Sewer Collection System Bioaugmentation Reduces Energy Use in Wastewater Treatment Plants

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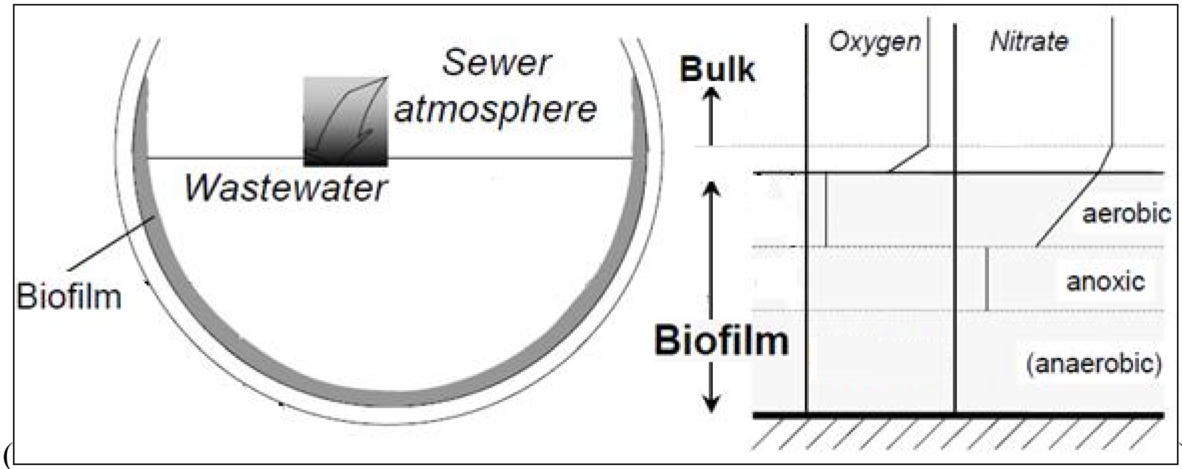
ABSTRACT

Reducing energy consumption at wastewater treatment plants (WWTPs) is critical since the energy cost in wastewater treatment processes places a financial burden on the local government. The New York State Energy Research Development Authority (NYSERDA) is mandated to fund the development and facilitate the use of innovative technologies to address energy challenges and the related environmental problems in the State. As a part of the energy management program, the effectiveness of In-Pipe Technology (IPT) patented sewer collection system bioaugmentation on energy usage in a WWTP was verified at a sequencing batch reactor (SBR) WWTP (Sewer District #20) in Suffolk County, Long Island, New York. This project was performed in collaboration with the Suffolk County Department of Public Works. IPT sewer collection system bioaugmentation aims to increase the beneficial bacterial density and the resulting enzymes production in order to increase the oxidation rates of organic materials in the sewer without requiring additional energy and without increasing the biosolids inventories within the wastewater treatment system. Results showed that, the influent loads, i.e., biochemical oxygen demand (BOD_5), total suspended solids (TSS), and total Kjeldahl nitrogen (TKN), to the WWTP decreased by ~13%, ~13%, and ~5%, respectively, With-IPT bioaugmentation treatment compared to Pre-IPT treatment. The WWTP operating costs associated with aeration energy were reduced ~19% due to the reduction of influent loads to the WWTP. In addition, the WWTP produced less sludge (~10%) and effluent water quality was improved with a reduction of BOD5 (~17%), TSS (~30%) and TKN (~13%) loads With-IPT bioaugmentation treatment compared to Pre-IPT treatment.

Introduction

The wastewater treatment system consists of the sewer collection system and wastewater treatment plant (WWTP), which prevents direct release of municipal and industrial wastewater into surface waters and protects water quality. The sewer collection system refers to networks of pipes, pumping stations, and all other facilities that collect and transport municipal and industrial wastewater only or in combination with infiltration/inflow and stormwater from point sources to the entry of a WWTP. Wastewater may be conveyed through the sewer collection system to the WWTP by gravity flow, by pumping through a pipeline, or by vacuum. Historically, hydraulics and wastewater transport phenomena have been the main consideration in designing and managing sewer collection systems, since it is considered mainly as a wastewater conveying system and seldom considered as a chemical and biological reactor (Gudjonsson et al., 2002; Qteishat et al., 2011). However, several studies have shown that microbial transformation of organics and nutrients does take place in the bulk wastewater and biofilm phase during transportation of wastewater into the sewer collection system

