25 μm film) for FAME analyses. The carrier gas was helium at a flow-rate of 40 mL/min. The detector base and injector port temperatures were set at 300 and 250 °C, respectively. The oven settings consisted a 2-min isothermal period at 50 °C, followed by a first temperature ramp to 180 °C at 10 °C/min, another 5-min isothermal period at 180 °C, and a final temperature ramp to 240 °C at 5 °C/min. The total analysis time was 31 min.

2.5. Statistical analysis

Triplicate samples were collected and analyzed, and the average and standard deviation were presented. The two-tail *t*-tests were used to compare between samples with and without Bio-Amp additions by pooling the nine data points of the three treatment months and the nine data points of the untreated months. For comparisons among the 6-month samples, one-way ANOVA and Tukey's multiple-comparisons were used. Minitab (Minitab Inc., State College, PA, USA) was used to perform these tests at a significant level of 0.05.

3. Results and discussion

3.1. FOG deposit formation

There was a significant decrease of FOG deposit formation with the application of Bio-Amp compared with those without Bio-Amp treatment ($p < 0.05$). Without Bio-Amp application (in September 2011, January and February 2012), average FOG deposits formed from grease trap effluent was 281 ± 36 mg/L; with Bio-Amp application (in October, November and December 2011), the FOG deposit content dropped down to 168 ± 68 mg/L (40% reduction). The FOG deposit data for the each month are plotted in Fig. 2. The FOG deposits decreased from 296 mg/L in September 2011 to 120 mg/L in October 2011. No significant decrease was observed in November 2011 when grease started to build up at high levels, but the decrease was significant again in December. After Bio-Amp addition was terminated, the FOG deposit formation went back to the original level. These results showed that Bio-Amp decreased FOG deposit formation, which could consequently reduce the potential sewer line blockages. However, routine grease trap clean-up is still needed despite the application of Bio-Amp. The research showed that the FOG build-up in grease traps was a concern, because it corresponded to the increase of FOG deposit formation, even under the influence of the Bio-Amp.

Long chain fatty acids were previously demonstrated to be the cause for the formation of FOG deposits that congeal in sewer line (He et al., 2011). The correlation between FOG deposit formation and long chain fatty acids is presented in Fig. 3a, and the results showed that the correlation was marginal, with an $R^2 = 0.61$. It is important to note that calcium ions are naturally present in the wastewater (Keener et al., 2008) and the ratio of calcium and fatty acid concentration may not be consistent in this investigation. Interestingly, the short-chain VFAs appeared to have a stronger correlation with FOG deposit formation at $R^2 = 0.76$ (Fig. 3b). VFAs were also recovered from FOG deposits under laboratory FOG deposit formation tests at high calcium dose, but not from actual FOG deposits of the sewer line (personal communication with Xia He, North Carolina State University). Therefore, despite the high correlation and the ability to form FOG deposits, the condition in the collection system may not allow FOG deposit formation from VFAs. The true impact of VFAs on FOG deposit formation in the actual sewer line may need to be further verified.

3.2. COD, TN, and TP

Table 2 presents the COD, TN and TP data for each month. There were significant reductions of COD, TN and TP with the application of Bio-Amp compared with those without Bio-Amp treatment ($p < 0.05$). For the 3 months without the Bio-Amp application, the COD, TN and TP of the grease trap effluent wastewater were 2570 ± 500, 145 ± 13 and 115 ± 15 mg/L, respectively. For the 3 months with the Bio-Amp treatment, they dropped down to 1570 ± 470, 97 ± 18 and 50 ± 22 mg/L, which represent an average reduction of 39%, 33% and 56%, respectively. The results indicate that the application of Bio-Amp was effective in reducing COD and nutrients entering the collection systems and treatment utilities, and therefore may alleviate treatment burden.

The influence of FOG built-up was evident as observed in November. As FOG built up in the grease trap, the levels of reductions decreased. The reductions were significant again in December after the grease trap was cleaned. This, once again, indicates the importance of grease trap cleaning, because without timely cleanings, the impact of FOG build-up may offset the benefits of Bio-Amp on COD, TN and TP reductions. After Bio-Amp addition was terminated, the COD, TN and TP went back to the original levels.

