Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 17-11

STICKNEY PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 8

FERMENTATION TEST RESULTS TO ASSIST IN DESIGN OF WASSTRIP© FOR THE STICKNEY WATER RECLAMATION PLANT (SWRP)

May 2017

Metropolitan Water Reclamation District of Greater Chicago

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May 2017

FOREWORD

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) recognizes the value of phosphorus as a non-renewable resource. In an effort to optimize the sustainable removal of phosphorus from its wastewater influents and the subsequent recover of phosphorus in various forms suitable for use as an agronomic fertilizer, the MWRD initiated a Phosphorus Removal and Recovery Task Force in 2012. The Task Force initiated a study phase at several of the MWRD's Water Reclamation Plants to evaluate the feasibility of implementing enhanced biological phosphorus removal and to develop operational guidelines for optimizing its effectiveness. The Task Force has created WRP specific study workgroups that are focused on each of the WRP's that have been identified to participate in this initiative. As the workgroups complete various phases of their studies and evaluations they are documenting their findings and recommendations in technical memoranda. These memoranda are written by the WRP specific workgroups and vetted by the Task Force before being published. Their purpose is to capture the state of knowledge and study findings and to make recommendations for implementation of enhanced biological phosphorus recovery as they are understood at the time the memoranda are published.

DISCLAIMER

The contents of this technical memoranda constitute the state of knowledge and recommendations developed by the MWRD's Phosphorus Task Force at the time of publication, and are subject to change as additional studies are completed and experience is attained, and as the full context of the MWRD's operating environment is considered.

Fermentation Test Results to Assist in Design of WASSTRIP® for the Stickney Water Reclamation Plant (SWRP)

Technical Memorandum 8

Date: August 26, 2015

To: Phosphorus Task Force & Advisory Committee

From: Mwende Lefler, Kamlesh Patel, Joseph Kozak, and Heng Zhang

Subject: Fermentation Test Results for WASSTRIP® Design

1.0 Purpose

The process to use waste activated sludge (WAS) to release additional ortho-phosphate (orthoP) for recovery has been marketed as the Waste Activated Sludge Stripping to Remove Internal Phosphorus (WASSTRIP®) process and has been implemented in several full-scale wastewater treatment plants.

The WASSTRIP® process is essentially holding WAS enriched in phosphate accumulating organism (PAO) biomass under anaerobic conditions which causes the PAOs to uptake volatile fatty acids (VFAs) and release soluble phosphorus (P) and magnesium (Mg) into the bulk liquid. If the carbon present in the reactor (whether added or endogenous) is in a readily biodegradable form, the P release is expedited. Thus, the type and amount of carbon added to the WASSTRIP® reactor is a key process control parameter. Based on preliminary WASSTRIP® testing, adding readily biodegradable carbon will increase the rate of P release by about four times, making the necessary WASSTRIP® reactor volume considerably less than when using only the available endogenous carbon in the WAS. As the amount of carbon recommended for WASSTRIP® from a literature review is considerable (an approximate VFA:TP ratio of 2:1 – 4:1 is suggested; Ostara recommends 4:1, however, successful WASSTRIP has been seen at other plants with a 2:1 ratio. A technical memorandum addressing the recommended site-specific SWRP WASSTRIP carbon ratio is forthcoming.), it is economical to generate the needed carbon through internal sources.

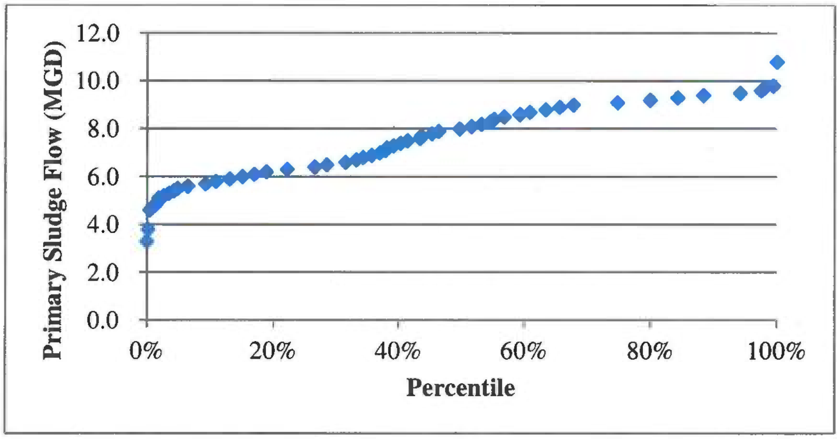
Internal sources at the plant consist of primary sludge (PS), thickened WAS (TWAS), and O'Brien sludge, to name a few. At SWRP, there are 10 existing gravity concentration tanks (GCTs) that will be used for WAS thickening, fermentation of an internal source, and the WASSTRIP® reactors. At the time of this memo, two of the existing GCTs are planned for fermentation of an internal source, most likely primary sludge. This technical memorandum summarizes the results of laboratory fermentation tests performed and how to maximize VFA production from these sources through fermentation in the shortest possible time.

2.0 Background

Primary Sludge Flows

2013 SWRP PS flows are shown in Figure 1 by percentile ranking. The average, 90th percentile, 10th percentile, and standard deviation for PS flows were 7.7 MGD, 9.4 MGD, 5.7 MGD, and 1.5 MGD, respectively. In addition, the average, 90th percentile, 10th percentile, and standard deviation for SWRP PS TS concentration for 2013 was 11,108 mg/L, 20,000 mg/L, 3,716 mg/L, and 6,299 mg/L, respectively.

Figure 1: Distribution of PS Flows at SWRP from 2013



3.0 Methods and Data Summary

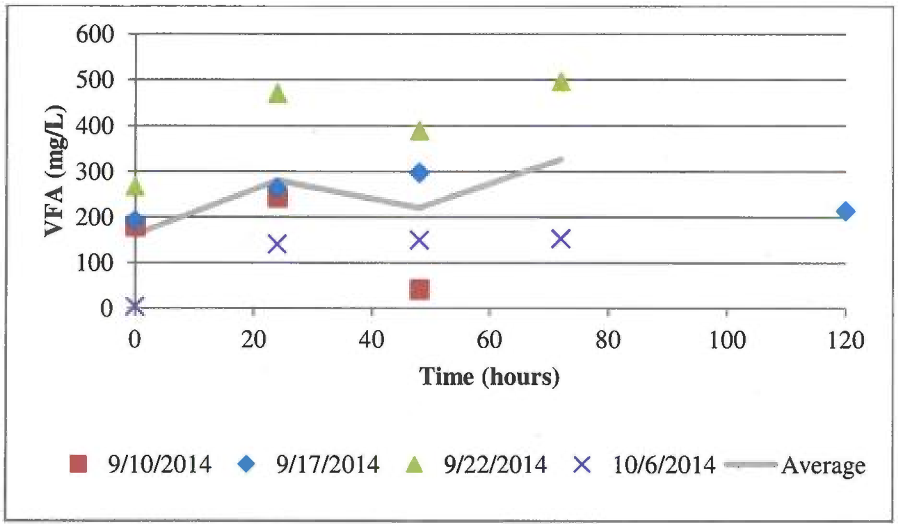
The workplan used in obtaining the data within this report is attached as Appendix I. The trials followed the workplan as written, except for fewer trials being completed and a deviation in the mixing protocol during testing, as discussed as a subsection within this memo. The *'Primary Sludge with Seeded Fermentation'* portion was completed in 4 trials, the *'Thickened WAS Fermentation'* had 2 trials, the *'Continuous versus Batch Reactors'* had 2 trials, and the *'O'Brien Sludge Fermentation'* was not run at all as there was difficulty in obtaining a sample during the testing period due to the rerouting of the O'Brien sludge to the new GCT facility. In addition, digester draw carbon concentrations were measured 4 times and pre-digestion centrifuge cake (a mixture of WAS and PS) underwent 3 fermentation trials.

VFA and soluble COD concentrations were considered as surrogates for available carbon in the study results below.