(

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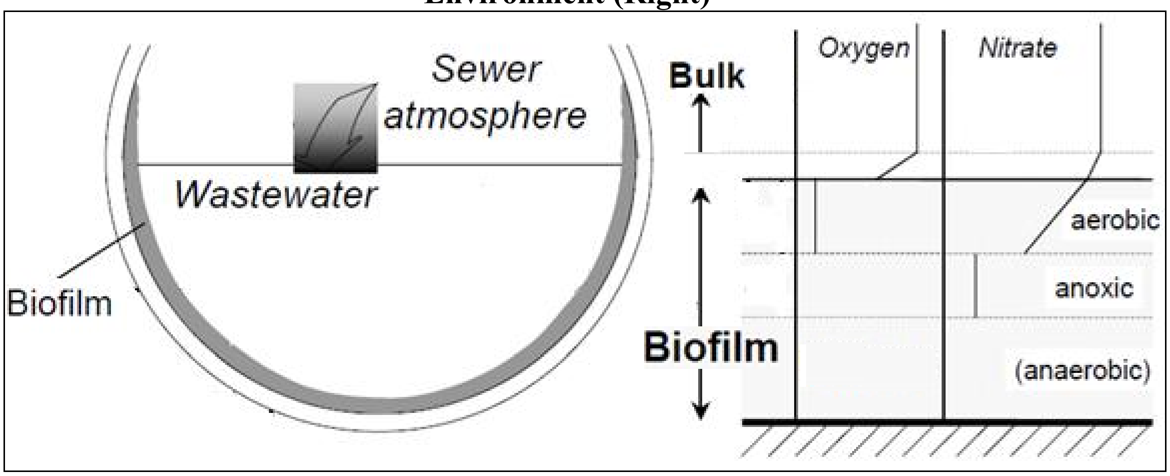
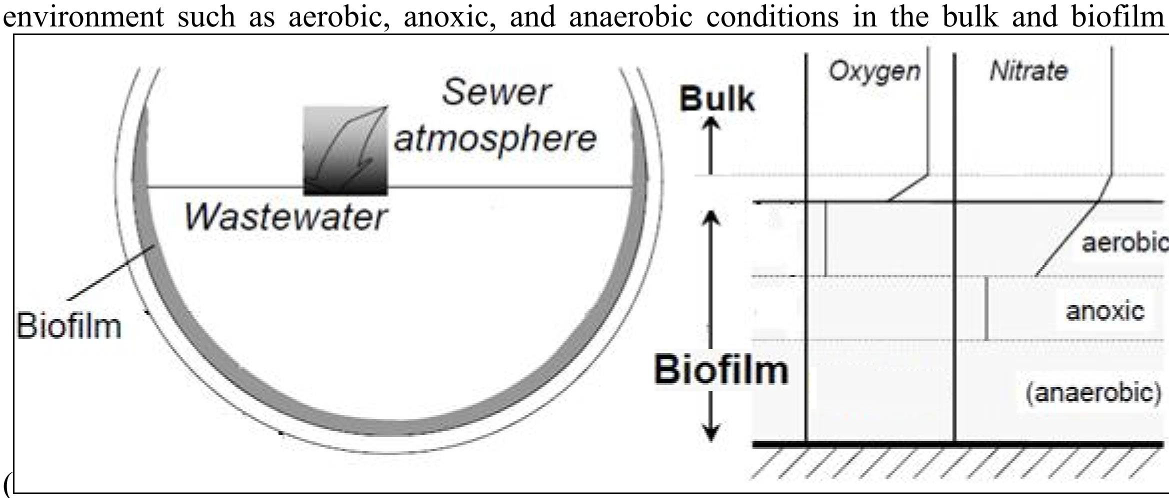
(Abdul-Talib et al., 2002; Huisman et al., 2003; Tanaka and Hvitved-Jacobsen, 1998).

Figure 1. Cross-Sectional View of a Sewer Pipe (Left) and Sewer Bulk Phase Environment (Right)



Source: Huisman et al., 2003

In wastewater collection systems the microbiological transformation of wastewater organics and nutrients mainly relies on indigenous wastewater bacteria and the sewer environment such as aerobic, anoxic, and anaerobic conditions in the bulk and biofilm phase (

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Aerobic respiration or oxidative metabolism of soluble organic compounds leads to the reduction of the organic load entering to the WWTP through the formation of carbon dioxide (CO_2) and water (H_2O) (Lehninger, 1971; Metcalf and Eddy, 2003). Aerobic respiration or oxidative metabolism can be explained by Equation 1 using glucose ($C_6H_{12}O_6$) as a model substance.

$$\text{Cells (Heterotrophs)} + C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{Cells} \qquad \text{Equation 1}$$

