TREATMENT OF MEAT-PROCESSING WASTEWATER WITH A FULL-SCALE, LOW-COST SAND/GRAVEL BIOREACTOR SYSTEM

K. M. Mancl, R. Kopp, O. H. Tuovinen

ABSTRACT. *A full-scale sand/gravel bioreactor system was constructed to treat turkey processing wastewater. The system was designed to treat 757,000 L day^{-1} at a surface application rate of 6 cm day^{-1}. Twelve 25 × 55 m sand bioreactors cover 1.6 ha on the plant property site. Construction cost was $1,426,000 (2011-2012) and operating costs were $57,600 per year. Normalized to volume of wastewater treatment, the estimated (2013) capital and operation cost is $1.03 m^{-3}. The plant began discharging effluent in 2013. Throughout 30 months, the plant has met all effluent requirements for CBOD$_5$, TSS, and fat, oil, and grease (FOG). FOG was always below the detection level of 5 mg L^{-1} in the treated effluent. Ammonia is removed by the sand/gravel bioreactors through the summer months. During the winter/spring months, supplemental ammonia removal with an ion-exchange system is used to meet effluent standards. The low cost of the sand bioreactor system makes it suitable for small-scale meat processors.*

Keywords. *Ammonia removal, FOG (fat, oil and grease), Sand filtration, Turkey processing, Ion-exchange.*

In 2000 a small, family-owned turkey processing plant was facing closure. The permitted lagoon system that had treated the plant wastewater for decades created odors and threatened the groundwater. The company was looking for a way to treat the high-strength, high-fat content wastewater in an affordable way. Pretreating the wastewater and constructing a sewer extension to the municipal treatment plant in the neighboring city of Harrison, Ohio, was deemed cost prohibitive. The third-generation meat processor was also concerned about the continuing employment of his 110 employees. Sand filtration was considered a possible alternative treatment system for the wastewater. Sand filtration represents a biofilm based technology for wastewater treatment. When properly designed, it offers low cost, low maintenance, and relatively high efficiency of treatment. Biofilm processes accumulate active microbial biomass on sand particles and active biofilms have resistance to overloading, toxic compounds, and other adverse operating conditions (Iwai and Kitao, 1994; Stewart, 2015; Leff et al., 2016). The performance of sand filters is influenced by numerous factors, which include bioaugmentation, media depth, grain size distribution, mineral composition of media, pretreatment, wastewater composition and nutrient concentration, hydraulic and organic loading rates, temperature, and dosing techniques (Crites and Tchobanoglous, 1998; Widrig et al., 1996). Sand filtration has multiple variables and traditionally sand filters have been designed based on hydraulic loading.

Sanitary wastewater has been treated by sand filters in the United States for over 100 years. In the late 1800s and early 1900s, sand filters were used to treat wastewater from 26 small communities in Massachusetts operating for 22 to 47 years (Mancl and Peeples, 1991). Sand filtration provides for nitrification with adjusted hydraulic and organic loadings (Widrig et al., 1996). It has been used for meat processing wastewater as an advanced or tertiary treatment (Witherow, 1976; US EPA, 1978). Sand filtration of lagoon-treated packinghouse wastewater experiments (Rowe, 1976) showed that the average BOD$_5$ and suspended solids in the effluent were reduced from average concentrations of 37 to 8 mg L^{-1} and 65 to 12 mg L^{-1}, respectively. While leading to considerable improvement in effluent quality, the data indicated incomplete removal, which may not be compatible with current NPDES requirements. In general, various treatment processes for slaughterhouse wastewater have been appraised in several reviews but sand filtration is not usually discussed as an option (Johns, 1995; Salminen and Rintala, 2002; Mittal, 2006; Bustillo-Lecompte and Mehryar, 2015; Harris and McCabe, 2015).

As a secondary biological treatment system, sand filtration has been tested for industrial wastewater. Xi et al. (2005) treated cheese-processing effluent with gravel/sand filtration with daily dosing of 42,000 and 84,000 mg COD m^{-2} day^{-1} and at initial pH 7.0 and 12.7. In laboratory experiments the performance reached >99% BOD$_5$ and 85% COD removal in all filters until the termination of sand filter run at 210 days. Organic loading had a small impact with increased COD loading rate, the COD removal slightly decreased.