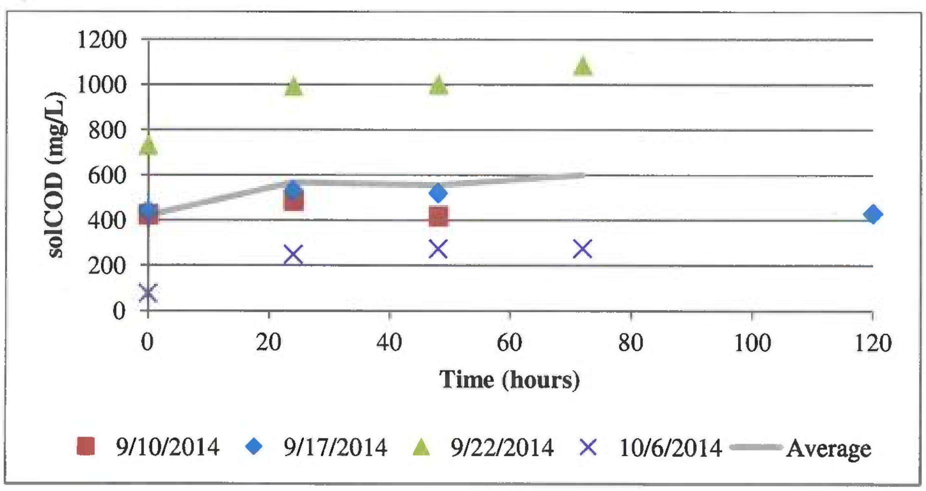
Fermentation Time

The time needed for fermentation of PS alone was examined as one of the objectives in this study. This time is defined as when the VFA concentrations cease to show a substantial increase. Figure 2 shows the carbon concentrations over time for unseeded PS held under unmixed anaerobic conditions. As seen, the VFA concentrations did not increase past 48 hours in 2 of the 4 trials and increased from 400 to 500 mg/L in the 9/22/14 trial after this time. Only one of the trials was continued to 120 hours and the VFA concentration dropped substantially by this end time. However, there were other minor decreases seen in the other trials as well as the trials progressed. It is unknown why this is occurring. The trials also measured solCOD; with this parameter, less of an increase in measured carbon was seen past 24 hours with respect to solCOD.

Figure 2: Unseeded and Unmixed Primary Sludge Fermentation – Carbon Concentrations over Time



(a) Carbon measured as VFA



(b) Carbon measured as solCOD

Table 1 shows the VFA and solCOD concentrations over the initial total volatile solids for each sample time in order to normalize the generated carbon by the amount of solids in the sample. In addition, the incremental increases in the VFA and solCOD concentrations over the fermentation time are also included.

Table 1: Summary of VFA and solCOD Concentrations, VFA and solCOD Concentrations over Initial Solids, and Incremental Changes in VFA and solCOD Concentrations per Fermentation Time for Unseeded and Unmixed Primary Sludge Trials

Trial Date	Time (hr)	VFA (mg/L)	VFA/TVS_0	[VFA] Change from Previous Sample Time (%)	solCOD (mg/L)	$solCOD/TVS_0$	[solCOD] Change from Previous Sample Time(%)
9/10/14	0	181	0.04		428	0.08	
	24	244	0.05	35	488	0.10	14
	48	42	0.01	-83	420	0.08	-14
9/17/14	0	193	0.03		445	0.06	
	24	264	0.04	37	533	0.07	20
	48	298	0.04	13	522	0.07	-2
	120	215	0.03	-28	433	0.06	-17
9/22/14	0	268	0.03		733	0.08	
	24	471	0.05	76	993	0.11	35
	48	390	0.04	-17	1002	0.11	1
	72	498	0.06	28	1087	0.12	8
10/6/14	0	<5	0.00		81	0.03	
	24	142	0.05	2,740	252	0.09	211
	48	151	0.05	6	277	0.10	10
	72	154	0.05	2	279	0.10	1

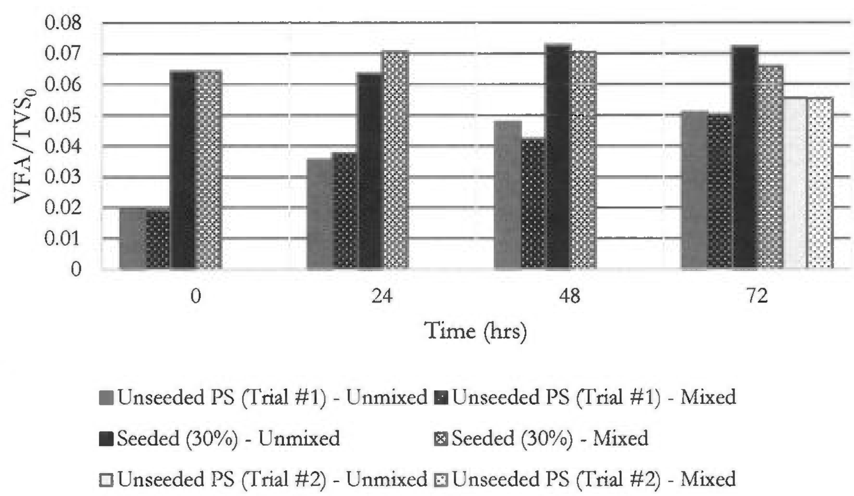
pH and ORP data were also collected over the length of these experiments. As the VFA and solCOD concentrations increased, the pH decreased; similarly, when the VFA and solCOD concentrations decreased (possibly due to volatilization), there was a corresponding increase in pH. The ORP data showed less of a correlation to both the carbon parameter concentrations and, at times, contradicted the expected inverse relationship between the two.

As minimal improvement in concentrations and decreases in pH were seen past 48 hours, 48 hours was chosen for the fermentation time to create the seed PS for the remaining experiments. While the seeded experiments were allowed to run for a longer time after adding the seed, the seed PS portion was fermented for 48 hours before being added to fresh PS.

Effect of Mixing on Fermentation

This test was not included in the original workplan but arose during the course of the experiment to determine the effect constant mixing plays in the fermentation process. Fermentation of mixed versus unmixed PS was tested twice without adding any prefermented PS and once by adding 30% prefermented PS, or seed PS, to fresh PS (this type of trial is described more fully below). Although the time selected for unseeded PS fermentation was 48 hours, these tests were allowed to run longer to gauge if there were differences past 48 hours from either mixing or the addition of seed PS. All three trials were statistically similar in terms of the impact of mixing. Figure 3 shows the VFA/TVS_0 and $solCOD/TVS_0$ ratios over time for each of the trials. As can be seen, the difference in the VFA production rate between the mixed and unmixed samples was minimal.

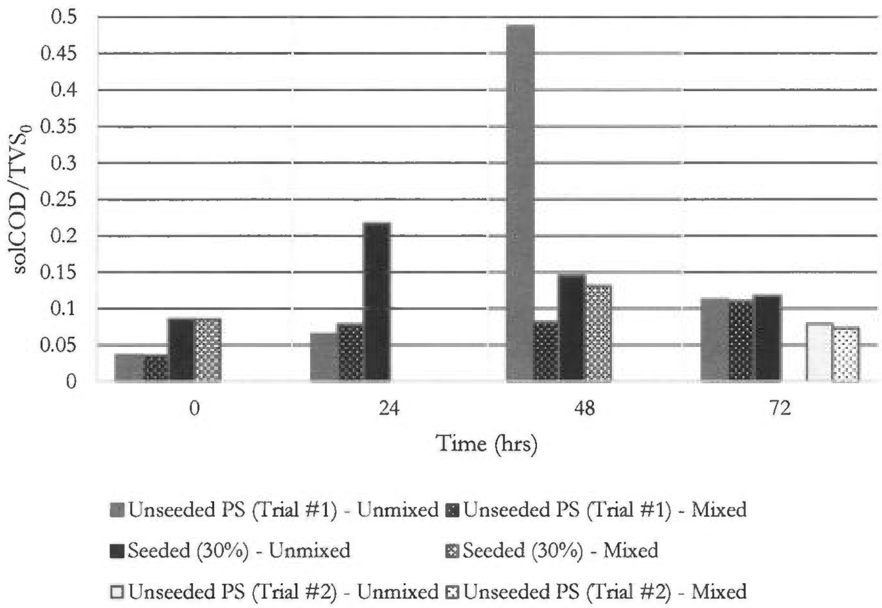
Figure 3: Effect of Constant Mixing on Carbon Production per Initial Solids Concentrations



Note:

a) Unseeded PS (Trial #2) only measured the VFA concentration at 72 hours.