Anoxic respiration or nitrate (NO_3^-)/nitrite (NO_2^-) metabolism of soluble organic compounds leads to the reduction of organic and nutrient load entering to the WWTP through the formation of carbon dioxide (CO_2), water (H_2O), and nitrogen gas (N_2) (Metcalf and Eddy, 2003). Anoxic respiration or nitrate (NO_3^-) /nitrite (NO_2^-) metabolism can be explained by Equation **2** using glucose ($C_6H_{12}O_6$) as a model substance.

$$\text{Cells (Heterotrophs)} + C_6H_{12}O_6 + NO_3^- \rightarrow CO_2 + H_2O + N_2 + \text{Cells} \qquad \text{Equation 2}$$

Anaerobic respiration (e.g., Sulfate (SO_4^{-2})) of soluble organic compounds leads to the reduction of organics load entering to the WWTP through the formation of odorous hydrogen sulfide (H_2S) and water (H_2O). Anaerobic respiration can be explained by Equation 3 using acetate ($CH3COO^-$) as a model substance (Bethke et al., 2008).

$$\text{Cells (Heterotrophs)} + CH_3COO^- + H^+ + SO_4^{-2} \rightarrow 2CO_2 + H_2S + H_2O + \text{Cells} \qquad \text{Equation 3}$$

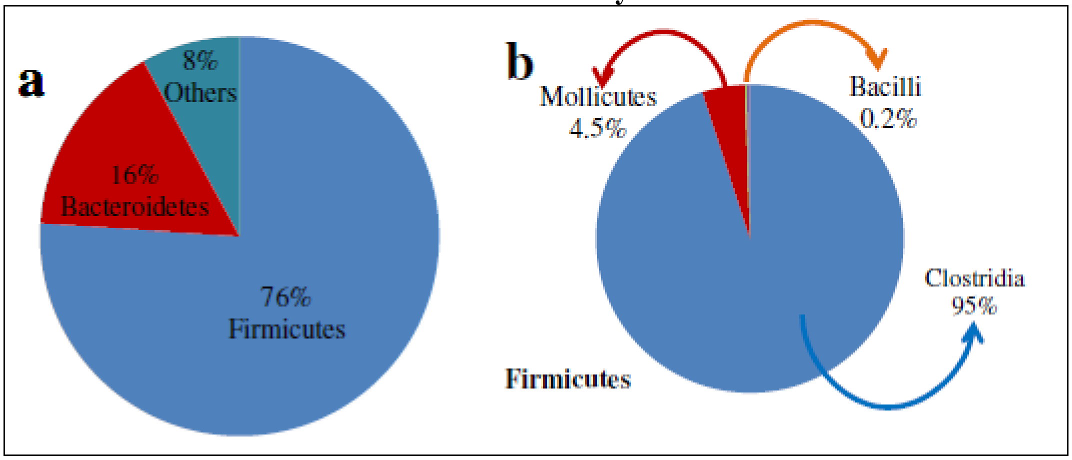
Fermentative oxidative metabolism is the oxidation of organic compounds using an endogenous electron acceptor which is usually an organic leading to the reduction of the organic load entering the WWTP through the formation of carbon dioxide (CO_2) and alcohol (C_2H_5OH). Fermentative oxidative metabolism can be explained by Equation **4** using glucose ($C_6H_{12}O_6$) as a model substance.

$$\text{Cells (heterotrophs)} + C_6H_{12}O_6 \rightarrow CO_2 + C_2H_5OH + \text{Cells} \qquad \text{Equation 4}$$

Additionally, microorganisms hydrolyze the particulate organics or slowly biodegradable organics through secretion of enzymes (Abdul-Talib et al., 2002; Vollertsen and Hvitved-Jacobsen, 1998). The microbial hydrolysis process can enhance the readily biodegradable organics fraction in the wastewater entering to the WWTP, which can further enhance biological nitrogen (N) and phosphorus (P) removal process efficiency in the WWTP (Nielsen et al., 1992).

Fecal wastes are the main sources of heterotrophic bacteria in wastewater flowing through the sewer collection system along with insignificant contribution from inflow/infiltration. Approximately 99.9% of fecal bacteria are strict anaerobes (Gossling and Slack, 1974) and are highly vulnerable to the changes in wastewater characteristics and environmental conditions such as temperature, pH, chemistry, etc. Most of the bacteria in fecal wastes are members of the *Firmicutes* and *Bacteroidetes* phyla (Figure 2a). The *Firmicutes* sequences mostly consist of the sulfate reducing *Clostridia* class (Figure 2b) which lacks the capability for aerobic respiration and are an obligate anaerobe with no tolerance for free oxygen (Eckburg et al., 2005).