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The authors are **Karen M. Mancl,** Professor, Department Food, Agricultural and Biological Engineering, The Ohio State University, Columbus, Ohio; **Ryan Kopp,** Owner, Whitewater Processing Company, Harrison, Ohio; **Olli H. Tuovinen,** Professor, Department of Microbiology, The Ohio State University, Columbus, Ohio. **Corresponding author:** Karen Mancl, 590 Woody Hayes Dr., Columbus, OH 43210; phone: 614-292-4505; e-mail: mancl.1@osu.edu.

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Liu et al. (1999) worked with multilayer sand bioreactors for dairy wastewater treatment. In the laboratory study, 60 cm deep single-layer bioreactors of sand (effective size 0.95 mm) were compared to 2-layer bioreactors. The 2-layer bioreactors had 30 cm sand layer under a 30 cm coarse sand layer (effective size 2.40 mm). Two-layer sand filters performed better in BOD_5 and COD removal as compared to single-layer filters. A 2-layer filter removed 85% of the total BOD_5 compared to 76% for a single-layer. They also tested adding a 30 cm deep third-layer of pea gravel on top of the 2-layer filter. The BOD_5 removal was 79% for the 3-layer bioreactor, and greatly prolonged filter operation before clogging (Liu et al., 2003). Filter clogging has been recognized as a major problem causing failure in sand filter systems, but this can be avoided or greatly reduced with intermittent loading by adjusting the dosing frequency and hydraulic loading rate to be compatible with the system capacity (Rogers et al., 2004, 2005; Leverenz et al., 2009).

Kang et al. (2007) demonstrated the concept of sand filtration treatment with turkey processing wastewater and determined the media criteria and application rates in a bench-scale system. Excellent performance was achieved with over 94% of TOC and 98% of BOD_5 removal. Sand filtration removed 340 mg TOC day^{-1} and 1,100 mg BOD_5 day^{-1} at hydraulic loading rates below 132 L m^{-2} day^{-1}. Subsequent work was undertaken to construct and test a pilot-scale sand filtration system at the turkey processing plant. With successful results from the pilot-scale, the decision was made to develop a full-scale treatment system for the plant. The purpose of this article is to describe the design, construction, operation and maintenance of the full-scale sand bioreactor treatment system that was used to treat turkey-processing wastewater. This study is also a case study of (i) the resource needs to construct the full-scale treatment system, (ii) quantifying the construction and operating costs, and (iii) a measure the system operation and performance.

Full-scale Sand/Gravel Bioreactor Treatment System

The system was designed to treat 757,000 L wastewater day^{-1} (200,000 gal day^{-1}) at a surface application rate of 6 cm day^{-1} (1.5 gal ft^{-2} day^{-1}). The system was designed for 50% excess capacity to provide for flexibility in operation and to handle peak flows. A grease trap and a screen were included to provide pretreatment. After the grease trap and screen, the wastewater was periodically tested about every 6 weeks and the BOD_5 ranged from 79 to 1,460 mg L^{-1}. With a typical BOD_5 concentration of 800 mg L^{-1} the organic loading is estimated at 0.016 kg BOD_5 m^{-2} day^{-1} (0.011 lb BOD_5 ft^{-2} day^{-1}). The wastewater is intermittently dosed on to sand/gravel bioreactors to provide secondary treatment. Final treatment is seasonal with ultraviolet light disinfection during summer months (1 May to 31 October) and an ion-exchange system for ammonia removal during winter months, as needed, before stream discharge (fig. 1).

In total, 1.6 ha (4 acre) of land was used to site twelve 25 × 55 m (82 × 180 ft) sand bioreactors as shown in figure 2. The figures have been renumbered. To prepare the site, 81,000 m^3 (106,000 cubic yards) of fill material was moved to raise the area above the flood plain. The bioreactors were constructed with layers of sand and gravel as specified by Kang et al. (2007). The bottom 15 cm layer of washed rock surrounded the drainage pipe topped with 15 cm pea gravel (fig. 3). The treatment system was built up on top of the drainage system in three layers with the bottom 45 cm of fine sand, the middle with 15 cm of coarse sand, and topped with 15 cm of pea gravel. A total of 27,215 metric tons (30,000 tons) of sand and gravel were purchased from a local gravel quarry to construct the bioreactors. The fine sand had an effective size of 0.3 mm and a uniformity coefficient of 4.0. The coarse sand had an effective size of 2.4 mm and a uniformity coefficient of 1.3. The pea gravel had an effective size of 3.8 mm and a uniformity coefficient of 1.7 (ASTM, 2003). The washed rock was 2 to 2.5 cm size fraction.