The COD of wastewaters can be categorized into readily biodegradable, slowly biodegradable, and unbiodegradable fractions (Ekama et al., 1986), and the rbCOD is known to stimulate Bio-P re-

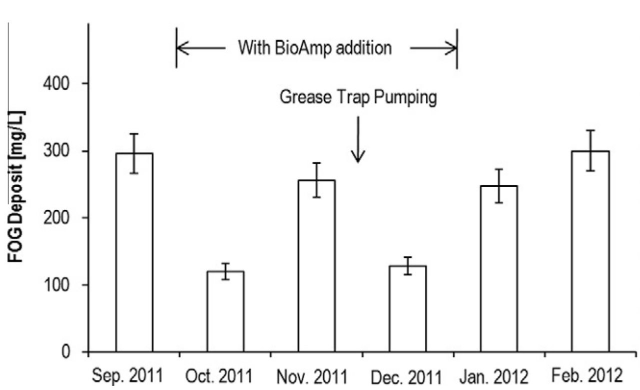

Fig. 2. Results of FOG deposit formation tests on grease trap effluent samples. Error bars represent 1 standard deviation.

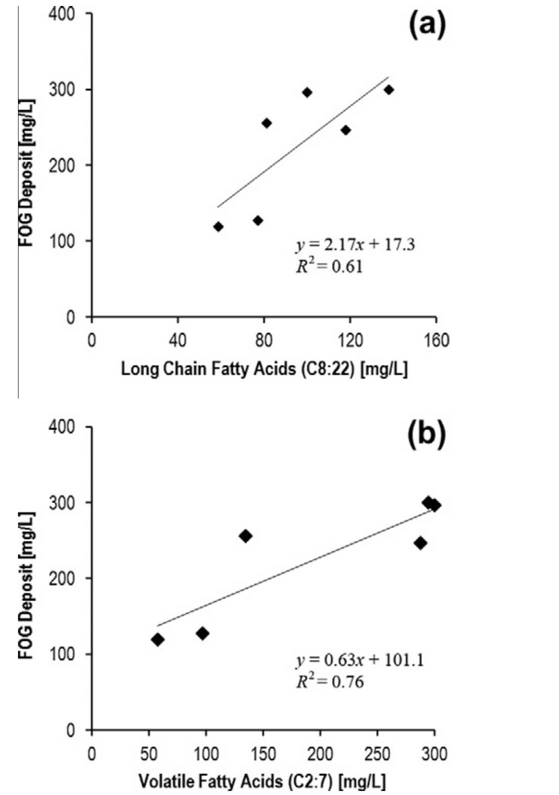

Fig. 3. Correlations between FOG deposit formation and (a) long chain fatty acids, (b) short chain fatty acids concentrations.

Table 2
COD, TN, and TP of grease trap effluent samples.

Sampling events	COD [mg/L]	TN [mg/L]	TP [mg/L]
Sep 2011	2700 ± 240	152 ± 13	97 ± 11
Oct 2011[a]	1740 ± 150	82 ± 7	38 ± 6
Nov 2011[a]	1980 ± 210	118 ± 13	78 ± 8
Dec 2011[a]	990 ± 60	92 ± 8	33 ± 5
Jan 2012	1980 ± 180	134 ± 11	110 ± 15
Feb 2012	3050 ± 130	150 ± 12	124 ± 8

Data presented are average of triplicate samples ±1 standard deviation.
[a] With Bio-Amp treatment.

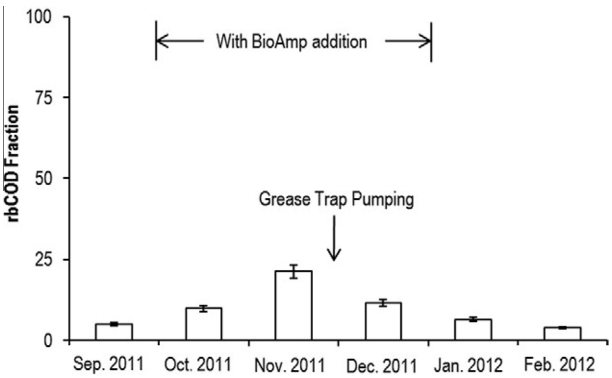

Fig. 4. rbCOD fractions in grease trap effluent samples. Error bars represent 1 standard deviation.