Figure 2. a) Bacterial Phyla Present in Fecal Material, and b) Presence of Clostridia Class in Firmicutes Phylum



Source: Eckburg et al., 2005

Although little has been done so far on the analysis of the microbial community sewer biofilm (Santo Domingo et al., 2011; Cayford et al., 2010), significant aerobic oxidation of organics will depend on i) the presence of dissolve oxygen (DO) ii) availability of the readily biodegradable organics, iii) establishment of the aerobic/facultative bacterial community. Influent load reduction through anoxic respiration is insignificant in sewer collection systems since nitrate (NO_3^-) or nitrite (NO_2^-) normally are not present in municipal wastewater, however, it may be present in certain wastewater loads from food and industrial branches (Gallert and Winter, 2005). The nitrogen containing compounds present in municipal wastewater are usually ammonia and organic nitrogen (urea, amines, amino acids, and proteins). Among these compounds, ammonia is the major nitrogen compound derived from urine through enzymatic reaction of urea by ureases (Gallert and Winter, 2005). For anoxic respiration to occur in wastewater treatment processes, ammonia must be nitrified. Ammonia nitrification is an aerobic process and is defined as the oxidation of ammonia to nitrite or nitrate. Historically, autotrophic nitrifiers, the *Nitrosomonas,* which oxidize ammonium (NH_4^+) to nitrite (NO_2^-) (Equation **5**) and the *Nitrobacter* which oxidize nitrite (NO_2^-) to nitrate (NO_3^-) (Equation 6) are considered as major nitrifying bacteria (Metcalf and Eddy, 2003), however, nitrification in the sewer collection system is thought to be questionable due to the insignificant population of nitrifying bacteria in the wastewater.

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H_2O \qquad \text{Equation 5}$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad \text{Equation 6}$$

Influent organic load reduction through anaerobic respiration could be possible in the presence of readily biodegradable organics due to the significant presence of anaerobic bacteria. However, anaerobic respiration is a slow process and significant reduction in the influent load is not obvious. Furthermore, anaerobic respiration using sulfate as the electron acceptor produces undesirable odorous/toxic byproduct hydrogen sulfide gas (Tanaka et al., 2002; Ǽsǿy et al., 1997). Similarly, fermentation is a slow process and significant influent load reduction may not be attainable.

The addition of a beneficial bacterial culture to the sewer collection system aims to increase the beneficial bacterial density and their enzymes in order to increase the oxidation rate of organic material in the sewer system thereby reducing energy consumption at the WWTP and saving money. Considering the beneficial bacteria enhancement approach, In-Pipe Technology (IPT) employs a sewer collection system bioaugmentation process that consists of automatic continual addition (24/7) of high concentrations of naturally-occurring, non-pathogenic, facultative *Bacillus* soil bacteria formulation at multiple points (i.e., manholes, lift stations) within the collection system. IPT bacteria grow throughout the surface of the sewer pipes, enhance the sewer biochemical processes, and reduce influent loads through accelerated aerobic, anoxic, and fermentation metabolisms in the sewer system. Anoxic respiration by IPT bacteria is speculated to occur in the collection system based on the published experimental demonstration of heterotrophic ammonia nitrification (Kim et al., 2005; Kuenen et al., 1994; van Niel et al., 1993; Robertson et al., 1988; Yan et al., 2006; Yang et al., 2011). Although often ignored, it is demonstrated in the literature that, heterotrophic nitrification by *Bacillus* species can significantly convert ammonia to nitrate/nitrite at a high COD/N ratio (Kim et al., 2005; Yang et al., 2011). However, heterotrophic nitrification mechanisms are still hypothetical and rates are slower than autotrophic nitrification (Robertson et al., 1988; Kuenen et al., 1994).