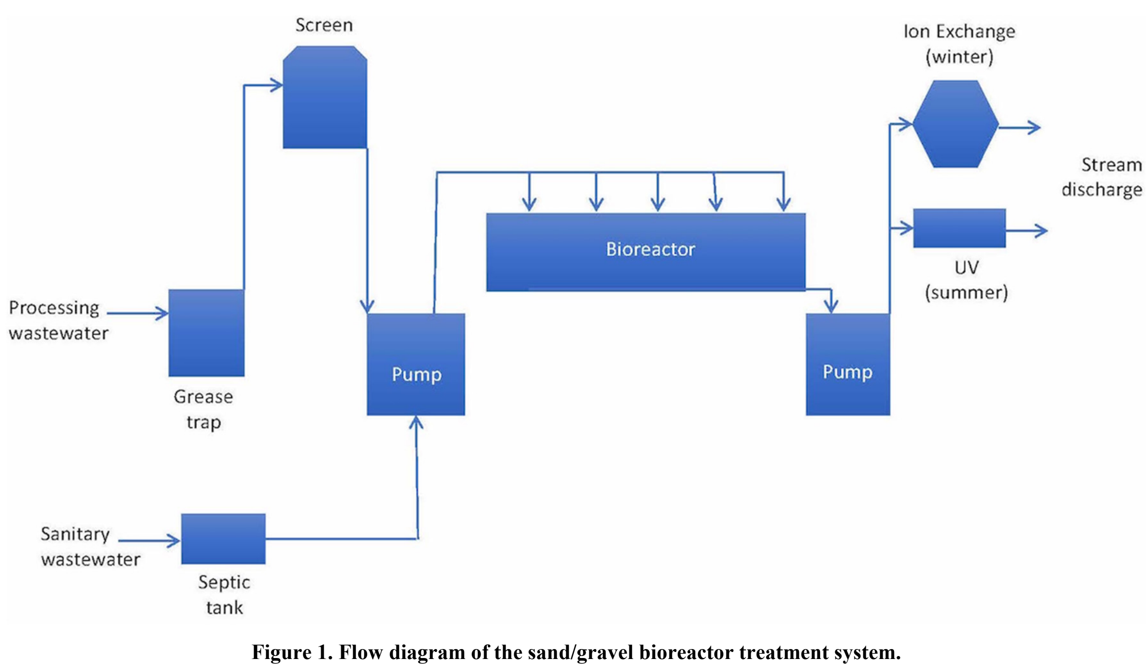

Figure 1. Flow diagram of the sand/gravel bioreactor treatment system.

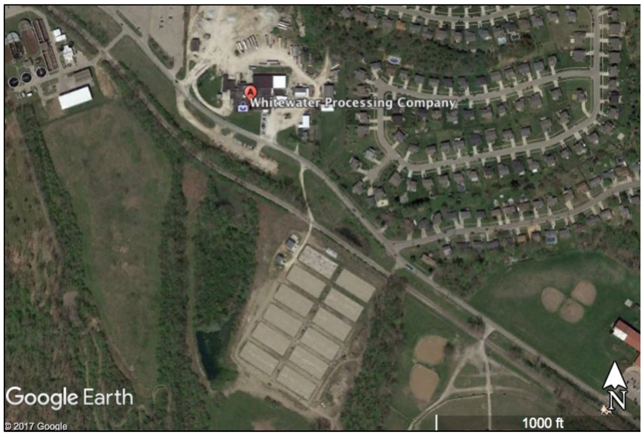

Figure2. Aerial photo of the sand/gravel bioreactor treatment system.

The bioreactors were constructed in 1.2 m (4 ft) deep excavations, lined with 28 × 58.5 m (92 × 192 ft), 30 mil PVC liners each weighing 1,632 kg (3,600 lb). While a 3-person crew constructed the treatment system, the liner placement required hand labor to prevent damage. A team of 20 people from the slaughterhouse production staff helped install each of the 12 liners.

For wastewater distribution and collection, 80,772 m (265,000 ft) of pipe was installed. Slotted pipe placed on the bottom of each bioreactor collects the treated effluent. Pressurized pipe delivers wastewater to each bioreactor for distribution over the top of each. The 2.5 cm (1 in.) diameter distribution pipe had 0.3 cm (1/8 in.) holes every 0.3 m and were installed 0.3 m (1 ft) apart. Distribution is controlled in the bioreactors with 240 motorized ball valves (Bonomi North America, Charlotte, N.C.).

