Cause-and-Effect Study of Biofermentation: A Novel Biosolids Residuals Point Source Reduction Technology

Rob Whiteman and Brad Macek

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Municipalities and utilities are continuing to face reduced federal subsidies, shrinking budgets, and increasing costs of operations for wastewater treatment plants (WWTPs). Residuals and biosolids handling from the biological wastewater treatment processes are a significant portion of the total cost of operation. The U.S Environmental Protection Agency (EPA) indicates that 40 to 60 percent of the operating costs of a wastewater treatment plant are associated with biosolids handling and disposal. For the past 100 years, the wastewater industry has relied on innovation via new engineering and mechanical process designs to produce less biosolids or to handle residuals more cost-effectively. Purchase of these new designs and equipment has been coupled with the commercial bidding process to maintain competition and suppress costs.

This competition has forced companies to focus on recovery/recycle and reuse under the banner of pollution prevention, leading to numerous technologies for both volume reduction and mass reduction of biosolids prior to various disposal methods, which are presented in Table 1 by function (Whiteman, 2016).

The EPA best management practices prioritize pollution as a hierarchy, starting with point source reduction (PSR), as shown in Figure 1.

As such, point source reduction (PSR) trumps recovery/recycle, which trumps reuse in the prioritization hierarchy. Reduction at the PSR of biological sludge has been left to design fundamentals and the operators to maintain the longest mean cell residence time (MCRT) possible in order to reduce the food-to-microorganism (F/M) ratio, thereby reducing the net yield, and hence, the amount of biosolids produced. Table 2 summarizes the current approaches to pollution prevention for residuals and biosolids handling (Whiteman, 2016).

The premise of activated sludge design has always been based on growing the desired microbes in-situ—in other words, in the biological treatment system. This assumes natural development of the desired bacteria for floc formation to drive good settleability, which is dependent on the MCRT, or the correct bacteria being present in sufficient number to populate the biomass.

Historically, the challenge for designers and operators with extending the MCRT above 20 to 30 days has been the development of excessive amounts of filamentous organisms, which re-

Table 1. Disposal, Volume, and Mass Reduction Strategies for Biosolids Processing

Downstream Processing, Handling, and Disposal Methods		
Volume Reduction	**Mass Reduction**	**Beneficial Use or Disposal**
Clarifiers	Aerobic Digestion	Landfill
Thickeners	Anaerobic Digestion (AD)	Land Application Fertilizer
Air Flotation	Thermophilic - Aerobic	Pelletized Fertilizer
Belt Presses	Thermophilic Anaerobic	Composted Fertilizer
Centrifuges	Composting (Exc. Bulking agent)	Incineration
Pressure Filtration	Mechanical Shearing	Wet Combustion
Vacuum Filtration		
Drying beds		
Oven Drying/Pelletization		

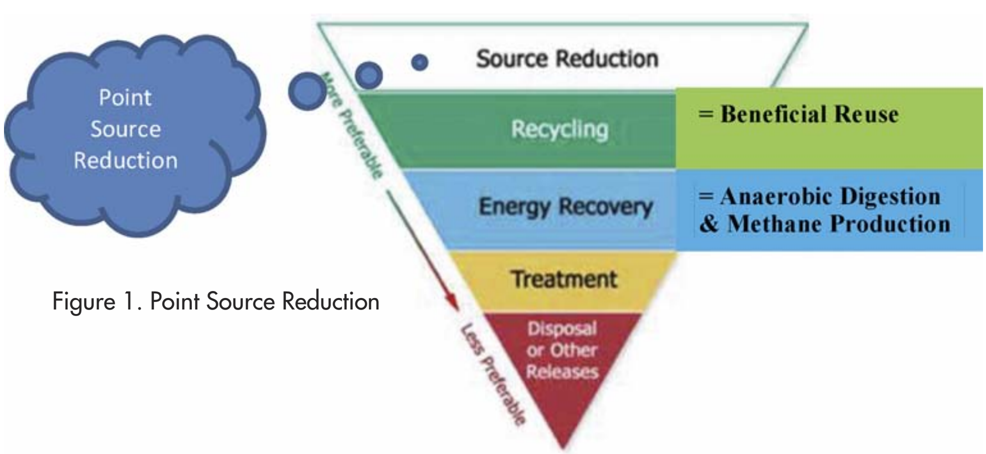

Figure 1. Point Source Reduction

Table 2. Pollution Prevention Control Strategies for Residuals and Biosolids Handling