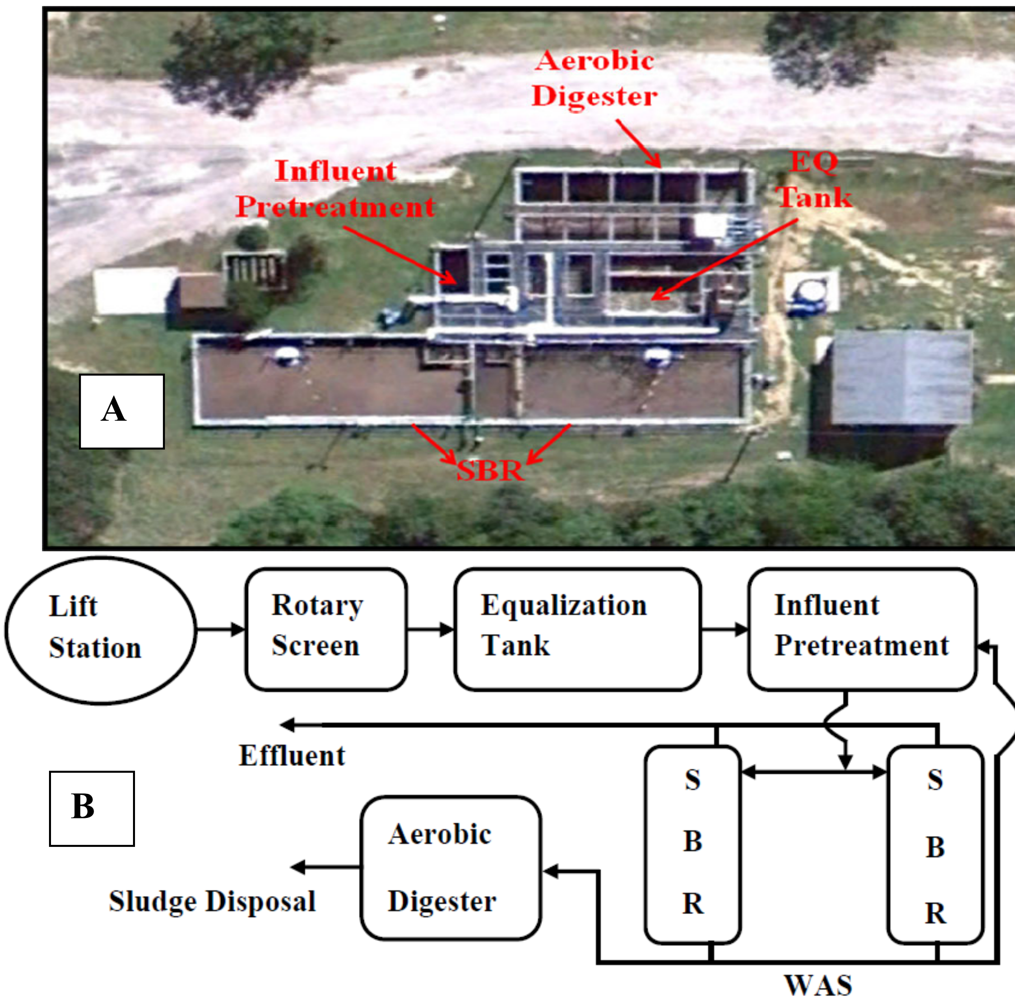
A research demonstration study in collaboration with New York State Energy Research Development Authority (NYSERDA) was carried out at a 0.3 MGD capacity WWTP in Suffolk County (Sewer District #20), Long Island, New York (NYSERDA, 2012). The goal of this study was to demonstrate the effectiveness of IPT sewer collection system engineered bioaugmentation treatment on i) the influent wastewater load to WWTP, ii) WWTP efficiency (e.g., reduction in energy use, reduction in sludge production, etc.), and iii) final effluent quality, through the enhancement of wastewater microbial activity in the sewer collection system and in the WWTP.

In-Pipe Technology Demonstration

Sewer District #20 WWTP

The WWTP is permitted for 0.3 MGD and consists of rotary screen, aerated equalization tank, sequencing batch reactor (SBR), and aerobic digestion. The aerial view of the WWTP is shown in Figure 3A. The simplified process flow diagram is shown in Figure 3B. The effluent nitrogen limit was a daily average of less than 10 mg/l. Due to the way the treatment plant was constructed with a side water depth of 10 feet rather than the more acceptable design of 12 feet, it was historically difficult to maintain 3,000 mg/L of mixed liquor suspended solids (MLSS) for effective nitrogen removal in cold weather. A new mechanical and control equipment upgrade was planned to overcome operational problems before IPT application.

Figure 3. (A) Aerial overview, and (B) Simplified Process Flow Diagram of the Sewer District #20 WWTP (WAS Stands for Waste Activated Sludge).