moval (Randall et al., 1997; Martinez et al., 2001). Fig. 4 presents the rbCOD fractions (the ratio of rbCOD to total COD) of grease trap effluent wastewater with and without the influence of Bio-Amp. During the 6-month test in this research, the rbCOD fractions of grease trap effluent samples ranged between 4% and 21%. There were significant increases of rbCOD fractions in grease trap effluents during the 3 months (October, November and December 2011) when the Bio-Amp was applied ($p < 0.05$), compared to those without Bio-Amp treatments. It is also noted that after grease trap clean-up, the rbCOD fraction remained higher than those with higher FOG but no Bio-Amp. This was possibly due to more FOG degradation by Bio-Amp bacteria which introduce more rbCOD as degradation byproducts. As the Bio-Amp application was terminated in December 2011, the rbCOD fractions gradually decreased to the original levels. The results indicate that the application of Bio-Amp can increase the rbCOD fractions in wastewater. It is known that rbCOD is an important element in stimulating the growth of Bio-P bacteria (Paul et al., 2001) and Bio-P removal performances are highly dependent on rbCOD fractions in wastewater (Paul et al., 2001; Sperandio et al., 2001). Observations of positive correlations between the increase of rbCOD fractions and the improvement of Bio-P removal have also been reported by Martinez et al. (2001). Therefore, it can be deduced that the application of Bio-Amp to grease trap could also potentially enhance Bio-P removal in subsequent wastewater treatment processes.

The downstream University Wastewater Treatment Plant accepts 7600 m^3/d of wastewater, of which 7.4% (565 m^3/d) are from student dining halls. Assuming each dining hall generates similar wastewater content, the total loadings to the plant from all dining halls are estimated to be 1452 kg/d COD, 82 kg/d TN and 65 kg/d TP. After Bio-Amp treatment, the loadings to the plant from dining halls can potentially drop down to 887 kg/d COD, 55 kg/d TN and 28 kg/d TP, which represent a loading reduction of 565 kg/d COD, 27 kg/d TN and 37 kg/d TP to the treatment plant from all the dining halls. This interprets to an overall loading reduction of 9%, 5%, and 40% for COD, TN, and TP, respectively. The results indicate that the application of Bio-Amp to grease trap could effectively reduce COD and nutrient loadings entering the subsequent wastewater treatment plant, and thus reduces burden to the treatment and implies a potentially better treated effluent quality.

3.3. Fatty acids and their constituents

There was a significant decrease of fatty acids after the application of Bio-Amp compared with those without Bio-Amp application ($p < 0.05$). For the 3 months without Bio-Amp treatment, the total fatty acids concentration was 413 ± 18 mg/L; for the 3 months with Bio-Amp treatment, the concentration dropped down to 169 ± 49 mg/L (59% reduction). Table 3 presents the fatty acid concentrations of grease trap effluent samples for each month. Before Bio-Amp application (in September 2011), the total fatty acids concentration was 400 mg/L (VFAs and long chain fatty acids contributed 300 and 100 mg/L, respectively); 1 month after Bio-Amp application, the concentration dropped down to 117 mg/L (71% reduction) (VFAs and long chain fatty acids contributed 58 and 59 mg/L, respectively). VFAs demonstrated higher reduction levels compared to long chain fatty acids, which indicates VFAs are easily degraded. The level of reduction decreased in November 2011 when grease started to build up at high levels, and it increased again in December. After Bio-Amp addition was terminated, the total fatty acid concentration went back to the original level. These results indicate that Bio-Amp can reduce fatty acids, which corresponds to the observed reduction of FOG deposit formation.