Wastewater from the plant first flows through a small grease trap (3 × 3 × 3.65 m). A small building was constructed next to the processing plant to house a 0.076 cm (0.03 in.) screen. The grease trap and the screen accumulate larger pieces of bone, meat, feathers, and fat that are sold to a renderer. The screen helps to protect the pumps from excess wear. The wastewater is then combined with the sanitary wastewater from the septic tank that serves the plant bathrooms and delivered to the bioreactors with 757 L min^{-1} pumps (HCP 200 gal min^{-1}).

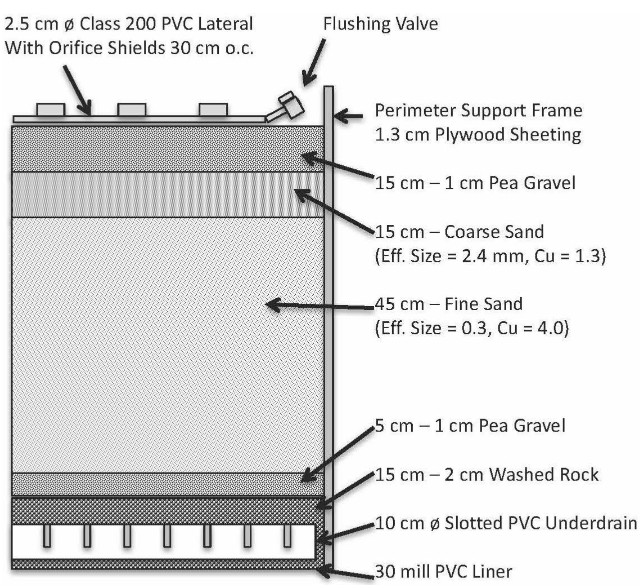

Figure 3. Sand bioreactor cross-section.

A small building was constructed at the treatment site to house the control system for the pumps and valves in the distribution system and the final treatment equipment. An ultraviolet light unit (Megatron UV Water Disinfection, 200 gal min^{-1}, Atlantic Ultraviolet Corporation, Hauppauge, N.Y.) was installed for effluent disinfection during the summer months. To assist in ammonia removal during the winter, a zeolite clinoptilolite ion exchange system (Siemens, Washington, D.C.) was installed. First developed by Koon and Kaufman (1975), the resin exchanges NH_4^+ for Na^+ and is regenerated with salt.

The treatment system was originally designed and constructed with a 681 m^3 (180,000 gal), baffled flow equalization tank. However, the tank soon created problems for the treatment system. The tank contents depleted dissolved oxygen quickly and turned anaerobic, creating odors. The tank also promoted the separation of fat, oil, and grease that the sand bioreactor was designed to treat. After a year, the flow equalization tank was bypassed with a smaller 9.5 m^3 (2500 gal) fiberglass dosing tank. The dosing tank is connected to the existing flow equalization tank and is used to hold any surge flows that might occur. By draining the tanks daily for application onto the bioreactors, anaerobic conditions and odors were eliminated.

Effluent samples were collected weekly and tested at an Ohio EPA certified lab (MASI Environmental Laboratories, Cincinnati, Ohio). The effluent was tested for $CBOD_5$, TSS, FOG, and ammonia-N and all other NPDES requirements.

System Costs

Treatment plants accepting wastewater from industry will often have a surcharge per gallon. In the case of the Harrison, Ohio municipal treatment plant, the first quote in 2000 to Whitewater Processing Company was \$2.79 m^{-3} (\$0.01056 gal^{-1}). Before discharge to a municipal treatment plant, the wastewater must first be pre-treated to reduce the FOG. This would require a dissolved air flotation unit, extended aeration, clarifier, and sludge holding. The cost to construct the pretreatment unit and connect to the city treatment system was estimated at \$1,200,000 with an annual operating cost of \$439,600 including the surcharges. The annualized 20-year capital and operating cost of this conventional option was \$499,600. Since the company was outside the city limits, they would also be required to annex increasing their annual income tax by an estimated 1% per year.