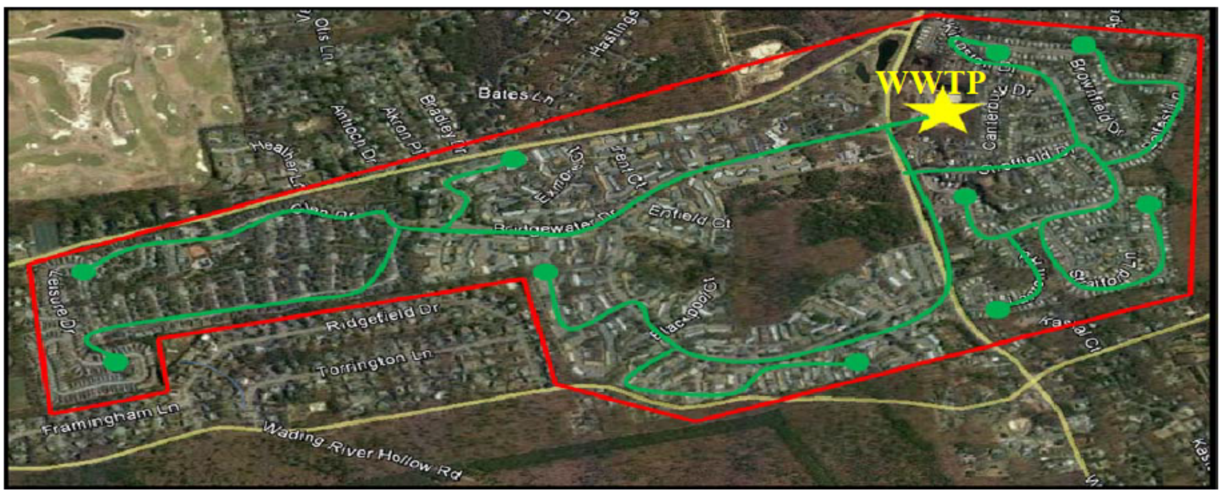


Collection System and In-Pipe Technology Treatment Strategy

The wastewater collection system is comprised of gravity sewers that feed a pump station before wastewater is pumped into the WWTP. The In-Pipe treatment strategy included the installation of ten automatic G2 dosing units at engineered locations under manholes at the farthest reaches of the sewer network (

Figure 4). Each G2 unit dispensed high concentrations (~10^{13} CFU/ml) of a naturally-occurring, non-pathogenic IPT *Bacillus* microbial solution approximately 0.1 milliliters at each location every five minutes. This provides 288 distinct microbe additions per day at each of the locations. This dosing strategy added a total of about ten liters of solution throughout the month, into the monthly wastewater volume of about 7.5 million gallons.

Figure 4. The Sewer Collection System Map (Red Boundary) Indicating the IPT Microbial Dosing Locations (Green Dots), the Microbe Flow Path (Green Lines), and WWTP (Yellow Star)



Data Analysis

The influent wastewater flow rate was measured daily and influent composite samples were collected weekly for BOD_5, TSS, and TKN analysis. Electrical usages at the WWTP EQ tank and SBR unit were recorded for a specific study period (Jan-Sep, 2008). Monthly sludge production from the WWTP was recorded based on the monthly sludge disposal. All sample analysis and data recording was carried out by Suffolk County Department of Public Works (SCDPW) WWTP staff and data provided to IPT.

Evaluation Process

IPT received 12 months of Pre-IPT (Jan-Dec 2006) data which was used to establish a baseline to evaluate the effectiveness of IPT sewer collection bioaugmentation treatment for 18 months (With-IPT, Jan 2007 to Jun 2008) period. IPT also received 6 moths of Post-IPT (Jul-

Dec 2008) influent BOD_5, TSS, and TKN data to evaluate the impact of reversion from IPT bioaugmentation technology on the influent wastewater loads.

Results and Discussions

Influent Flow Rate

The daily average influent flow rate to the sewer district #20 WWTP during the baseline period (Pre-IPT, Jan-Dec 2006) was 0.251 MGD. The daily average influent flow rate during IPT treatment period (With-IPT, Jan 2007-Jun 2008) was 0.249 MGD. The daily average influent flow rate after IPT treatment period (Post-IPT, Jul 2008-Dec 2008) was 0.260 MGD. The daily average influent flow rate to Sewer District #20 WWTP was essentially constant before, during and after IPT treatment. Consequently, differences in organic load received at the WWTP are not due to a significant difference in flow rate.

Influent Load

The overall performance analysis (18 month With-IPT vs. 12 months Pre-IPT) showed that influent BOD_5, TSS and TKN loads With-IPT treatment decreased by ~13% from 454 lbs/day to 397 lbs/day, ~13% from 485 lbs/day to 424 lbs/day and ~5% from 116 lbs/day to 110 lbs/day, respectively, compared to Pre-IPT treatment (**Table 1**). After reversion from IPT bioaugmentation (6 months Post-IPT vs. 18 months With-IPT), the BOD_5, TSS, and TKN load increased by ~10%, 20%, and 8%, respectively (**Table 1**).