(a) Carbon measured as VFA



Notes:

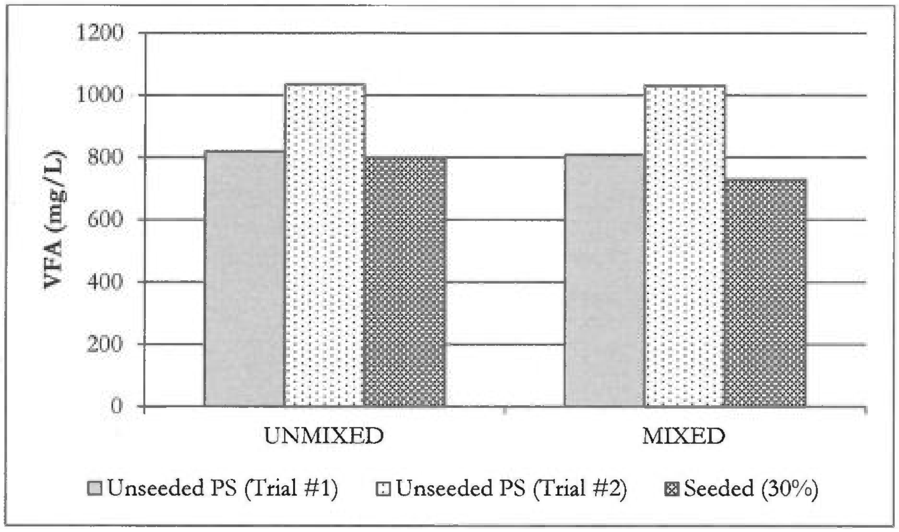
a) Seeded (30%) – Mixed solCOD/TVS_0 were 3.77 and 5.23 at times of 24 and 72 hours, respectively; these are not included on the figure as there seems to be an error in the measurement of the solCOD concentration as both were uncharacteristically high.

b) Unseeded PS (Trial #2) only measured the solCOD concentration at 72 hours.

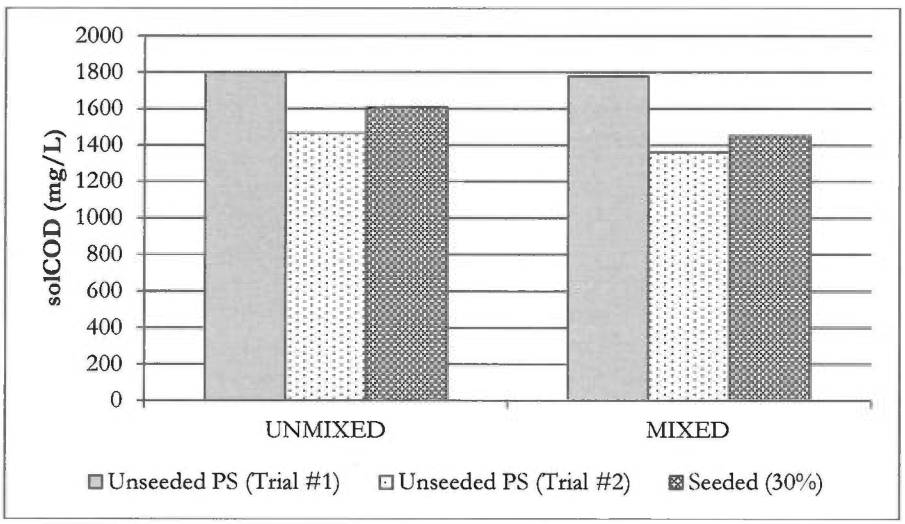
(b) Carbon measured as solCOD

Figure 4 shows the VFA and solCOD concentrations at 72 hours. The VFA concentrations for the unmixed samples varied between 800 and 1,034 mg/L while the VFA concentrations for mixed samples varied between 729 and 1,030 mg/L; the average difference between unmixed and mixed samples showed 28 mg/L more VFA in the unmixed samples. Similarly, the average difference between unmixed and mixed samples was 95 mg/L more solCOD in the unmixed samples.

Figure 4: Effect of Constant Mixing on Total Carbon Production (Including Initial Seed Carbon) Measured as the Difference After 72 Hours of Fermentation



(a) Carbon measured as VFA



Note:

a) Seeded (30%) – Unmixed and Seeded (30%) – Mixed solCOD concentrations shown are from 48 hours. solCOD concentrations for these two points at 72 hours were 1,299 and 57,980 mg/L, respectively; the Mixed value is considered to be an outlier and not included in the figure.

(b) Carbon measured as solCOD

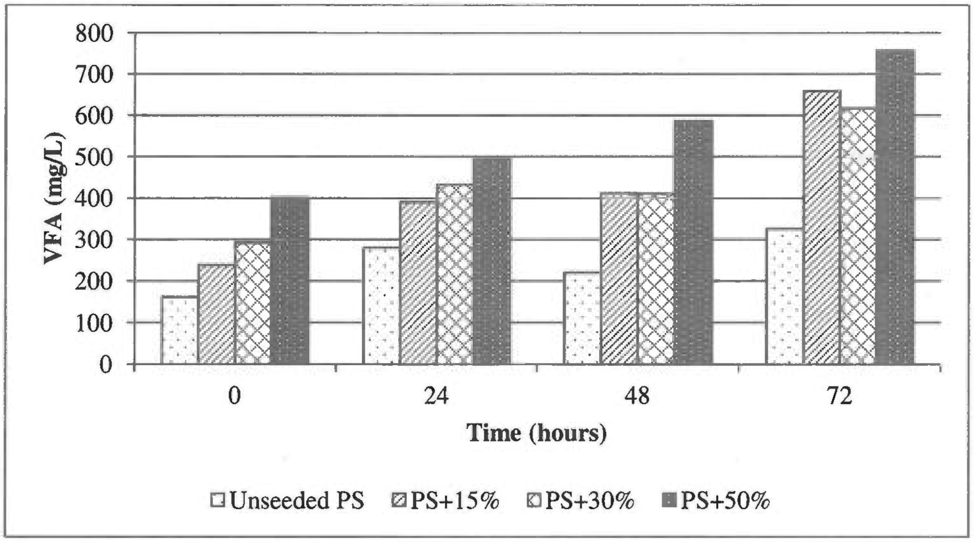
The difference between mixed and unmixed samples was negligible in the 3 trials and was determined to be statistically insignificant. As such, samples were not continuously mixed for the remaining trials.

Effects of Seeding on Fermentation

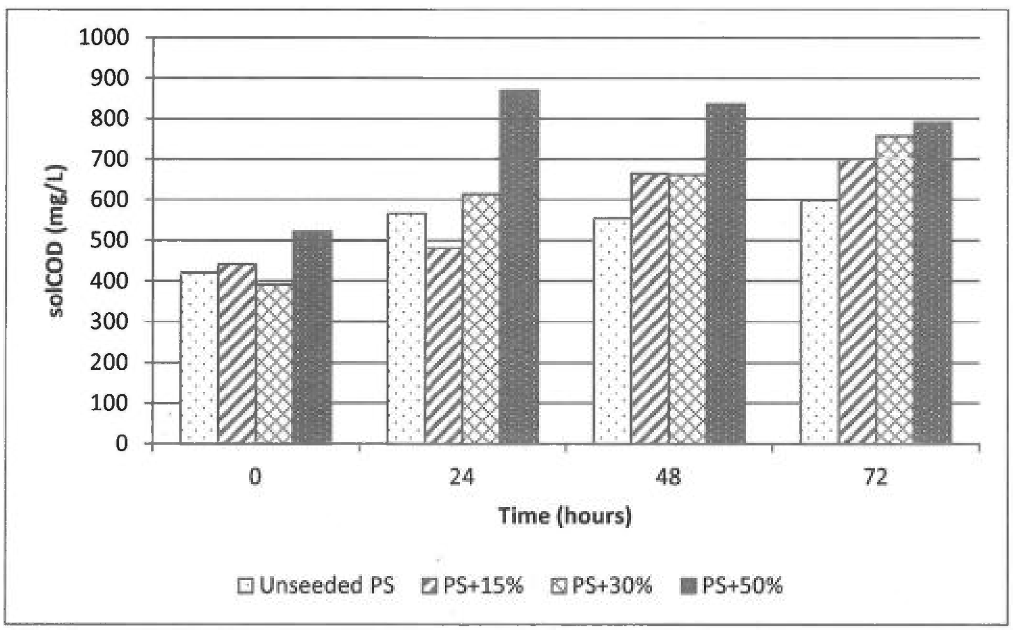
The SRT for a PS fermentation trial can be increased past the HRT through reseeding a portion of already fermented PS to fresh PS. In full-scale PS fermentation operations, this would be accomplished through recycle of a portion of the fermented sludge and/or limiting wasting to achieve the longer SRT. For this set of trials, seed PS was fermented in the lab and combined with new PS in an attempt to accelerate fermentation. The seed PS is pre-fermented PS; the pre-fermentation was accomplished by collecting fresh PS and holding it for 48 hours under unmixed anaerobic conditions. This seed PS was then gently mixed before adding it to the fresh PS. Three different volumes of seed PS were added to the same volumes of fresh PS for the trials, resulting in 15, 30, and 50% of the total volume being comprised of seed PS.