Pollution Prevention Control Strategies		
1-Point Source Reduction	**2-Recovery of Energy**	**3-Reuse/Renewables**
Design: MCRT/F:M	Mesophilic AD - methane	Fertilizer - Land Application
Operation: MCRT/F:M	Thermophilic AD - methane	Fertilizer - Pelletization
		Fertilizer - Composting

duces biomass settleability and dewaterability, along with fragmentation of the floc, causing poor effluent quality. Typically, WWTPs are therefore operated in the five-to-20-day MCRT range, depending on the design (Eckenfelder, 1998) to meet the National Permit Discharge Elimination System (NPDES), season temperature variations, and comfort level of the operator. The last three decades have seen oxidation ditch designs eliminate primary clarifiers, saving capital costs with resultant higher biological sludge production as primary solids buildup under aeration. This has led to the introduction of various innovative membrane separation designs that have theoretically overcome the dependency on biomass settleability and the need to operate at conservative MCRTs with resultant high energy costs. Many of these membrane systems have to operate at moderate MCRTs to maintain membrane permeability, while the membranes are further negatively impacted by accumulation of fats, oils, and grease (FOG). Other developments in the last decade have focused on harnessing the biology more effectively for nutrient removal with reduced energy requirements and biosolids production in designs, such as Anammox, by encouraging in-situ growth of the microbes that convert ammonia to nitrite, then directly to nitrogen gas under anaerobic conditions. The myriad of process designs in the last 100 years of activated sludge have taught designers and operators one thing: There is no one simplistic and elegant solution to wastewater treatment; it is a complex multidisciplinary subject requiring understanding of engineering, operations, and microbiology.

Figure 2. Visualization of Viability Versus Mass

Many utility directors are now asking, "How do we get more out of an existing wastewater facility?" One answer is to develop cost-effective PSR technologies to obviate the huge capital and operating costs associated with downstream processing and handling of biosolids residuals.

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Bioaugmentation products have been well-documented to benefit industrial biological plants (Whiteman 1987, 1989, 1991, 1992, and 1994), but the technology has failed to become broadly validated within the wastewater industry due to lack of cause-and-effect data. Biofermentation is a biological sidestream reactor process (not product) designed to grow pre-acclimated microbes ex-situ under ideal conditions, thereby minimizing the need for in-situ growth, which is the basis of all current engineering practices. The primary benefit of a sidestream reactor is better control over the growth of the desired pre-acclimated microbes. A second benefit is the sheer number of microbes that can be added to the system on a daily basis, which is discussed further.