The constituents of fatty acids include saturated, monounsaturated, and polyunsaturated acids. For the long chain fatty acids in the grease trap effluents, the primary saturated acids were caprilic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), stearic (C18:0), and behenic acids (C22:0). The predominant monounsaturated acids were elaidic (C18:1 trans) and oleic acids (C18:1 cis), while linoleic acid (C18:2) was the main polyunsaturated acid. These constituents are all commonly found in general vegetable and animal FOG (Broughton et al., 1998; Gonzalez Casado et al., 1998; Nisola et al., 2009).

Although various fatty acids were detected in grease trap effluents, over 90% of long chain fatty acids in domestic wastewater are saturated myristic (C14:0), palmitic (C16:0), and stearic acids (C18:0), and the unsaturated oleic (C18:1) and linoleic acids (C18:2) (Novak and Carlson, 1970; Lalman and Bagley, 2000). Therefore, the research into these five fatty acids is of particular interest. Fig. 5 presents the relative abundance of these five representative fatty acids in saturated, monounsaturated and polyunsaturated fractions. It was found that after the application of Bio-Amp, the unsaturated fractions were diminished while the saturated fractions increased. The mechanism for degradation of the unsaturated fatty acids is believed to be hydrogenation to the saturated form followed by β-oxidation (Novak and Carlson, 1970; Pereira et al., 2005). Therefore, the unsaturated fatty acids may be transformed to their saturated counterparts as intermediates before a complete degradation takes place. This could have positive implications to subsequent biological wastewater treatment processes. Because the unsaturated fatty acids are more difficult to degrade due to the double bonds (de Waard et al., 1993), Bio-Amp pretreatment is able to lower the loading of unsaturated fractions and therefore reduces the burden of biodegradation at subsequent biological wastewater treatment processes.

For short chain VFAs, acetic and propionic acids are the two most common VFAs present in domestic wastewater. Acetic acid

Table 3
Fatty acid concentrations of grease trap effluent samples.

Sampling events	VFAs [mg/L]	LCFAs [mg/L]	Total FAs [mg/L]
September 2011	300 ± 45	100 ± 18	400 ± 42
October 2011[a]	58 ± 7	59 ± 6	117 ± 16
November 2011[a]	134 ± 12	81 ± 11	215 ± 10
December 2011[a]	97 ± 5	77 ± 10	174 ± 7
January 2012	288 ± 18	118 ± 13	406 ± 30
February 2012	295 ± 17	138 ± 9	433 ± 20

VFAs: volatile fatty acids (C2:7).
LCFAs: long chain fatty acids (C8:22).
Total FAs: total fatty acids (C2:22).
Data presented are average of triplicate samples ± 1 standard deviation.
[a] With Bio-Amp treatment.

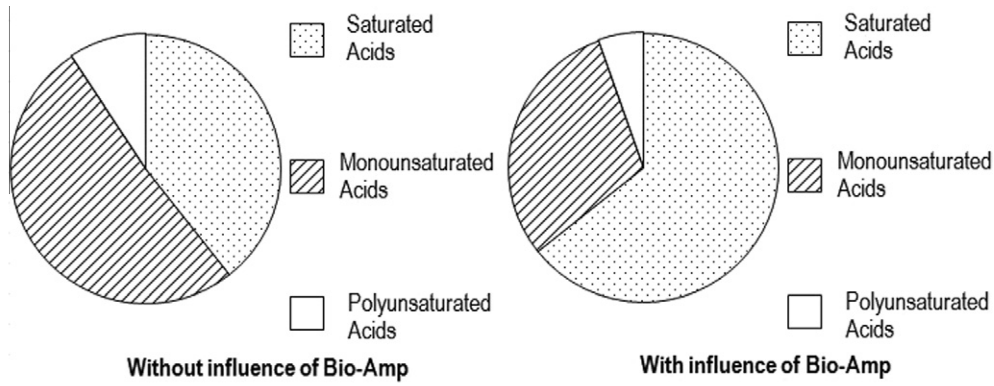

Fig. 5. Relative abundance of five representative fatty acids in saturated, monounsaturated, and polyunsaturated fractions in grease trap effluent samples under the influence of Bio-Amp. Data presented are values of September (w/o Bio-Amp) and October 2011 (w/ Bio-Amp) samplings.

is beneficial to Bio-P removal while propionic acid is inhibitory to Bio-P removal (Eilersen et al., 1995). Without the influence of Bio-Amp (September 2011, January and February 2012), the average carbon molar ratios of propionic to acetic acids was 0.65; with the influence of Bio-Amp (October, November, and December 2012), the average carbon molar ratios of propionic to acetic acids was 0.47. Though their differences are statistically significant, both values were within the typical range of domestic wastewater (von Muench, 1998), and therefore, the slight increase may pose very limited impacts.