Figure 5 shows the average total carbon concentrations over fermentation time from four trials comparing the seeded PS to the unseeded PS; these are the total carbon concentrations including both the carbon added from the prefermented seed PS as well as carbon generated from the mixture. These results, as well as the individual trials, indicate that there is little difference between adding 15% or 30% seed to the PS; the similarity in data sets was confirmed through statistical difference testing when using the VFA concentrations, but a difference was detected when comparing solCOD concentrations. There is a higher average solCOD concentration when 50% of the volume is from seed PS. The difference in the averages of PS with 15% versus 50% was approximately 174 mg/L VFA and 260 mg/L solCOD at 48 hours, or an increase of roughly 35% and 42%, respectively; in addition, using a paired t-test, the data sets were determined to be significantly different. Using the average carbon production from these treatments should be viewed with discretion due to large variability in the data and limited data for each treatment. Carbon concentrations in the PS+50% sample were higher in only 2 of the 4 trials at 48 hours. This difference in averages was decreased to 98 mg/L VFA and increased to 346 mg/L solCOD by 72 hours; this largely reflects the result from one trial as the PS+50% was only higher in 1 of 3 trials at 72 hours using both VFA and solCOD as metrics. While results as to the most optimal percentage of seed PS to add were mixed, the addition of seed PS showed increased VFA and solCOD concentrations over the unseeded PS in all cases, and these differences were also seen through statistical difference testing to the fermentation of unseeded PS. In addition, the increase in carbon concentrations occurred past 48 hours, with average carbon concentrations increasing at all three seed PS percentages from 48 to 72 hours.

Figure 5: Effect of Seeded Sludge as Measured by Total Carbon Production (Including Initial Seed Carbon) Over Time



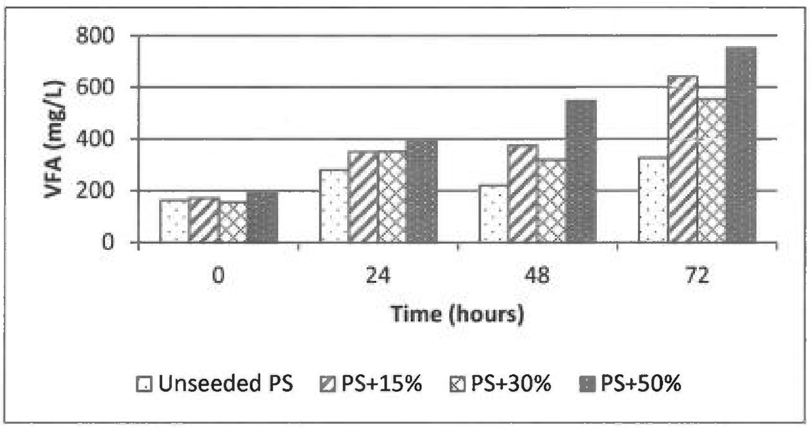
(a) Carbon measured as VFA



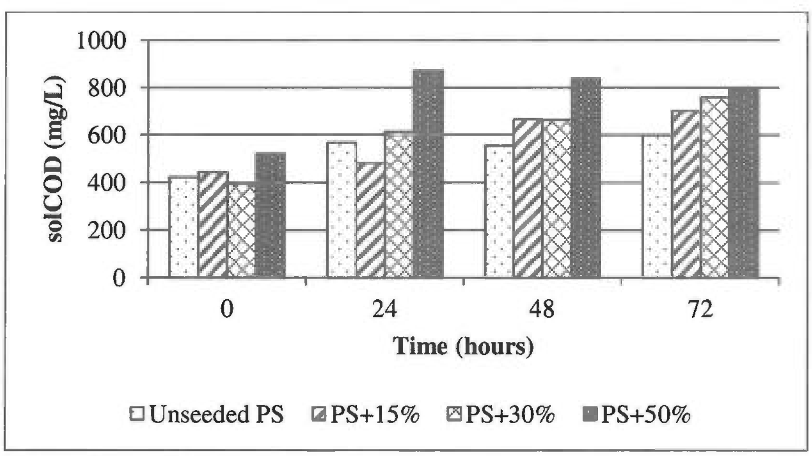
(b) Carbon measured as solCOD

Figure 6 adjusts the carbon concentrations over time to reflect the carbon concentration of only the unseeded portion. This is done by subtracting the initial carbon mass from the seed PS volume and recalculating the actual concentration in the fresh PS over time. These calculated concentrations help to show the effect of the various seed percentages on carbon generation from the fresh sludge. As seen, the average VFA concentrations at 72 hours are 326, 641, 554, and 750 mg/L for unseeded PS, PS+15% seed PS, PS+30% seed PS, and PS+50% seed PS, respectively. Using solCOD as a metric, unseeded PS, PS+15% seed PS, PS+30% seed PS, and PS+50% seed PS had average solCOD concentrations of 600, 700, 757, and 791 mg/L at 72 hours. Using this method, both carbon measurements would again indicate that the carbon generation in the fresh PS is increased by the addition of seed PS.

Figure 6: Effect of Seeded Sludge as Measured by Calculated Carbon Concentrations in Unseeded Portion (Excluding the Effect of Initial Seed Carbon) Concentration Over Time



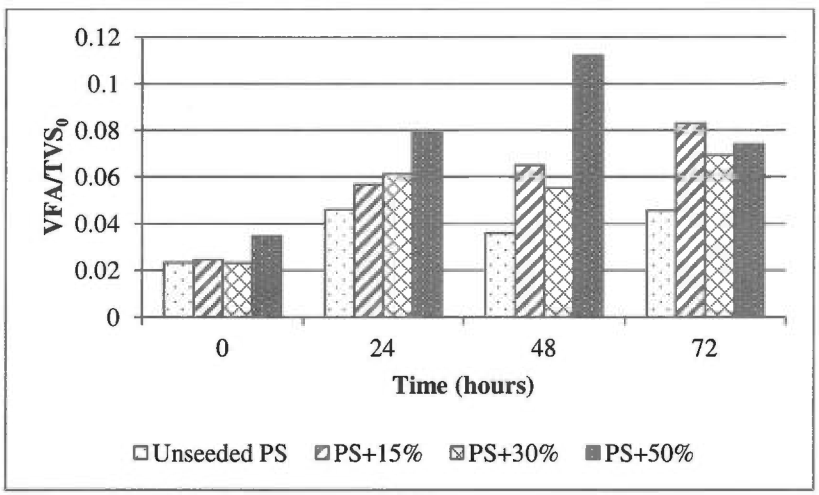
(a) Carbon measured as VFA



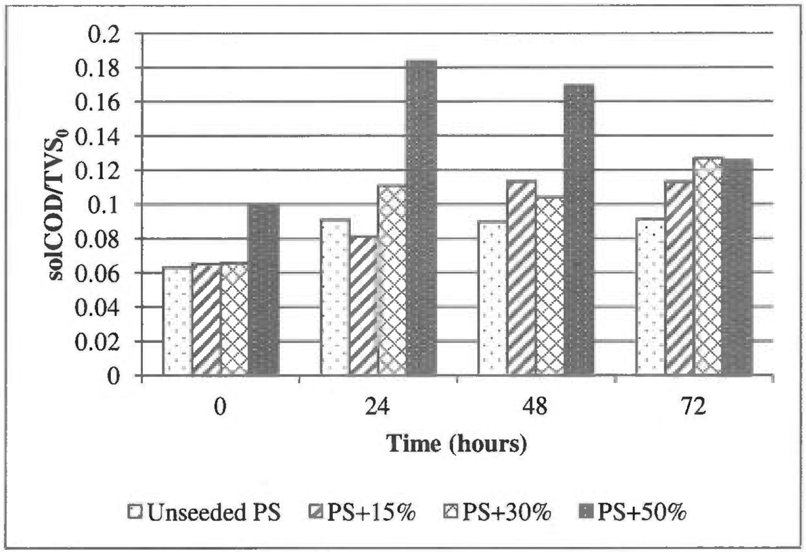
(b) Carbon measured as solCOD

The calculated carbon concentrations can also be normalized relative to the initial volatile solids concentrations by examining the VFA/TVS_0 and $solCOD/TVS_0$ ratios over time. Expected yields per volatile solids content range from 0.05 – 0.3 mg VFA/mg VS ('Fermenters for Biological Phosphorus Removal Carbon Augmentation', Issued by WERF, August 9, 2011). In Figure 7, these ratios are shown as averages from the trials. These results show that additions of seed PS at any percentage generate more carbon per initial solids concentration than the unseeded treatment. Aside from the 72 hour data, the PS with 50% seed PS added generated more carbon per initial solids concentration than the other treatments. There was a decrease in VFA/TVS_0 noted after 48 hours in 1 of 3 trials and a decrease in $solCOD/TVS_0$ noted after 48 hours in 2 of 4 trials which means that the VFAs may be converted or volatilized if the residence time in of the primary sludge in the fermentation process is too long. However, by 72 hours, all seeded treatments are relatively similar for this ratio.