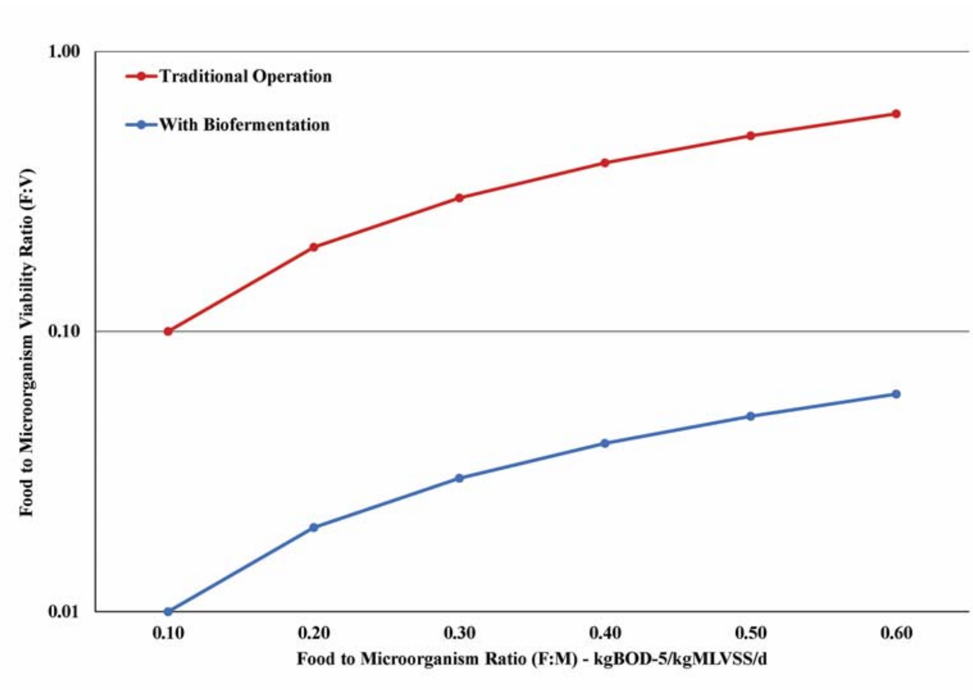

Figure 3. Impact of Biofermentation on F/V Ratio

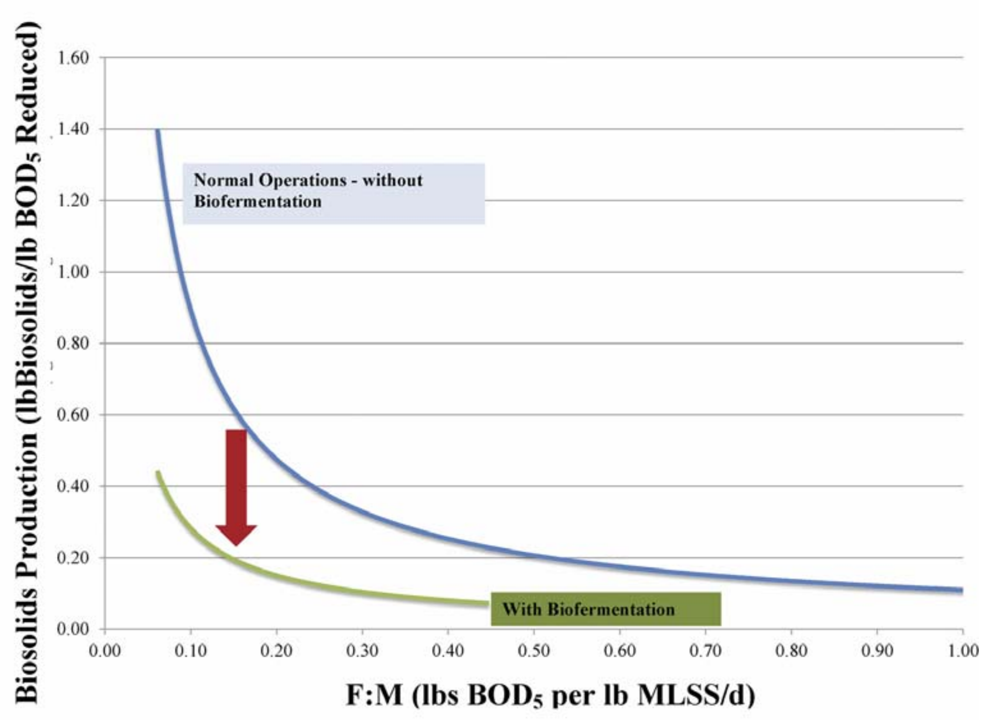

Figure 4. Impact of Biofermentation on Secondary Biosolids Production

One application of biofermentation is as a PSR technology introduced in 2009 by ABS Inc. The technology was originally developed for the pulp and paper industry to rapidly recover biology of the plant after toxic shocks. Using equipment called biofermentors, the biofermentation process grows bacteria onsite, adjacent to the biological wastewater plant, and injects these cultures on a daily basis. In the municipal sector, demonstrations carried out in 2008 led to an astounding discovery: Biofermentation significantly reduces the mass of secondary biosolids produced per pound (lb) of biochemical oxygen demand (BOD_5) removed.

The biofermentation process reduces biosolids production via two main mechanisms: firstly, by increasing the number/viability of specific indigenous BOD_5 degraders, thereby reducing the actual amount of food to viable BOD_5 degraders; and secondly, by addition of floc formers, which improves biomass settleability, increasing return activated sludge (RAS) concentrations and, in turn, allowing higher mixed liquor suspended solids (MLSS); hence, operation at longer MCRT with lower F/M results in further reduction of biosolids production.

This concept is visualized using the "cupcake" analogy to illustrate the difference between viability and mass. In Figure 2 the cupcake represents the activated sludge floc, which is made up of various constituents, including inorganic and organic matter, the latter of which consists of nonbiological and biological matter. The biological matter consists of bacteria responsible for biodegradation of soluble/insoluble organics as measured by BOD_5 removal and those not contributing to BOD_5 removal. The specific bacteria that remove BOD_5 do so by absorption of organics; by definition, therefore, the BOD_5 removal process must take place by specific bacteria on the surface of the floc, which is represented in the left-hand picture by the red sprinkles.

By injection of specific bacteria targeted at BOD_5 removal and floc formation, the single-cell bacteria become attached to the surface of the floc and compete for food, as represented in the right-hand picture in Figure 2 by the "green sprinkles." This increases the viability of the biomass by at least tenfold. This also results in a reduction in the ratio of food/microorganism viability (F/V) of specific BOD degraders, because there are now 10 times more BOD_5-eating bacteria to eat the same amount of food, as shown in Figure 3. Microbial viability was measured with Standard Methods

Agar (SMA) media using standard serial dilution microbiology procedures.

