Performance of High-Rate Biotrickling Filter Under Ultra-High H_2S Loadings at a Municipal WWTP

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ABSTRACT

A full-scale biotrickling filter (BTF) was installed at the JEA Buckman Water Reclamation Facility in Jacksonville, Florida. The objective was to determine the effect of very low empty bed residence times (EBRTs) (< 3 s) and high hydrogen sulfide loadings (> 300 g H_2S/m^3.hr) on the BTF's performance. The BTF uses structured synthetic EcoBase™ media and it was treating air from the biosolids building.

The inlet and outlet H_2S concentrations were continuously measured and recorded with OdaLogs over a 6 month period. The EBRT for the reactor was controlled using a variable frequency drive on the blower motor and varied between 3 and 10 s. The H_2S concentration in the untreated air varied between 50 and 350 ppmv.

At an average EBRT of 2.8 s, the BTF removed more than 99% of the H_2S at a volumetric loading rate of 247 g/m^3.hr. The H_2S removal efficiency was 95% at a volumetric loading rate of 524 g/m^3.hr at the same EBRT.

The results show that the BTF could effectively remove H_2S under very high volumetric loading rates (> 300 g/m^3.hr) and short residence times (< 3 s). The significance of this finding is that it is possible to size the BTF reactor at 2.8 s residence time (even at high H_2S loadings), which result in a much smaller reactor size and footprint compared to the reactor size required for the higher residence times typically specified for municipal H_2S odor removal applications.

KEYWORDS

Biotrickling filter, hydrogen sulfide removal, biological odor control

INTRODUCTION

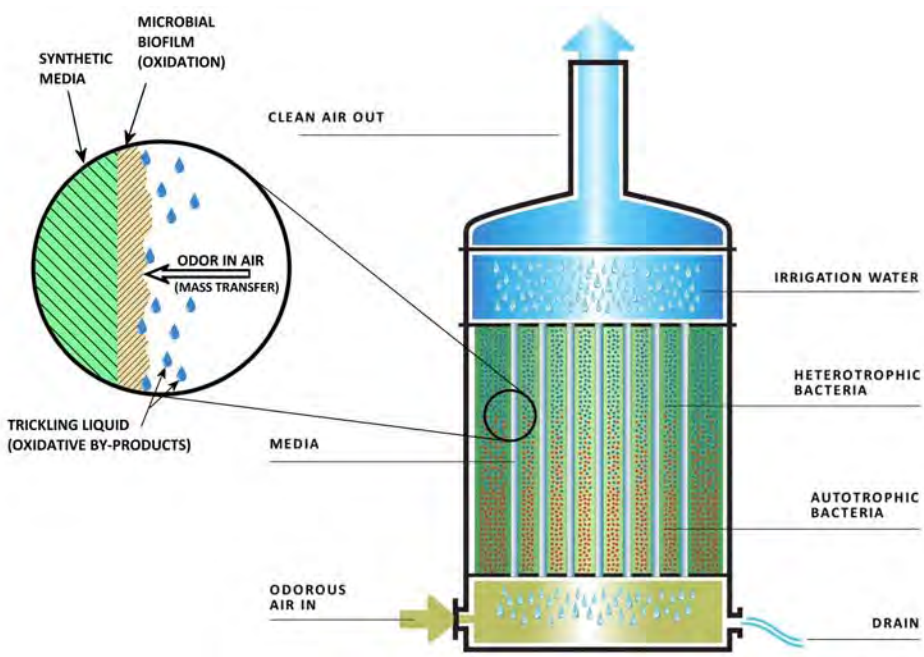
There is increasing public concern and intolerance of odors and other air contaminants from municipal wastewater treatment plants (WWTPs) (Clark, 2004). As such, odor management has become a significant activity for the more than 16,000 municipalities in the United States (US EPA, 1989). Municipal odors typically consists of a complex blend of hydrogen sulfide (H_2S), reduced sulfur compounds (RSCs), amines, and low molecular weight carboxylic acids, all with very low odor thresholds (Gabriel et al., 2003). H_2S is by far the largest contributor to odor nuisances and a key compound targeted by wastewater treatment facilities for removal (Card, 2001).

Until the early 2000's, H_2S-containing odors were removed mostly with wet scrubbing in which H_2S is absorbed in a caustic solution or absorbed and oxidized in a caustic-hypochlorite scrubber. Chemical scrubbing in packed-bed towers is an established technique and is effective at empty bed residence times (EBRTs) between 1.3 and 2 s (Gabriel et al., 2003). However, chemical scrubbing has important drawbacks such as high operating costs, generation of halomethanes that are known air toxics, and the requirement to use hazardous chemicals, which pose serious health and safety concerns (Cox et al., 2002).

During the past decade, biotrickling filters have become increasingly popular for the treatment of municipal odors. Biotrickling filter technology utilizes immobilized microbial cells that are attached to a medium inside the reactor, which then oxidize the odorous constituents to odorless compounds (see Figure 1) (le Roux et al., 2009). The odor contaminants transfer from the gas to the liquid phase and subsequently to the microbial biofilm, or it is transferred directly from the gas to the biofilm, where it is oxidized biologically to odorless compounds. The oxidative by-products are then removed through the trickling effluent (Deshusses, 2005).