Figure 7: Effect of Seeded Sludge as Measured by Total Carbon Production (Including Initial Seed Carbon) over Initial Volatile Solids Over Time



(a) Carbon measured as VFA



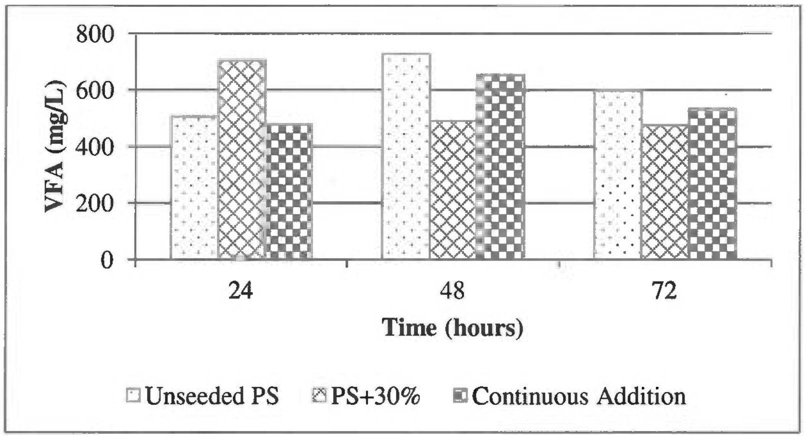
(b) Carbon measured as solCOD

Seeding the sludge was an effective way to stimulate more carbon from the initial solids content in the fermentation process. From this set of trials, the optimal time for seeded sludge seemed to be past the 48 hour mark which was considered optimal in the unseeded trials documented above. On average, seeding with 50% prefermented sludge gave the highest VFA concentrations at 24, 48, and 72 hours. However, by 72 hours, there was less of a difference between both average VFA concentrations and the VFA/TVS_0 ratio in the three seeded treatments.

Continuous Feeding

Most of the trials were run as batch experiments. The last of the trials involved an attempt to simulate a continuous reactor by adding a portion of the fermented sludge to fresh sludge on a daily basis while removing an equal amount over the course of three days; the prefermented portion comprised 15% of the total volume. For these trials, initial TS was measured, and solCOD and VFA were measured over time; however, ORP and pH were not measured. Figure 8 shows the average of the two trials performed. As seen, the results do not show a consistent increase in carbon production, and the seeded treatments are not outperforming the unseeded treatment. One possible reason for this may be that the solids concentrations through the experiment changed through volatilization, thus also changing the amount of fermenting biomass. It is suggested that the continuous reactor trials be rerun, with measures in place such as a larger working volume and ensuring the solids are essentially maintained through the duration of the trial.

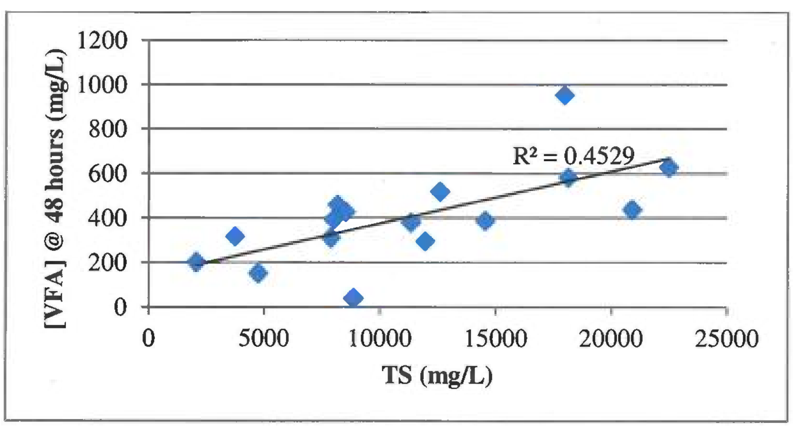
Figure 8: Effect of Fermenting Sludge in a Continuous Reactor as Measured by Total VFA Production (Including Seed Sludge) Over Time



Effect of Initial TS

During the first set of fermentation trials, one of the strongest correlations for higher carbon concentrations was the initial TS in the sample. Figure 9 shows that during testing this round, a similar correlation exists for VFA concentrations measured at 48 hours; although not shown, there are similar correlations for VFA concentrations at other times, as well. However, the initial TS concentration was measured prior to fermentation during this second round of testing to target a TS concentration of 7,000 – 13,000 mg/L. In Figure 9, all trials are shown, including the differing seeding additions. At times, these additions caused a slight decrease or increase from the initial values.

Figure 9: Initial Total Solids Compared to Total VFA Concentrations (Including the Seed Sludge) at 48 Hours



Comparison of Sludge Sources

The other sources tested included unthickened and TWAS as well as pre-digestion centrifuge cake, i.e. TWAS and PS. In all of the other sources tested, only endogenous fermentation was examined. The average and standard deviation results from the trials are presented in Table 2 with unseeded PS included for comparison. The carbon production of both thickened and unthickened WAS fermentation tests were quite low with a maximum in the TWAS fermentation of 111 mg VFA/L at 72 hours. From the data, the fermentation of pre-digestion centrifuge cake (only fermented for 48 hours) showed a higher VFA concentration than unseeded PS by itself. As the yield from the TWAS fermentation was low, the driving force in the pre-digestion centrifuge cake carbon production would seem to be from the thickened PS as the carbon concentrations in PS increase with higher initial TVS_0 concentrations. The VFA concentration in digester draw was also measured (no fermentation) and averaged 15 mg/L for 4 samples, making it an unusable source because of low VFA concentrations.

Table 2: Summary of Average VFA and solCOD Concentrations and Concentrations over Initial Solids for Unthick WAS, Thick WAS and PreCent Cake

Elapsed Time (hrs)	Average VFA (mg/L)				Average solCOD (mg/L)			
	Unseeded PS	Unthick WAS	Thick WAS	PreCent Cake	Unseeded PS	Unthick WAS	Thick WAS	PreCent Cake
0	162	14	10	304	422	35	29	508
24	280	15	51	434	567	65	104	1,006
48	220	31	94	366	555	70	151	936
72	289	40	111	---	600	110[1]	238[2]	---
	Average [VFA]@48 hours / $[TVS]_0$				**Average [solCOD]@48 hours / $[TVS]_0$**			
	0.036	0.018	0.012	0.019	0.090	0.042	0.019	0.048

1. Average for Unthick WAS at 72 hours only includes 1 trial as second trial yielded a solCOD concentration of 11,895 mg/L and was determined to be an outlier based on a concentration of 66 mg/L in the same sample from the previous day.
2. Average for TWAS at 72 hours only includes 1 trial as second trial yielded a solCOD concentration of 4,854 mg/L and was determined to be an outlier based on a concentration of 130 mg/L in the same sample from the previous day.

Optimizing the VFA Concentrations

Based on the information gathered during the fermentation testing, new WASSTRIP® testing began again using PS fermentate as the carbon source. The fermentation method used was to create the seed PS, add to fresh PS so that 30% of volume was seed PS, and further ferment the mixture for 96 hours. Initially, sludge was fermented 96 hours based on lab schedule and collection availability; however, after running in this manner, further benefit to total carbon production was noticed, and it was continued. The average, maximum, minimum, and standard deviation VFA concentrations from 4 trials were 1,459 mg/L, 1,624 mg/L, 1,320 mg/L, and 139 mg/L, respectively; using solCOD concentrations the average, maximum, minimum and standard deviation are 2,944 mg/L, 3,339 mg/L, 2,618 mg/L, and 364 mg/L, respectively. This method seemed adequate to give reproducible carbon concentrations based on the standard deviations. In addition, the average VFA/TVS_0 ratio was 0.15, which, based on literature, is an average yield for fermentation.

4.0 Implications for WASSTRIP® Process

From P-release literature, the target is to add carbon as acetate at a 4:1 mass ratio to the anticipated mass of orthoP released. Ostara has also seen successful release from running WASSTRIP® with a 2:1 carbon to released orthoP ratio; this ratio is used herein. From WASSTRIP® settling experiments described in Technical Memo 7, the average TP in thickened WAS was 342 mg TP/L when the WAS is thickened to 15,000 mg SS/L and 405 mg TP/L at a TWAS SS concentration of 18,000 mg SS/L; a 25% release (the average release seen in previous WASSTRIP® experiments) from those values would yield orthoP concentrations of 86 mg/L and 101 mg/L, respectively, meaning carbon should be added to bring the WAS carbon concentrations to 172-344 mg acetate/L and 202-404 mg acetate/L, respectively, in the WASSTRIP® reactors for each of these scenarios. The average VFA concentration from the renewed WASSTRIP® testing (described in '*Optimizing the VFA Concentrations*' above) was 1,459 mg VFA/L. With this concentration, the flows of primary sludge fermentate necessary, the resulting hydraulic retention time (HRT) in the WASSTRIP® reactors, and the estimated orthoP load produced can be calculated.