The result of reducing the F/V is to reduce the amount of secondary biosolids produced, irrespective of the actual F/M ratio measured as volatile suspended solids (VSS) and as shown in mathematical modeling work from actual plant data in Figure 4 (actual data shown in Figure 7). The model predicts that at an F/M ratio of 0.15 lb BOD_5/lbMLSS/d a municipal plant without a primary clarifier would produce 0.6 lb of biosolids per lb of BOD_5 removed, while with biofermentation, the plant would only produce 0.2lb of biosolids per lb of BOD_5 removed, or a PSR of 66 percent with no additional air requirements.

Biofermentation has been proven to reduce secondary biosolids production in many types of wastewater treatment processes. This article focuses on the cause-and-effect work of the Port St. Lucie Glades facility for validating the process for reducing secondary biosolids production, while touching on the potential to increase hydraulic and organic throughput.

Table 3. Periods of Data Evaluation (Port St. Lucie Glades Facility)

EVALUATION PERIOD	PERIOD	DAYS	START	END
Prior to evaluation	1	395	4/1/2009	4/30/2010
Evaluation with 1 basin	2	122	6/1/2010	9/30/2010
Evaluation with 2 basins	3	31	10/1/2010	10/31/2010
Post Biofermentation	4	335	12/1/2010	10/31/2011
Post Biofermentation	5	366	11/1/2011	10/31/2012

Table 4. Influent, Effluent, and Design Data (Port St. Lucie Glades Facility)

Period #	Flow (MGD)	# Basins On-line	HRT (hrs)	Inf. BOD (lbs/d)	Final Eff. BOD (lbs/d)	BOD Removal (lbs/d per Basin)	Inf. TSS (lbs/d)	Final Eff. TSS (lbs/d)
1	3.70	2	12.99	12,024	47	5,989	13,686	93
2	3.67	1	6.65	14,347	63	14,050	17,011	84
3	3.43	2	14.01	12,110	42	6,034	11,204	57
4	3.81	2	12.62	12,104	47	6,029	12,321	65
5	4.11	2	11.73	9,203	57	4,,559	8,032	117

- HRT = Hydraulic retention time

Table 5. Operational Characteristics (Port St. Lucie Glades Facility)

Period #	MLSS (mg/L)	MLSS (lbs aerated)	TSS Wasted (lbs)	MCRT (Days)	F:M (lb/lb/day)	Biosolids Production (lb/lb/day)	BOD Removal (%)
1	3060	51042	5623	14	0.21	0.49	99.59%
2	4605	39042	4467	85	0.24	0.33	99.53%
3	4347	72515	2211	201	0.13	0.18	99.65%
4	4108	68517	4600	25	0.13	0.39	99.60%
5	2774	46406	5406	18	0.14	0.60	99.37%

Note: The VSS data were not available at this facility; therefore, the MLSS has been used for calculating F/M ratios, assuming that the VSS percentage did not change significantly. The F/M was calculated based on mass in the aeration basin plus clarifier. The MLSS (lbs) in Table 5 only includes biomass under aeration.

Methodology

The methodology for the process starts with a laboratory service provided by ABS for the isolation of specific indigenous BOD degraders and floc formers for a particular site. From these cultures ABS creates a unique biomass blueprint of the key indigenous populations to be grown in the biofermentor, or the pre-acclimated microbes. The biofermentation process is operated and supplied by ABS as a turnkey service on a flat-fee basis. This service includes equipment in the form of a biofermentor to grow the specific indigenous bacteria onsite, along with the necessary materials for growth of the microbes and technical support throughout to demonstrate that the process is achieving the desired performance criteria. There are no capital costs or manpower requirements to the client; only a small operating cost for water and electricity. Batches of microbes are made daily, or on an as-needed basis, by ABS personnel, depending on the specific site in the aeration basin. Demonstrations are easily executed using trailer-mounted mobile systems, which are later replaced under long-term contracts with skid-mounted equipment inside a permanent installation.