4. Conclusions

In this research, it was found that Bio-Amp reduced FOG deposit formation and thus is helpful for alleviating potential sewer line blockages in wastewater collection systems. Bio-Amp also reduced COD, TN, and TP in grease trap effluents which helps alleviate downstream treatment burdens. Bio-Amp increased rbCOD fractions, which can potentially enhance Bio-P removal in subsequent wastewater treatment processes. Increased removal of unsaturated fatty acids fractions, which are more difficult to biodegrade in treatments, was also observed. However, routine grease trap clean-up is still needed despite the application of Bio-Amp in order to maintain optimal performance.

Acknowledgements

This study was supported by the Office of Physical Plant at The Pennsylvania State University. The authors acknowledge Mr. John Gaudlip and Mrs. Ping Zhang from Office of Physical Plant, Mr. Joseph Swanderski and the staff at University Wastewater Treatment Plant for the assistance on field sampling. The authors also thank Mrs. Georgine Suder from Chemsearch for providing Bio-Amp for this research.

References

AOCS, 2004. Official Methods and Recommended Practices of the American Oil Chemists Society, 5th ed., Firestone, D., Ed., Champaign, Illinois.
APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed., Washington, DC.
Auerbach, I.D., Sorensen, C., Hansma, G., Holden, P.A., 2000. Physical morphology and surface properties of unsaturated *Pseudomonas putida* biofilms. J. Bacteriol. 182 (13), 3809–3815.
Becker, P., Koster, D., Popov, M.N., Markossin, S., Antranikian, G., Markl, H., 1999. The biodegradation of olive oil and the treatment of lipid-rich wool scouring wastewater under aerobic thermophilic conditions. Water Res. 33 (3), 653–660.
Bielefeldt, A., Gutierrez-Padilla, M.G.D., Ovtchinnikov, S., Silverstein, J., Hernandez, M., 2010. Bacterial kinetics of sulfur oxidizing bacteria and their biodegradation rates of concrete sewer pipe samples. J. Environ. Eng. ASCE 136 (7), 731–738.
Broughton, M.J., Thiele, J.H., Birch, E.J., Cohen, A., 1998. Anaerobic batch digestion of sheep tallow. Water Res. 32 (5), 1423–1428.
Canler, J.P., Royer, C., Duchene, P., 2001. Aerobic biological treatment of grease from urban wastewater treatment plants. Water Sci. Technol. 44 (2–3), 219–226.
Chan, H., 2010. Removal and recycling of pollutants from Hong Kong restaurant wastewaters. Bioresour. Technol. 101 (17), 6859–6867.
Chu, W., Ng, F.L., 2000. Upgrading the conventional grease trap using a tube settler. Environ. Int. 26 (1–2), 17–22.
de Waard, P., van der Wal, H., Huijberts, G.N., Eggink, G., 1993. Heteronuclear NMR analysis of unsaturated fatty acids in poly(3-hydroxyalkanoates). Study of beta-oxidation in *Pseudomonas putida*. J. Biol. Chem. 268, 315–319.
Dueholm, T., Andreasen, K., Nielsen, P., 2000. Transformation of lipids in activated sludge. Water Sci. Technol. 43 (1), 165–172.
Eilersen, A.M., Henze, M., Kloft, L., 1995. Effect of volatile fatty acids and trimethylamine on denitrification in active sludge. Water Res. 29 (5), 1259–1266.
Ekama, G.A., Dold, P.L., Marais, G.v.R., 1986. Procedures for determining influent COD fractions and the maximum specific growth rate of heterotrophs in activated sludge systems. Water Sci. Technol. 18 (6), 91–114.
Gonzalez Casado, A.G., Hernandez, E.J.A., Vilchez, J.L., 1998. Determination of fatty acids C8–C22 in urban wastewater by GC-MS. Water Res. 32 (10), 3168–3172.