Table 3 expands on the data in Table 5 from Technical Memo 7 to indicate the carbon loads necessary, the fermentate flows producing the carbon load, and the PS flows to 2 GCTs that would generate the appropriate fermentate flow. Assumptions surrounding the use of 2 GCTs as fermentors include a design SRT of 4 days, a 90% capture of solids in the sludge blanket, and a 0.15 VFA/VSS ratio (from the data generated within this set of experiments).

Table 3 also shows the impacts from adding the fermentate to the WASSTRIP® process. In particular, the HRTs are found by using the number of WASSTRIP® tanks available and the necessary fermentate flow combined with the TWAS flow. From previous WASSTRIP® studies, the suggested HRT with carbon added is 6 hours. Using only 2 tanks for settling restricts the influent WAS flow substantially, leaving a decreased TWAS flow and an HRT in the WASSTRIP® tanks of 15 – 16 hours, significantly higher than necessary. Scenario 2 uses 4 GCTs as thickeners and 4 as WASSTRIP® reactor tanks; with the predicted flows, the HRT in the WASSTRIP reactors is still close to the recommended 6 hours and could be driven towards the higher end pending optimization of the fermentate to TP ratio. Also of note is that if all of the average WAS flow is treated to maximize the TWAS flow (Scenario 4 and, potentially, with the use of a polymer), the HRT in 4 WASSTRIP® reactors is then limited to 4 hours making the HRT a potential limiting factor in this scenario. The subsequent TM will address the carbon ratios necessary for maximum release and the release over time to gauge the effects of the HRTs developed herein.

It should also be noted that it is possible to achieve the 4 day target SRT with only one GCT operating as a fermentor with PS flows under approximately 1.2 MGD. This would allow for redundancy in the fermentor operations in several of the scenarios if the carbon ratio necessary is closer to 2:1.

Lastly, using 4 GCTs as thickeners, 4 as WASSTRIP reactors, and 2 as fermentors for the design configuration, the maximum orthoP load produced is estimated at 3,640 lb/day (a 25% release from the TP load in Scenario 2). This is about 40% lower than the estimates from a modeling effort completed by Black & Veatch; in their report presented to the District, the orthoP load from the implementation of the WASSTRIP® process was estimated at roughly 6,000 lb/day. However, this model assumed all existing GCTs were used for thickening and WASSTRIP® with fermentation occurring elsewhere in the plant (the new GCTs). As shown in Scenario 4, a 25% release from the TP load of 19,110 lb/day to orthoP would near this value.

Table 3: Effects of Fermentation Results on Tank Usage Scenarios – Amended from TM 7

Scenario	Condition	TWAS Underflow (MGD)	TWAS TP Load (lb/day)	Carbon Load Needed (lb/day)[1]	PS Fermentate Flow (MGD)	WASSTRIP® HRT (hrs)	PS Flow to Fermentor for SRT ~ 4 days with No Recycle (MGD)	PS Flow to Fermentor for SRT ~ 4 days with Q_R/Q_0 ~ 0.5 (MGD)
1	Maximum WAS Flow Treated Based on Limits of 2 GCTs as Thickeners & 15,000 mg SS/L in Underflow	2.6	7,420	3,710 – 7,420	0.3 – 0.6	15.3 – 16.9	0.6 – 1.2	0.4 – 0.7
2	Maximum WAS Flow Treated Based on Limits of 4 GCTs as Thickeners & 15,000 mg SS/L in Underflow	5.1	14,550	7,275 – 14,550	0.6 – 1.2	5.2 – 5.7	1 – 2	0.7 – 1.4
3	Maximum WAS Flow Treated Based on Limits of 4 GCTs as Thickeners & 18,000 mg SS/L in Underflow	3.6	12,160	6,080 – 12,160	0.5 – 1	7.1 – 8.0	0.9 – 1.8	0.6 – 1.1
4	Use of 6 GCTs as Thickeners & 15,000 mg SS/L in Underflow	7.2	19,110	9,560 – 19,120	0.8 – 1.6	3.7 – 4.1	1.6 – 2.6 [2]	0.9 – 1.7
Other Alternatives	Based on Operation of Existing GCTs • All Flow Sent to 4 GCTs as Thickeners & 15,000 mg SS/L in Underflow[1]	2.6	7,420	3,710 – 7,420	0.3 – 0.6	10.2 – 11.2	0.6 – 1.2	0.4 – 0.7
	Theoretical • 4 GCTs as Thickeners, Polymer Addition, & 20,000 mgSS/L underflow[2]	5.3	19,110	9,560 – 19,120	0.8 – 1.6	4.7 – 5.4	1.6 – 2.6 [2]	0.9 – 1.7

1: Range based on using a 25% release of TP to orthoP and either 2:1 or 4:1 as the carbon to potential orthoP ratio. The ratio needed for SWRP WASSTRIP® will be further refined in the next TM on the subject.
2: SRT at a flow of 2.6 MGD is closer to 3.5 days, rather than 4.

5.0 Findings

Mixing, seeding, and continuous feeding of PS were tested as ways to stimulate carbon production past the production seen through just endogenous decay of PS over time. Whether or not the treatments were mixed did not seem to have a significant impact on the rate or magnitude of carbon produced. The trials with the continuous feeding and seeding of PS were inconclusive. However, the carbon production was stimulated through the addition of seed PS, and the production seemed to continue through the duration of the experiment. Although the amount of seed PS added showed varying results as to which percentage was optimal, it was clear that the addition of any amount of seed PS led to higher carbon production than the unseeded PS. Increased carbon concentrations were also correlated to increasing initial solids concentrations.

Of the different sludge sources tested as endogenous and unseeded decay, the pre-digestion centrifuge cake (currently a combination of thickened WAS and PS) yielded the greatest carbon concentrations. Similar to PS, the pre-digestion centrifuge cake may be capable of yielding greater carbon concentrations when seeded with prefermented sludge. However, the carbon concentrations in here seem to be driven by the PS portion, rather than the WAS, as both unthickened WAS and TWAS yielded less carbon through fermentation than other sources. Given the correlation between initial solids concentrations and maximum carbon concentrations produced from the previous experiments, it would follow that the pre-digestion centrifuge cake would have higher carbon concentrations due to higher solids content.

Carbon is still a significant factor as high PS fermentate flows are necessary to drive the WASSTRIP® P release. For the implementation of WASSTRIP®, the use of primary sludge is still recommended. Based on average maximum carbon concentrations seen through the fermentation trials and projected TWAS loadings from all scenarios, an estimated range of 0.4 – 2.6 MGD of PS would need to be fermented in 2 of the existing GCTs. In the scenario currently being developed, Scenario 2, the maximum PS flow would range between 1.4 – 2 MGD. In addition, these maximum concentrations were achieved through seeding of fermented sludge, The fermentor design should include recycle pumps with the capability to vary the flow to up to 50% of the influent flow; this would allow for optimization of the recycled sludge in the field. pH was also helpful in discerning trends in the fermentation process and can be used at the full-scale to help control the process while ORP should be further examined as a control parameter.

WORK PLAN OUTLINE FOR PRIMARY SLUDGE FERMENTATION TESTS

INTRODUCTION

Design of a waste activated sludge (WAS) phosphorus release process is underway as part of the P-recovery system at SWRP. This process has been marketed as the Waste Activated Sludge Stripping to Remove Internal Phosphorus® (WASSTRIP) process and has been implemented in full-scale wastewater treatment processes. It is meant to increase the P loading to the P-recovery system.

A key process control parameter that affects P release efficiency is the type and amount of carbon added to the WASSTRIP reactor. Based on initial WASSTRIP data collected in studies at SWRP, adding carbon will increase the rate of P release by about four times, making the necessary reactor volume considerably less than employing WASSTRIP with endogenous carbon. This project will focus on determination of the carbon concentrations from sources internal to the SWRP plant, primary sludge (PS) and thickened WAS, and generation of VFA from these sources separately through fermentation in the shortest possible time.

From P-release literature, the target is to add carbon as acetate at a 4:1 mass ratio to the P released. From initial WASSTRIP experiments, the average TP in thickened WAS is around 300 mg/L; a 30% release from that would yield an orthoP concentration of 90 mg/L, meaning carbon should be added to bring the WAS concentration to 360 mg acetate/L. If the carbon demands can be met through internal sources, the plant would not need to purchase an external carbon supplement.