The estimated construction cost for the on-site sand bioreactor system was \$1,169,000. The operation and maintenance was estimated at \$54,000 for a 20-year annualized capital and operational cost of \$112,500. Most of the operating costs are for a full-time operator. The electrical cost estimate was \$700 per month. The only chemical to be used was salt for the ion-exchange system at \$2,000 per year. The company already owned the land for the treatment system. It was the site of the lagoon systems that treated the wastewater for over 30 years since the 1960s. The 8-acre site containing the 4-acre bioreactor system and the required set-backs has an estimated value of \$56,000.

The actual construction and operating costs varied somewhat from the initial estimates. The system cost to construct was \$1,426,000 in 2012 and cost in 2015 was \$57,600 per year to operate. On a cost per m^3 basis, the capital and operation cost is \$1.03 m^{-3} (\$0.00390 gal^{-1}).

The costs of discharging to the Harrison wastewater treatment plant have changed. In 2015, the surcharge has decreased to \$2.69 m^{-3} (\$0.01019 gal^{-1}) to discharge.

Treatment Performance

The average daily flow for the treatment system is 511 m^{-3} day^{-1} (135,000 gal day^{-1}). Higher flows are experienced at the turkey processing plant during November just before Thanksgiving. The slaughterhouse effluent ranges from 567 to 2040 mg L^{-1} $CBOD_5$, 166 to 1540 mg L^{-1} TSS, 42 to 374 mg L^{-1} FOG and 18 to 44 mg L^{-1} ammonia-N. The effluent from the treatment plant discharges to the Whitewater River and has strict effluent limits in the NPDES permit (table 1).

Typical daily bioreactor loading over the 12 filters is 6 cm day^{-1} on 4 filters, the remaining wastewater is evenly distributed on 4 filters and 4 filters are rested with no wastewater applied. Each month, the operator changes the dosing arrangements to rest different filters.

The plant began discharging effluent to the Whitewater River in July of 2013. Throughout 30 months of operation, the plant has met all effluent requirements for $CBOD_5$, TSS and FOG. FOG was always below the detection level of 5 mg L^{-1} in the treated effluent.

Table 1. NPDES effluent limits for Whitewater Processing Company.

Pollutant	7-Day Limit (mg L^{-1})	30-Day Limit (mg L^{-1})
$CBOD_5$	15	10
Total Suspended Solids	18	12
FOG	NA[a]	8
Ammonia-N	1.5 Summer 4.5 Winter	1 Summer 3 Winter

[a] Not applicable

Ammonia levels in the effluent fluctuated throughout the operation and the year. Late spring was always a challenging time just as air temperatures were rising, but the filters were still cold. The ion-exchange system was needed during the high production month of November and 2 to 3 months each year in the late spring to remove excess ammonia to meet effluent limits. With months of operation, the ammonia level has stayed below the effluent limits, indicating that nitrification has been established.

The average monthly effluent concentrations with the corresponding NPDES limits are presented in figures 4-7. With meat processing wastewater FOG is a major concern. Therefore, the removal of variably high FOG was closely examined. Two different laboratories were used to test for FOG. Table 2 shows the influent and effluent FOG for the first 7 months of operation from Q Laboratories (Cincinnati, Ohio), which used a test method (E1664A) with a low detection limit of 2.7 mg L^{-1}. While the influent FOG fluctuated from 42 to 374 mg L^{-1} the effluent had no detectable FOG. After the initial detailed testing, effluent testing was shifted to another state certified laboratory (MASI Environmental