He, X., Iasmin, M., Dean, L.O., Lappi, S.E., Ducoste, J.J., de los Reyes III, F.L., 2011. Evidence for Fat, Oil, and Grease (FOG) deposit formation mechanisms in sewer lines. Environ. Sci. Technol. 45, 4385–4391.
Keener, K.M., Ducoste, J.J., Holt, L.M., 2008. Properties influencing fat, oil and grease deposit formation. Water Environ. Res. 80, 2241–2246.
Kizilaslan, O., 2007. Investigation of vegetable oil containing wastewater treatment by biological methods. Master's Thesis, Dokuz Eylul University.
Kunst, F. et al., 1997. The complete genome sequence of the Gram-positive bacterium *Bacillus subtilis*. Nature 390, 249–256.
Lalman, J.A., Bagley, D.M., 2000. Anaerobic degradation and inhibitory effects of linoleic acid. Water Res. 34 (17), 4220–4228.
Manni, G., Caron, F., 1995. Calibration and determination of the volatile fatty acids in waste leachates by gas chromatography. J. Chromatogr. A 690, 237–242.
Martinez, A., Canizares, P.C., Mayor, L.R., Camacho, J.V., 2001. Short-term effects of wastewater biodegradability on biological phosphorus removal. J. Environ. Eng. ASCE 127 (3), 259–265.
Nisola, G.M., Cho, E.S., Shon, H.K., Tian, D., Chun, D.J., Gwon, E.M., Chung, W.J., 2009. Cell immobilized FOG-Trap system for fat, oil, and grease removal from restaurant wastewater. J. Environ. Eng. ASCE 135 (9), 876–884.
Novak, J.T., Carlson, D.A., 1970. The kinetics of anaerobic long chain fatty acid degrdadation. J. Water Pollut. Control Fed. 42 (11), 1932–1943.
O'Connell, M., McNally, C., Richardson, M.G., 2010. Biochemical attack on concrete in wastewater applications: a state of the art review. Cem. Concr. Compos. 32, 479–488.
Paul, E., Laval, M.L., Sperandio, M., 2001. Excess sludge production and costs due to phosphorus removal. Environ. Technol. 22, 1363–1371.
Pereira, M.A., Pires, O.C., Mota, M., Alves, M.M., 2005. Anaerobic biodegradation of oleic and palmitic acids: evidence of mass transfer limitations caused by long chain fatty acid accumulation onto the anaerobic sludge. Biotechnol. Bioeng. 92 (1), 15–23.
Randall, A.A., Benefield, L.D., Hill, W.E., Nicol, J.-P., Boman, G.K., Jing, S.-R., 1997. The effect of volatile fatty acids on enhanced biological phosphorus removal and population structure in anaerobic/aerobic sequencing batch reactors. Water Sci. Tech. 35 (1), 153–160.
Roheim, J.R., 2003. Low cost automated on site system for growing and dispensing vegetative bacteria. In: Proceedings of the Water Environment Federation, Industrial Wastes, pp. 634–647.
Schutz, W.A., 2008. Aerobic pretreatment of grease trap wastes. In: Proceedings of the Water Environment Federation, Residuals and Biosolids Conference, pp. 277–302.

Siedlecka, E.M., Kumirska, J., Ossowski, T., Glamowski, P., Gołębiowski, M., Gajdus, J., Kaczyński, Z., Stepnowski, P., 2008. Determination of volatile fatty acids in environmental aqueous samples. Polish J. Environ. Stud. 17 (3), 351–356.
Sperandio, M., Urbain, V., Ginestet, P., Audic, J.M., Paul, E., 2001. Application of COD fractionation by a new combined technique: comparison of various wastewaters and sources of variability. Water Sci. Technol. 43, 181–190.
von Muench, E., 1998. DSP Prefermenter Technology Book. Brisbane, Old., Australia.
Wakelin, N.G., Forster, C.F., 1997. An investigation into microbial removal of fats, oils and greases. Bioresour. Technol. 59 (1), 37–43.