Table 1. Pre-, With-, and Post-IPT influent BOD_5, TSS and TKN Load to WWTP.

Period	Seasonal Performance Analysis (lbs/day)		
	BOD_5	**TSS**	**TKN**
Pre-IPT (Jul-Dec 2006)	454	485	116
With-IPT (Jul-Dec 2007)	397	424	110
Post-IPT (Jul - Dec 2008)	435	510	119
% Change With-IPT vs. pre-IPT	**-13%**	**-13%**	**-5%**
% Change Post-IPT vs. With-IPT	**10%**	**20%**	**8%**

The establishment of a high density IPT beneficial microbial community in the sewer biofilm and in the bulk wastewater enhanced sewer biochemical processes and reduced the influent load to the WWTP. The post-IPT increase in influent load further reveals that when the IPT dosing program was suspended, the sewer microbiology was not as efficient in processing the influent complex wastewater organics whereas the IPT *Bacillus* bacterial formulation was more effective in degrading the complex wastewater organics (e.g., reducing influent BOD_5 load). The influent BOD_5 load reduction is due to enhanced oxidation of complex mixed organics (i.e., combination of municipal waste and industrial waste) under aerobic, anoxic, and anaerobic conditions. Since only TKN data were available for comparison for the influent nitrogen load, we do not know the extent of denitrification in this system, though it is expected that much of the nitrate produced would have been denitrified in the sewer environment. We hypothesize that under a high C/N ratio, heterotrophic nitrification along with the presence of nitrate/nitrite may facilitate anoxic respiration. The reduction in influent TSS load could be due to the growth characteristics and metabolism of IPT bacteria (e.g., a higher growth rate through the expense of high maintenance energy), hydrolysis and solubilization of less biodegradable and slowly hydrolysable organics to readily biodegradable organics through enzyme production, cannibalism, and bacteriocin production.

Electrical Energy Usage Reduction

The electrical usage data was collected for the period of With-IPT operation (Jan-Jun 2008) and Post-IPT (Jul-Sep 2008) operation.

Based on the suggestions provided by the engineering consultant, Malcolm Pirnie (The water division of ARCADIS), employed by NYSERDA to evaluate IPT performance, the performance analysis was carried out using electricity data from April 15 to Sep 15 of 2008 (With-IPT, April 15-Jun 30, 2008; Post-IPT, Jul 1-Sep 15, 2008) to minimize the seasonal (e.g., temperature) impact. The daily average kWh use in the SBR unit was 307 kWh/day during IPT treatment (April 15-Jun 30, 2008) and 377 kWh/day Post-IPT (Jul 1-Sep 15, 2008) treatment after reversion from IPT treatment (

Figure **5**A). The kWh use increased approximately 23% during the Post-IPT operation. The daily average kWh use in the EQ tank was 230 kWh/day With-IPT treatment and 262 kWh/day Post-IPT after reversion from the IPT treatment (

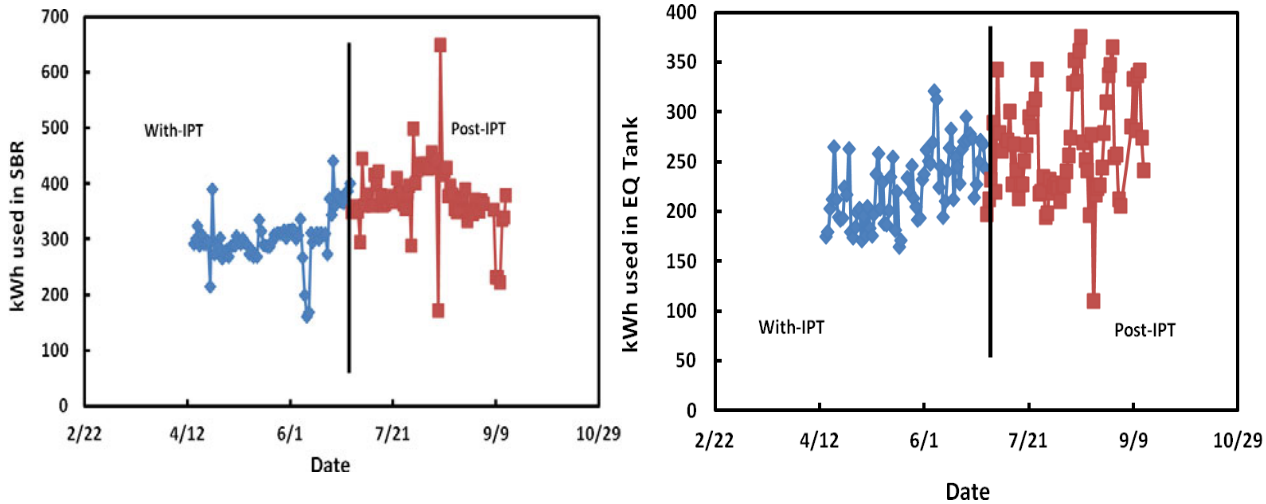
Figure **5**B). The kWh use increased approximately 14% during the Post-IPT operation. Metering from these units showed that electricity usage was reduced from 14% to 23% with an average of 19% with the application of IPT sewer collection system bioaugmentation treatment. The total kWh/day saved in both SBR and EQ tank unit with IPT treatment was 102 kWh/day. This is projected to save (102kWh/day x 365 day/yr*0.12$/kWh) $4467 annually in kWh usage.