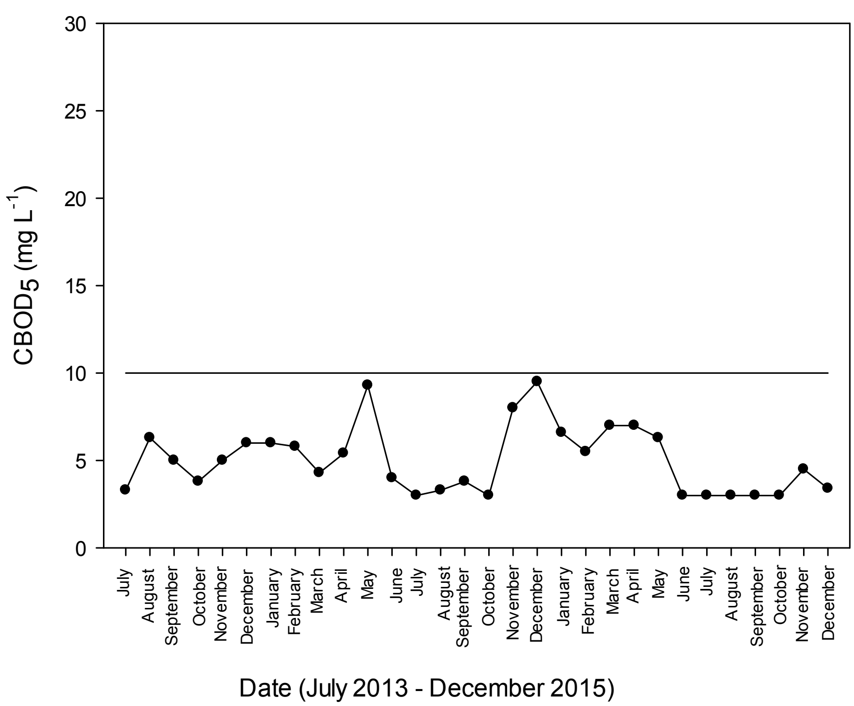

Figure 4. Average monthly system effluent $CBOD_5$ for July 2013-December 2015. NPDES monthly average is 10 mg L^{-1}.

Laboratories) that used a different test method (1664 A/B) for FOG that had a detection level of 5.0 mg L^{-1}. During the entire operation of the treatment system no FOG has ever been detected.

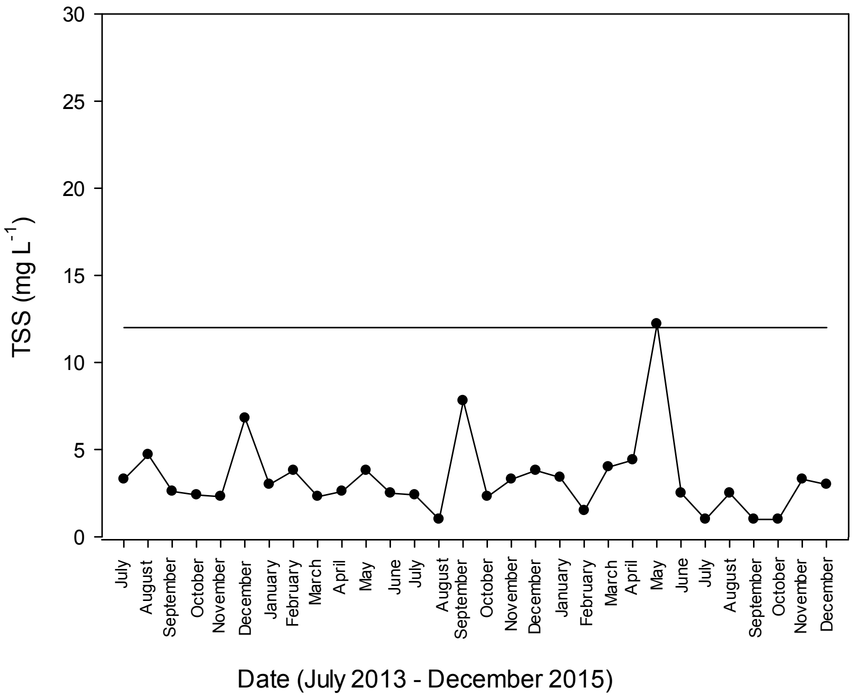

Figure 5. Average monthly system effluent TSS for July 2013-December 2015. NPDES monthly average is 12 mg L^{-1}.