Port St. Lucie Glades Facility in Florida

Port St Lucie operates a 12-mil-gal-per-day (mgd) facility called the Glades, which was designed as a modified Ludzak-Ettinger-activated sludge plant with no primary clarifiers, four aeration basins, diffused air, anoxic zones, and internal recycle. The plant was designed to handle 25,000 lbsBOD/d or 6255 lbsBOD/basin/d, with hydraulic loads of 3mgd/basin. Historically, the facility had been receiving approximately 12,000 lbsBOD/d, with a flow of 3.7 mgd, and was operating with two aeration basins: 6000lbsBOD/basin/d with flows of 1.85 mgd/basin. Thus, the facility was operating well within design parameters. There were two goals of this study to evaluate the ability of the biofermentation process:

1) To increase throughput and capacity by operating off one train (period 2)
2) As a PSR technology (period 2 and period 3)

The study started in mid-April 2010 and was concluded at the end of October 2010 after seven months. Two mobile-trailer-mounted biofermentation units were used to dose the system with an individualized biomass blueprint of the indigenous microbes. The first six weeks were taken to stabilize the biofermentation culture and move the inventory to one basin. The periods of data analysis are shown in Table 3, while a summary of the influent, effluent, and design data are provided in Table 4, and operating data in Table 5.

In evaluating the first goal to determine the ability to operate off one train in period 2, the data showed that the hydraulic retention was reduced from 12.99 to 6.65 hours, or almost exactly 50 percent as a result of moving treatment to one aeration basin, while influent BOD_5 increased by an additional 2323 lbs BOD_5/d, with a total of 14,347 lbs BOD_5/day from a base of 12,024 lbs BOD_5/d. This represented an increase in organic loading rate of 122 percent above the baseline data. Despite the increase BOD_5 load, decrease in hydraulic retention time, and a higher F/M of

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0.24, the final effluent BOD_5 only rose 34 percent, which is equivalent to the increase in F/M. This resulted in the final effluent BOD_5 rising from 47 lbs BOD_5/d to 63 lbs BOD_5/d, with BOD_5 removal efficiencies dropping from 99.59 to 99.53 percent, representing a decrease of 0.06 percent in BOD_5 removal at higher F/M.

Overall, the demonstration for period 2 represents a hydraulic loading of 133 percent of design, with an organic loading rate of 230 percent of design and only a minute reduction in efficiency that was caused by the increase in F/M; this increase could have been offset by further adjustment of MLSS to compensate. It is worthy to note that this is consistent with results observed at other facilities.

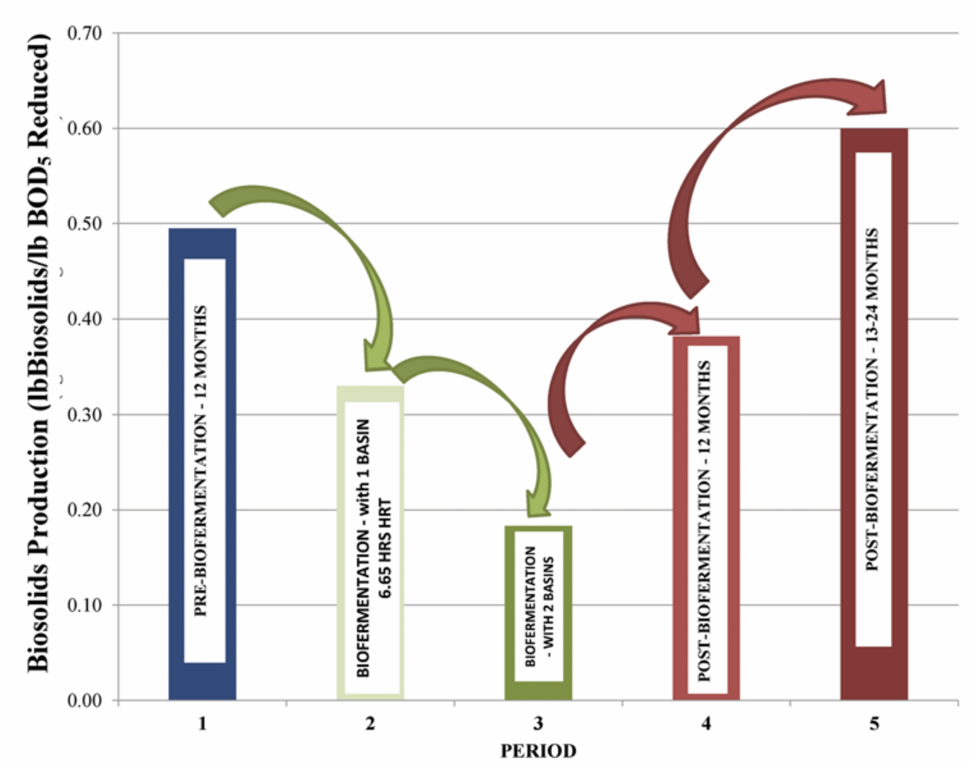

Figure 6. Period Versus Biosolids Production (lb Biosolids per lb BOD_5 Removed)