A theoretical calculation was carried out using the influent and effluent BOD5 and TKN load (Table 2) during the electricity usage metering period. Actual oxygen required (AOR) was calculated using

$$AOR = [(BODin-BODout) + 4.6 * (TKNin-TKNout)]/24 \quad \text{Equation 7}$$

(Eckenfelder et al., 2003):

Figure 5. The Daily Kwh Use in (A) SBR and (B) EQ Tank Process Unit With-IPT and Post-IPT Treatment.



AOR = [(BODin-BODout) + 4.6 * (TKNin-TKNout)]/24 Equation 7
AOR (With-IPT) = 36.3 lbs/hr
AOR (Post-IPT) = 40.7 lbs/hr

Table 2. With-, and Post-IPT influent BOD_5, and TKN Load to WWTP

Electricity usage analysis period	(lbs/day)			
	Influent		Effluent	
	BOD_5	TKN	BOD_5	TKN
With-IPT (Apr 15-Jun 30, 2008)	393	114	27.8	4.1
Post-IPT (Apr 15-Jun 30, 2008)	456	125	30.9	5.2

The theoretical AOR demand increased by ~12% to oxidize the additional BOD_5 and TKN loads during the reversion from IPT treatment period. Actual meter data showed an increase of 14% to 23% electricity use after reversion from IPT treatment. The differences between actual and theoretical electrical energy usages could be due to changes in the solids inventory within the plant through return activated sludge (RAS) pumping but was never identified.

Sludge Production

As a result of the significant presence of the IPT bacterial community and their activity in the biological treatment processes, dry pounds of sludge production decreased by ~10% from 282 lbs/day (Pre-IPT treatment) to 255 lbs/day (With-IPT treatment). An energy and environmental impact analysis was carried out by using 27 lbs/day of sludge production reduction. The wet sludge (2.5% solid) was hauled from WWTP to the Bergen Point WWTP for dewatering which is a 70 mile round trip. Based on the solid content of the wet sludge, the amount of wet sludge hauled before IPT was (282×100/2.5) 11,280 wet lbs of sludge/day and amount of wet sludge hauled with IPT was (255×100/2.5) 10,200 wet lbs of sludge/day. Approximately 1080 wet lbs of sludge/day sludge hauling was saved with IPT treatment. Wet sludge contains 97.5% water. Considering sludge density of 8.34 lbs/gallon, the hauling of wet sludge volume saved (1,080 wet lbs saved per day/8.34) was 129.4964 gallons/day which is equivalent to (129.4964 gallons/day x 365 days/yr) 47,266 gallons/yr. A reduction in 27 pounds/day or 47,266 gallons/yr wet sludge hauling saved 10 truck trips/yr (5,000 gallons/truck trip) which saved approximately 700 miles of transportation and 9.1 Million BTU/yr (129,500 BTU energy equivalent per gallon and 10 MPG energy consumption efficiency) in Diesel #2 fuel consumption (USEPA, 2002), and saved 1,554 lbs CO_2/yr green house gas generation (22.2 lbs CO_2 emitted/gallon Diesel #2 burned) (USEPA, 2011).

Conclusions

In-Pipe's sewer collection system green bioaugmentation treatment technology significantly enhances sewer biochemical processes. Consequently, the WWTP receives reduced BOD_5, TSS and TKN load with In-Pipe's collection system bioaugmentation treatment technology. Due to the lower influent load, the WWTP, plant is able to significantly reduce its aeration energy cost. Additionally, the WWTP receives beneficial bacteria well acclimated to the wastewater, which improves WWTP operational efficiencies such as lower sludge production, and improved effluent quality. In-Pipe's demonstration showed that sewer collection system bioaugmentation can be used an active part of the overall wastewater treatment process.

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