BACKGROUND

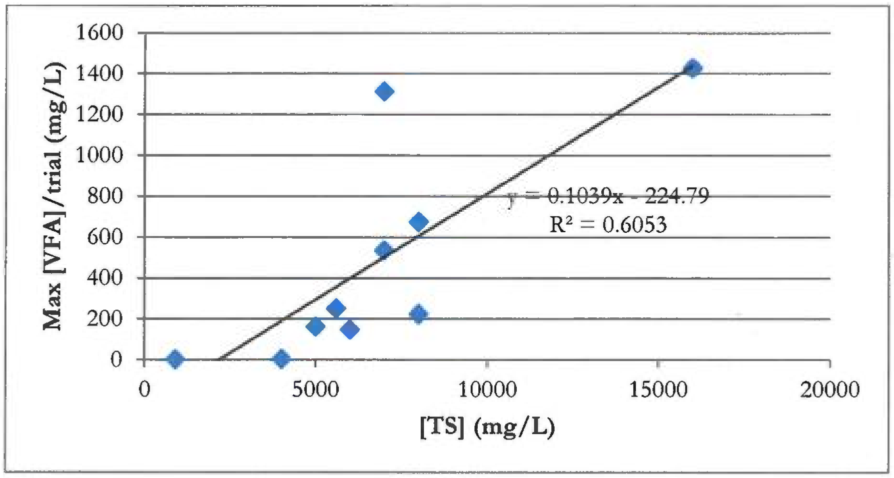
An initial study on VFA formation through SWRP PS fermentation was conducted in 2013. Table 1 summarizes the data collected during this period. As can be seen, fermentation resulted in inconsistent VFA production with average VFA concentrations of 357 mg/L reached after 48 hours, but a range from <5 – 1,431 mg/L. solCOD was another measurement used as an indicator of available carbon produced; the results seen for solCOD concentrations followed similar patterns to the VFAs. As also seen in Table 1, the TS concentrations in the raw samples were quite variable. The average yield ($[VFA]/[TS]_0$) was 0.043 mg VFA/mg TS after 48 hours from these trials; expected yields range from 0.05 – 0.3 mg VFA/mg VS ('Fermenters for Biological Phosphorus Removal Carbon Augmentation', Issued by WERF August 9, 2011). Assuming an average VS/TS ratio of 0.65 would make the average yield at 48 hours approximately 0.066 mg VFA/mg VS; the average values from the initial study are at the lower end of literature range.

TABLE 1:
RESULTS FROM PRELIMINARY PRIMARY SLUDGE FERMENTATION STUDY CONDUCTED 1/2013 – 4/2013

	[VFA]			[solCOD]		
Time (hrs)	Average [VFA] (mg/L)	[VFA] Range (min-max)	Average [VFA]/ $[TS]_0$	Average [solCOD] (mg/L)	[solCOD] Range (min-max)	Average [solCOD]/ $[TS]_0$
0	24	<5-79		86	46-148	
4-5	92	<5-772	0.013	480	40-1,650	0.079
24	147	<5-1,076	0.022	609	61-1,968	0.104
48	357	<5-1,431	0.043	650	59-1,671	0.125
Trials	10			4		
Avg [TS] (mg/L)	6,928					
[TS] Range (min – max)	896 – 16,000					

Figure 1 shows the correlation between maximum VFA concentrations seen during the preliminary fermentation trials and initial TS concentrations. As can be seen, there is a significant correlation between these two, with an R^2 of 0.61.

FIGURE 1:
EFFECT OF INITIAL SOLIDS CONCENTRATIONS ON FINAL VFA PRODUCED



At SWRP from 2010 – 2013, the percent solids in the PS averaged 1.0%. To narrow the variations seen in the carbon concentration data, this study will attempt to obtain a more consistent initial TS from the PS (closer to the plant average) to see the true VFA formation potential. Based on the equation generated in Figure 1, an initial PS of 1.0% would yield a maximum VFA concentration of 814 mg/L; given average PS and WAS flows, fermented PS has potential to meet the carbon demands of WASSTRIP.

The preliminary trials were done through holding PS undisturbed at room temperature under anaerobic conditions, gently stirring, and then taking a sample for TS, COD, and other parameters. These trials simulated a batch reactor system where the HRT was equal to the SRT. The SRT for a PS fermentor can be increased past the HRT through reseeding a portion of already fermented PS to fresh PS. For this trial, seed sludge will be fermented in the lab and used to feed new PS in an attempt to accelerate fermentation. However, in practice, the fermentors may operate more similarly to a continuous mode. As such, this set of trials will evaluate the difference in continuous versus unseeded and reseeded batch reactors in terms of maximizing VFA production. The readily available carbon will be similar whether fermented PS or fermentate is used, the difference being the volume and solids added to the WASSTRIP reactor. As such, these trials will give an approximation of the VFA potential for both, and calculations can determine the volumes of either one to add to reactor.

A second potential carbon source is through the fermentation of thickened WAS. Benefits of using thickened WAS as a carbon source include the separation of WAS and PS, the ability to use PS fermentation for other plant needs, and the release of additional orthoP that would occur in thickened WAS fermentation. Initial trials for unthickened WAS fermentation were conducted in February and March, 2014; these results are shown in Table 2. Here, the carbon formation potential was measured for different temperatures, simulating winter and summer conditions. As seen, the solCOD concentrations reached the same levels as PS fermentation only in the summer conditions after 3 days. The reduced VFA production from unthickened WAS is also confirmed in literature ("*Phosphorus Recovery and VFA Generation from Waste Activated Sludge Alone and Co-thickened with Primary Sludge*", Zurzolo, F., Kruk, D., and Oleszkiewicz, J., WEFTEC 2013). Because fermentation of unthickened WAS would necessitate a large volume to produce adequate VFAs for WASSTRIP, this trial will focus on the fermentation of thickened WAS, either through WAS thickened in lab and then fermented or after the dedicated WAS pre-digestion centrifuges are online. As suggested in the paper, another option is to use both PS and WAS combined for fermentation; if results from this set of trials are not producing adequate VFAs, this is another option that can be tested.

TABLE 2:
RESULTS FROM PRELIMINARY UNTHICKENED WAS FERMENTATION STUDY CONDUCTED 2/2013 – 3/2014

Time	Winter				Summer			
	Average [solCOD] (mg/L)	[solCOD] Range (min-max)	Average [solCOD]/ $[TSS]_0$	Average [orthoP] (mg/L)	Average [solCOD] (mg/L)	[solCOD] Range (min-max)	Average [solCOD]/ $[TSS]_0$	Average [orthoP] (mg/L)
0	28	<25-31	0.0046	2.53	28	25-31	0.0048	3.28
24	51	33-79	0.0083	19.04	224	170-256	0.038	38.26
48	56	33-88	0.0090	23.14	256	176-400	0.044	39.78
72	116	65-172	0.018	34.43	600	505-692	0.102	57.04
Trials	3				3			
Avg [TSS] (mg/L)	7,884				8,120			
[TSS] Range (min – max)	7,330 – 8,480				6,730 – 8,980			

OBJECTIVES

There are multiple objectives of this subproject:

1. To determine the VFA formation potential from fermenting primary sludge without seeding in a batch reactor.
2. Assess the VFA formation potential using a portion of fermented primary sludge to accelerate the fermentation of a new batch of primary sludge.
3. Evaluate the difference in running the fermentation process in a continuous versus batch mode.
4. To determine the VFA formation potential from fermenting thickened WAS using batch fermentation.
5. To determine if the VFA generated through primary sludge fermentation or thickened WAS fermentation is sufficient to meet WASSTRIP carbon demands based on VFA formation rates and available detention time.

MATERIALS AND METHODS

Seed Sludge Fermentation – Hold Time Determination

1. Collect first a gallon bottle of PS by using half north and half south PS. Measure sample for TS concentration using the quick microwave method.
2. With this information, collect one 5-gallon carboy of PS, mixing sludge from the north and south side preliminary tanks. Mix the two sludges respectively to achieve a 0.7 – 1.3% sludge if possible to produce 3 gallons working volume. Measure %TS. If TS concentration is greater than 1.3 or less than 0.7%, dilute with primary effluent or settle and decant, respectively.
3. Upon generating a 1% sludge, take a T=0 hr sample of the sludge (approximately 500 mL) for TS, VS, VFA, and solCOD. Measure and record pH, DO, and ORP.
4. Allow sludge to sit in laboratory with gentle mixing through duration of tests. Stir enough to ensure all solids are in suspension before taking sample. Take daily sample of fermenting sludge (approximately 500 mL) for VFA and solCOD at T=24, 48, 72, and 96 hours. Measure and record pH, DO, and ORP.
5. An appropriate hold time can be determined based on when the VFA and solCOD concentrations begin to plateau.

This portion of the study will run once per week and be repeated approximately 2 times.