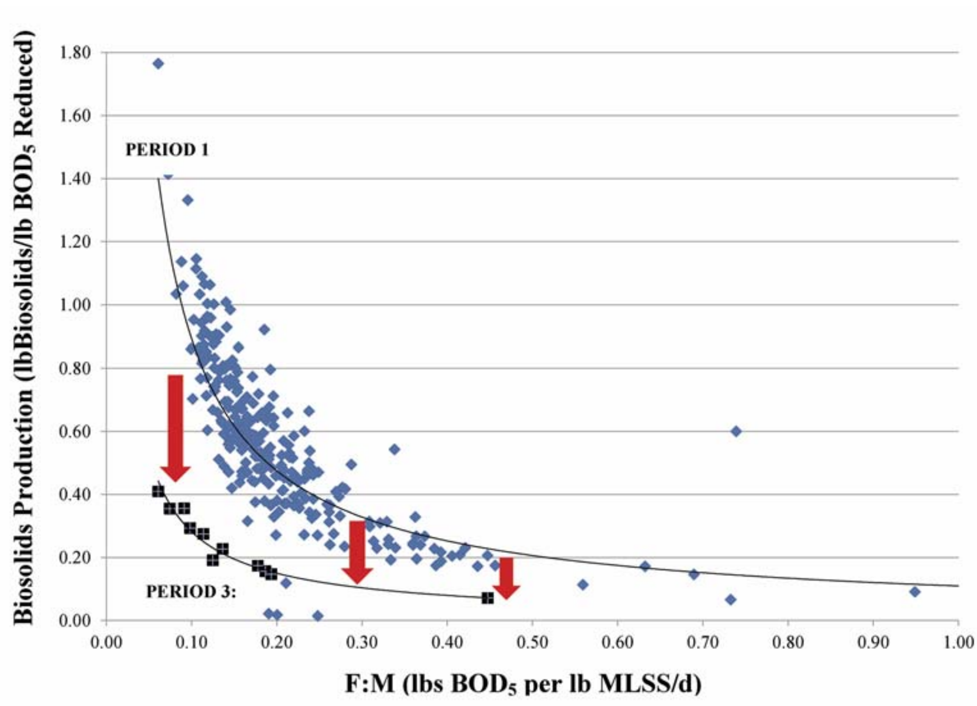

Figure 7. F/M Versus Biosolids Production per lb BOD Removed

The second goal was to evaluate the potential of PSR biosolids. After the evaluation of period 2, the plant returned to operation off two basins in period 3 for comparison to the baseline. In order to normalize this data further, analysis was undertaken for periods 1-5 based on lbs biosolids produced per lbs of BOD_5 reduced, which is shown in Table 5 and Figure 6 as a mean for the period.

This analysis shows several interesting facts:

1) In period 2, when hydraulic retention time is 50 percent of design, the biofermentation process works to stabilize BOD removal, but becomes less efficient at reducing biosolids production. This may in part be reflective of the increased F/M.
2) In period 3, when hydraulic retention time is within design range, biofermentation reduces secondary biosolids production readily (0.18 lb biosolids/lb BOD_5 removed), representing approximately 59 to 53 percent reduction, compared to periods 1 and 4, respectively.
3) In period 4, after the biofermentation process had ceased, the reduction in the biosolids produced continued to a lesser degree (18.9 percent less than period 1) due to the impact of the residual cultures, while in period 5 the plant returned to normal. These results are exactly the same observed in a similar study carried out at the Department of Corrections in Hardee County, Fla.
4) In period 5, after complete washout of the biofermentation bacteria, the process returns to a higher level of biosolids production, with 0.6 lb biosolids/lb BOD_5 removed.

The Port St. Lucie Glades facility, while having a very stable flow, was shown to experience large swings in influent BOD load, which caused the F/M to vary enormously. As net biosolids production will vary based on F/M, it was decided to analyze the daily data for period 1 against period 3, as shown in Figures 7. This analysis confirms that during period 3 a significant reduction in biosolids production occurred, which had never previously been observed, and that in fact was irrespective of the F/M ratio. Consequently, this data have been used to develop equations to model the biofermentation process, as shown in Figure 3. These equations, along with R2 coefficients, are:

Period 1 – Prior to Biofermentation:

$y = 0.1096x^{-0.911}$

$R^2 = 0.4587$

Period 3 – During Biofermentation:
$y = 0.0347x-0.91$
$R^2 = 0.968$

The exceptionally high R2 correlation of 0.968 for period 3 shows that biofermentation is a highly predictable, definable process. Subsequent work has used this data for engineering designs using BioWin.