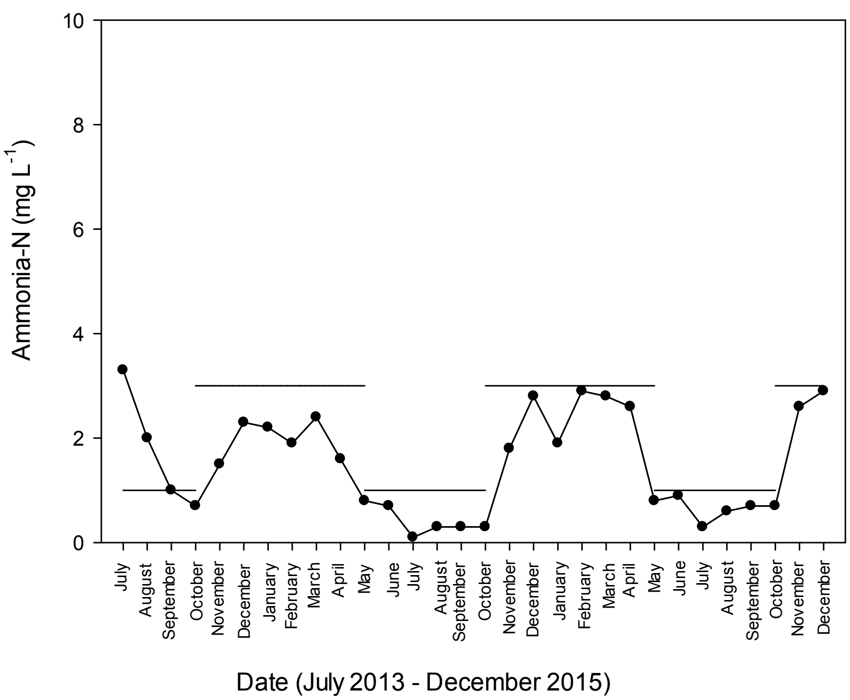

Figure 6. Average monthly system effluent ammonia-N for July 2013-December 2015. NPDES monthly average is 1 mg L^{-1} in summer and 3 mg L^{-1} in winter.

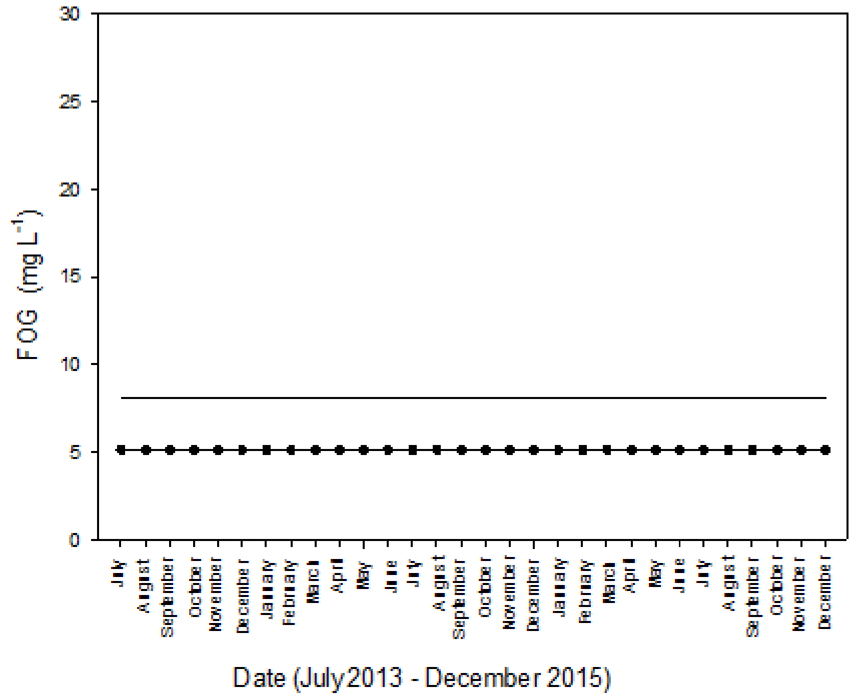

Figure 7. Average monthly system effluent FOG for July 2013-December 2015. NPDES monthly average is 8 mg L^{-1}. Note that 5 mg L^{-1} is the detection limit and all samples are below the detection limit.

Table 2. Influent and effluent FOG for the sand bioreactor treatment system.

Date	Influent FOG (mg L^{-1})	Effluent FOG (mg L^{-1})
6 September 2012	212	<2.7
30 October 2012	139	<2.7
19 November 2012	189	<2.7
19 December. 2012	374	<2.7
9 January 2013	80.8	<2.7
13 February 2013	168	<2.7
27 February 2013	273	<2.7
27 March 2013	42.4	<2.7

CONCLUSION

The construction of a sand bioreactor wastewater treatment system was a sound, economic choice for the small-scale meat processing plant. The treatment system removes FOG, eliminating the need for a dissolved air flotation unit. The system was simple to construct on-site using locally available materials and labor.

A sand bioreactor system is compatible with the high-strength and high-fat content wastewater discharged from a meat processing plant. With the addition of an ion-exchange system for cold weather, the system can meet all effluent limits protecting a high-quality, recreational river.

The relatively low cost of the sand bioreactor treatment system makes it suitable for small-scale meat processors. With treatment costs of \$1.03 m^{-3} (\$3.90 1,000 gal^{-1}) the system offers significant savings over the surcharges of a municipal wastewater treatment plant.

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