Primary Sludge with Seeded Fermentation

1. Prepare Seed Sludge prior to the trial (dependent upon previously established time in first portion of study) by following steps 1 and 2 from 'Seed Sludge Fermentation – Hold Time Determination'; ferment for 48 hours or designated time. Take initial and final seed sludge samples for TS, VS, VFA, and solCOD.
2. Collect 2 5-gallon carboys of fresh PS, mixing sludge from the north and south side preliminary tanks. Prepare fresh PS through following Steps 1 and 2 from 'Seed Sludge Fermentation – Hold Time Determination'. Generate a 1% sample as suggested in Step 2 above.
3. Label 4 test containers as PS Alone, 15% seeded, 30% seeded, and 50% seeded.
4. Add the pre-fermented sludge and freshly collected PS to the labeled containers in the following amounts:
    a. PS Alone – 3 gallon fresh PS
    b. 15% Seeded – 2.55 gallon fresh PS, 0.45 gallon seed sludge
    c. 30% Seeded – 2.1 gallon fresh PS, 0.9 gallon seed sludge
    d. 50% Seeded – 1.5 gallon fresh PS, 1.5 gallon seed sludge
5. Take a T=0 hr 750 mL sample for TS, VS, VFA, and solCOD from each of the containers. Measure and record pH, DO, and ORP readings from each container. Allow sludge to sit in laboratory with gentle mixing through duration of tests. On Day 2, collect a 500 mL sample from each of the containers at T = 24 hr and T = 30 hr. These should be analyzed for VFA and solCOD. Take and record pH, DO, and ORP for each sample.
6. On Day 3 or until hold time determined from 'Seed Sludge Fermentation – Hold Time Determination', collect a 750 mL sample from each of the containers at T = 48 hr or designated time. These should be analyzed for TS, VS, VFA and solCOD. Measure and record pH, DO, and ORP for each sample.

This portion of the study will run once per week and be repeated approximately 4 times in an attempt to select the optimal seeding percentage and to capture varying PS characteristics.

Thickened WAS Fermentation

1. If dedicated pre-digestion centrifuges are running and processing only WAS from SWRP, collect a 2.5-gallon carboy of WAS processed through these pre-digestion centrifuges. If these are not operational, collect a 5-gallon carboy of WAS and allow to thicken in lab for approximately 1 hour. Decant filtrate from top of carboy; use the thickened WAS portion for the remainder of study.
2. Take a T = 0 hr 750 mL sample for TS, VS, VFA, and solCOD from the container. Measure and record pH, DO, and ORP readings from each container. Allow sludge to sit in laboratory with gentle mixing through duration of tests. On Day 2, collect a 500 mL sample from each of the containers at T = 24 hr. This should be analyzed for VFA and solCOD. Take and record pH, DO, and ORP for sample.
3. On subsequent days (T = 48 hr, T = 72 hr), collect and record measurements as described in Step 2. On last day of test, collect a 750 mL sample from the container (tentatively at T = 96 hr) for analysis of TS, VS, VFA and solCOD. Measure and record pH, DO, and

ORP. If initial tests show that fermentation is complete sooner, the duration of the test can be shortened.

This portion of the study will run once per week and be run at the same time the '*Primary Sludge with Seeded Fermentation*' portion (approximately 4 times).

Continuous versus Batch Reactors

1. Prepare Seed Sludge prior to the trial (dependent upon previously established time in first portion of study) by following steps 1 and 2 from 'Seed Sludge Fermentation – Hold Time Determination'; ferment for 48 hours or designated time. Take initial and final seed sludge samples for TS, VS, VFA, and solCOD.
2. Collect 2 5-gallon carboys of fresh PS, mixing sludge from the north and south side preliminary tanks. Prepare fresh PS through following Steps 1 and 2 from 'Seed Sludge Fermentation – Hold Time Determination'. Generate a 1% sample as suggested in Step 2 above.
3. Label 3 2.5-gallon test containers as PS Alone, Seeded, and Continuous.
4. Add the pre-fermented sludge and freshly collected PS to the labeled containers in the following amounts:
    a. PS Alone – 2.5 gallon fresh PS
    b. Seeded – Using one reactor, add the optimum fresh and pre-fermented sludge in volumes consistent with the ratio determined in '*Primary Sludge with Seeded Fermentation*'
    c. Continuous – Add same volumes of fresh and pre-fermented sludge as to Seeded reactor
5. Take a T=0 hr 750 mL sample for TS, VS, VFA, and solCOD from each of the containers. Measure and record pH, DO, and ORP readings from each container. Allow sludge to sit in laboratory with gentle mixing through duration of tests.
6. On Day 2, collect a 500 mL sample from each of the containers at T = 24 hr. These should be analyzed for VFA and solCOD. Take and record pH, DO, and ORP for each sample.
7. Collect 0.5 gallon of fresh PS from the field. After taking samples on Day 2, allow the Continuous reactor to settle. Waste approximately 0.5 gallon of the solids portion through use of a wide-mouth pipette or peristaltic pump. Pour 0.5 gallon of the fresh PS into the Continuous reactor and restart mixing.
8. Daily samples from all tests and wasting and addition of fresh PS to the Continuous reactor will continue for Days 3 and Day 4 as described in Steps 6 and 7 above.
9. On Day 5, collect a 750 mL sample from each of the containers at T = 48 hr or designated time. These should be analyzed for TS, VS, VFA and solCOD. Measure and record pH, DO, and ORP for each sample.

This portion of the study will run once per week and be repeated approximately 4 times after the first two phases described above.

DATA EVALUATION

Data obtained from this study and all data analyses completed will be reviewed for accuracy. Data evaluation will focus on:

1. Determination of the fermented PS average, maximum, and minimum VFA and solCOD concentrations over time.
2. Using carbon concentrations, determine when fermentation for the PS and thickened WAS tests is complete.
3. Rates and comparisons of VFA and solCOD increases compared to initial solids concentrations from PS fermentation tests.
4. Rates and comparisons of VFA and solCOD increases between continuous and batch fermentation.
5. Determination of the fermented thickened WAS average, maximum, and minimum VFA and solCOD concentrations over time.
6. Comparison of average VFA and solCOD concentrations produced from PS, fermented PS, and fermented thickened WASsamples with how much is necessary for a WASSTRIP reactor.

QUALITY ASSURANCE AND QUALITY CONTROL

A QA/QC program will be employed to ensure the evaluation is representative of the test. All field samples will be collected in a manner that will ensure analysis and evaluation will provide an accurate representation of the test. These factors include preparation of sample containers (new or cleaned bottles), sample collection techniques (rinse scooper with PS or WAS before sampling), sample preparation, sample storage and delivery in a timely manner, and laboratory analysis. During the experiments, ORP and DO measurements will be taken to ensure anaerobic conditions and verify the occurrence fermentation. TS and VS samples will be taken at the end of each trial and compared to those at the start to ensure that decreasing system volume from sampling will not compromise results. The chain of custody form will be filled in and the samples stored in the cooler immediately after collection. However, VFA and solCOD samples will be filtered immediately after collection. The data quality will be evaluated as soon as possible after each study day. Extreme data values will be investigated to determine legitimacy. All instruments used in the field and/or lab will be calibrated and checked to ensure accuracy.

TS, VS, VFA, and solCOD will be analyzed using standard methods (2008) at ALD, and ALD will use their internal QA/QC methods.

SCHEDULE

The study will be run approximately once per week. Dependent upon tech and lab availability, this could be finished in around 3 months.

Task	Duration
Test Preparation	Sept 8-12, 2014
Lab Testing	Sept 15-Dec 19, 2014
Data Analysis	Jan 5-Jan 9 , 2015
Summary	Jan 12-Jan 16, 2015

PERSONNEL INVOLVED AND TIME COMMITMENT

The estimated man-hours required to complete this experiment are included below. The majority of the sample collection and laboratory work will be completed by Laboratory Technicians in the Wastewater Treatment Process Research Section. Data analysis, summary of data, and supervision will be completed by a Senior Civil Engineer in collaboration with a Senior Environmental Research Scientist. All others listed below will provide direction, consultation, and review of the project's deliverables.

	Person-Hours
Laboratory Technician (1 LT)	
Prepare sample bottles	30
Sample collection	30
Experimentation	70
Total Laboratory Technician Hours	**130**
SERS/CEIII	
Coordination with ALD	2
Supervision/Training for Experimentation	24
Data analysis	32
Preparation of Summary	40
Total SERS/CEIII Hours	**90**
Supervising Environmental Research Scientist	
Provision of direction to AERS/CEIII	2
Review of products	3
Total Supervising Environmental Research Scientist Hours	**5**

	Person-Hours
Managing Civil Engineer	
Review of products	2
Total Managing Civil Engineer Hours	**2**
Assistant Director of Monitoring and Research	
Provision of direction	2
Review of Data	2
Total Assistant Director of Monitoring and Research Hours	**4**

Signature Page

Project Leader	______________________	**Date**	__________
Supervising ERS	______________________	**Date**	__________
Managing Civil Engineer	______________________	**Date**	__________
Assistant Head of M&R	______________________	**Date**	__________