Biomass analysis over periods 1-4 showed that the biomass structure became less filamentous and more closed/firm during use of the biofermentaion process. A comparison of periods 1 and 2 are provided in plates 3 and 4. The filamentous scale used is 0-6, where 0 represents no filaments and 6 represents a severely filamentous biomass (Jenkins et al, 1993).

The improvement in floc strutcure during periods 2 and 3 was apparent in other operating data during biofermentation, such as higher return activated sludge concentrations rising from 12-14,000 to 18-22,000 mg/L.

In period 3, postbiofermentation filamentous ratings increased, although the deficient photograph, when comparing Plates 5 and 6 with what was recorded on paper during period 4, were filamentous ratings of 3. This data is confirmed by other operational data after ceasing biofermentation in periods 4 and 5. In period 4, wastage rates increased three months in a row despite the F/M remaining the same as period 3 as a result of poorer settleability.

In conclusion, the biofermentation process results at Port St. Lucie showed enormous benefits, both in terms of improving the ability to treat more hydraulically and organically and improving settleability, as well as demonstrating the ability under normal design HRT to reduce biosolids production significantly.

In summary, the biofermentation process has been proven and validated through cause-and-effect studies at two treatment facilities as a PSR process for reducing the production of secondary biosolids and associated processing and handling costs without the need for additional aeration. The development of this PSR process has commercially been shown to create a net operational savings to operations without primary clarifiers. The opportunity for facilties with primary clarifiers and anaerobic digestion to benefit from this PSR process is being evaluated further by considering increasing digester capacity to handle higher-value methanogenic fuels, such as FOG. In some cases, this may eliminate the need for construction of another anaerobic digester where plant expansion is occurring, allowing scarce capital resources to be allocated to other projects. For biofermentation, the next logical step is the creation of an adjunct process to create Class A biosolids. This work has started in 2016.

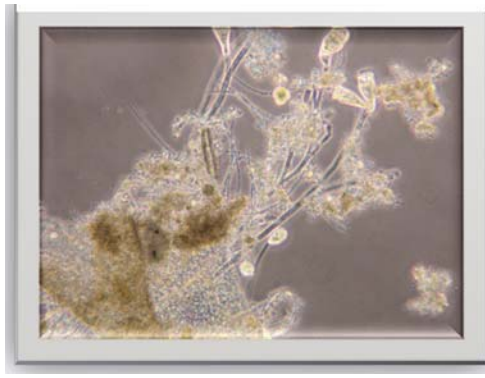

Plate 3, Period 1: Prebiofermentation
Filamentous rating 1-2. Open/Closed floc
with weak-firm, irregular structure.

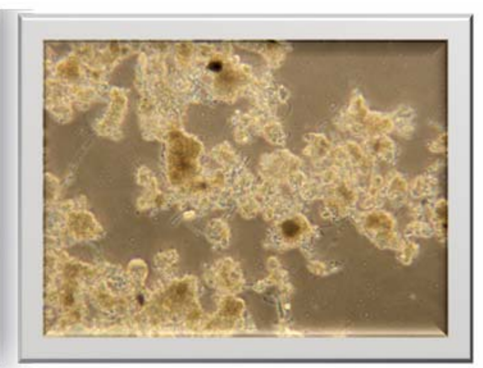

Plate 4, Period 2: During Biofermentation
Filamentous rating 0-1. Closed floc
with firm, irregular structure.

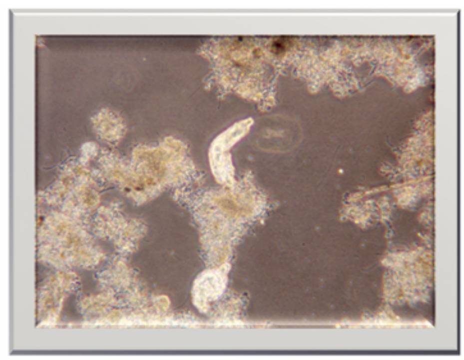

Plate 5, Period 3: Biofermentation
Filamentous rating 0-1. Closed floc
with firm, irregular structure.

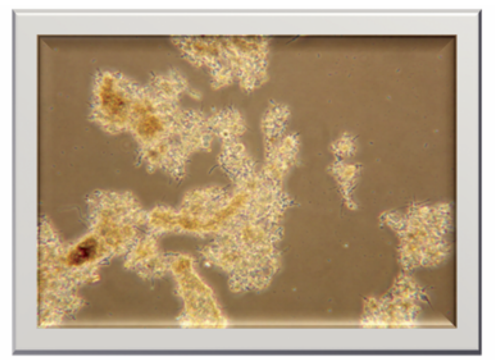

Plate 6, Period 4: Postbiofermentation
Filamentous rating 3. Open/closed floc
with weak-firm, irregular structure.

Other benefits regarding the ability of the biofermentation process to create additional hydraulic or organc loading capacity deserve further evaluation as an intermediate alternative for maintaining compliance, while design/engineering expansion occurs. Ultimately, the biofermentation process should be considered by environmental engineers as an integral part of the design of future wastewater treatment plants.

Acknowledgments

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Another Year, Another Great Conference, Thanks to Great Volunteers

Scott Anaheim
President, FWPCOA

The 2016 Florida Water Resource Conference was a great success again this year, and it was in part due to the cooperation of the Florida Water and Pollution Control Operators Association, the Florida Section of the American Water Works Association, and the Florida Water Environment Association.

The conference was held at the Gaylord Palms Resort and Convention Center from April 24 -27 and both the attendance and number of booths sold were up again this year. Holly Hanson did another amazing job and should be commended, along with the others on her staff, for the job they did in making this conference a success. The FWPCOA was well represented again at this conference and I want to thank all the folks that worked at our booth in the exhibit hall: Tim and Terry McVeigh, Al Monteleone, Mike Darrow, and others.

Operators Showcase

The Operators Showcase that was held on Sunday afternoon and led by our own Tom King was very informative and covered a variety of topics. The two items that stood out the most were a discussion on when we may see a return of computer-based testing (CBT) by the Florida Department of Environmental Protection for water and wastewater licenses and the lead in water crisis in Flint, Mich.

There were so many really good comments on the need for more sites in south Florida for state exams and the possibility of having the exams proctored at health departments until the CBTs are put back in place.

The Flint water crisis discussion brought up some good comments on when operators should speak up when they know something is wrong, and what they should do about it. I believe all of us will be watching the outcome of this and we'll all see our local news stations doing stories on how safe our drinking water is, so this will not be going away anytime soon. We as licensed operators have a duty to bring our concerns to the right people and not worry about our job being in jeopardy for coming forward.

This was the second year of the showcase and we plan on doing it again next year, so if you attend the 2017 conference be sure and drop in, have a beer or two, and bring any topic you would like to discuss.

Operators Challenge

It was another great year for the Operators Challenge, with teams competing from all over the state. Congratulations to St. Cloud and Gainesville Regional Utilities for sharing first place in this year's competition. All the teams improved on the times from last year and competition was very competitive this year, so congrats to all the teams that participated.

FWPCOA Reboot, New Website on the Way

The FWPCOA is in the process of updating its website, which went live in late April, and Walt Smyser will be giving regional directors and webmasters training at the August board of directors meeting in Ft. Pierce. The new site will provide more access to our training, including registering online, and will support mobile devices. The new site also includes an association management system to provide our members with greater access and functionality to their membership information, which includes, among other things, the ability for them to view and edit their member information in an online database; join and/or renew memberships; and communicate with us by email, social media, telephone, or mail.

One of the other changes is an improved jobs board. This one will require posting of jobs to be done by members. So if your human resources personnel need to post a job, they should sign up for an associate membership ($30 a year). There still will be no fee to post jobs.

If you're a member and we have a valid email address for you, you will get a notification on how to log into the new site when it goes live. However, many members either do not have their email address on file with us, or we are unable to tie your email address to your membership due to name conflicts. Therefore, after the new site is running, if you are a member in good standing and do not receive a notice, please send us an email from the email address you want to tie to your membership, along with your name as it appears in your membership, and your member number, if you have it.

Please note that all nonmembers that have signed up to be on our email list will need to reregister on the new site.

I want to personally thank Walt for all the time and energy that he has exhausted in getting this site up and running, while still maintaining our old site with duct tape and bailing wire until we made the switch. Walt is another example of the people who make this organization so great by volunteering their own time to take on tasks behind the scenes. We often forget that he does have a real job, and so the work he is doing for us is on his own time. I'm sure he has asked himself why he ever agreed to do this, but Walt, we thank you for stepping up.

Online Training

The FWPCOA Online Institute presently has 78 active courses and 256 registered students. For the 2017 license renewal cycle, FWPCOA has sold an average of 29 online courses per month, which is greater than the monthly average of 24 courses sold during the 2015 cycle.

Please continue to advise your members of the availability of the Online Institute in your newsletters and at your membership meetings. We have completed the first 12 months of the 2017 license renewal cycle, so continue to encourage operators to start earning CEUs for the new cycle.