Since municipal odors normally consists of both organic and inorganic odors, there are two main groups of bacteria active in biotrickling filters, i.e. autotrophic bacteria that are responsible for oxidation of inorganic odors (mainly H_2S), and heterotrophic bacteria that are responsible for oxidation of organic odors such as methyl mercaptan (MM), dimethyl sulfide (DMS) and dimethyl disulfide (DMDS) (le Roux et al., 2009). Co-treatment of both inorganic and organic odors in a single biotrickling filter reactor therefore requires the existence of a consortium of both autotrophic and heterotrophic microorganisms containing sub-populations with different requirements for energy and growth.

Figure 1 – Schematic presentation of the operation of a biotrickling filter



Since the biotrickling filter process relies completely on biological means, it is environmentally-friendly and has a much lower operating cost compared to chemical scrubbers. However, one of the disadvantages of older type biotrickling filter systems compared to chemical scrubbers, is the fact that it requires longer EBRTs (up to 5 to 7 times that of chemical scrubbers), thus often making it capital cost prohibitive for the treatment of very large airflows.

This study reports on the operation of a full-scale biotrickling filter running at EBRTs similar to that of chemical scrubbers, thus clearing a significant hurdle for the widespread use of biotrickling filters to treat large municipal air streams.

OBJECTIVES

The objectives of this research were to determine the effect of very low EBRT (< 3 s) and very high H_2S loadings (> 300 g H_2S/m^3.hr) on the performance of a full scale biotrickling filter.

MATERIALS AND METHODS

Biotrickling Filter System (System)

The System consisted of an EcoFilter™ EF51 reactor (BioAir Solutions, LLC, Voorhees, NJ), radial fume exhauster, RFE-315 fiberglass blower (New York Blower Company, Willowbrook, IL), control and water panel (BioAir Solutions, LLC, Voorhees, NJ), all mounted on a common skid (see Figure 2). The EcoFilter EF51 reactor has approximate overall dimensions of Ø5 ft x 9 ft tall (excluding stack) and has a 4 ft stack. The reactor contains EcoBase™ structured synthetic media (BioAir Solutions, LLC, Voorhees, NJ). The blower is equipped with an adjustable frequency drive (Allen Bradley PowerFlex 4) to control the airflow to the reactor. The System was equipped with a single spray nozzle (Coefficient of Uniformity = 92.6%) that was used to provide moisture to the bacteria, to remove the oxidative by-products and sloughed off microorganisms from the reactor. See Figure 2 for details on the System.

Figure 2 – Skid mounted EcoFilter EF51 biotrickling filter.

Instrumentation and Measurements

The System air velocity was measured with a handheld Dwyer Series 471-2 Digital Thermo-Anemometer at mid-point (2 ft from reactor outlet flange) on the Ø16” exhaust stack. The airflow was calculated by multiplying the air velocity with the cross sectional surface area of the exhaust stack.

The H_2S concentration of the air entering, and exiting, the reactor was measured with electro-chemical sensors (OdaLog Gas Data Loggers, Detection Instruments, Phoenix, AZ). The inlet and outlet air H_2S concentrations were measured with 0 – 1000 ppmv OdaLog (1 ppmv display resolution) and 0 – 50 ppmv OdaLog (0.1 ppmv display resolution), respectively. The OdaLogs were installed in a MOSS-2 Sampling System (Detection Instruments, Phoenix, AZ) and set to measure H_2S at 20 s intervals. The outlet air H_2S concentration was verified with 0 – 2 ppmv Low Range OdaLogs (0.01 ppmv display resolution) at 10 minute intervals. The OdaLogs were calibrated every other week using 50 ppmv calibration gas in accordance with the manufacturer’s instructions.

The overall odor removal of the System was assessed through olfactometry measurements at the various EBRT tested. The odor sample collection protocol consisted of collecting duplicate reactor inlet and outlet air samples in 10 L Tedlar bags with a vacuum chamber system (St. Croix Sensory, Lake Elmo, MN), which were shipped to St. Croix Sensory for odor analysis within 24 hrs of collection of the samples. The odor analysis was performed in accordance with ASTM E679-04 at 20 LPM introduction rate.

The drain water pH exiting the reactor was measured continuously with a pH meter (GF Signet, Tustin, CA) that was mounted in the drain line. Periodic spot drain water samples were taken and measured with a handheld Oakton Waterproof pHTestr 30 pH sensor (Cole-Palmer, Vernon Hill, IL).

Odor Source

The System was installed at the JEA Buckman Water Reclamation Facility (WRF) in Jacksonville, FL. The odor source was the gravity belt thickeners located in the biosolids building.

RESULTS AND DISCUSSION

The System was started in February 2009 and in operation for approximately three months prior to the start of the H_2S experiments reported herein.

10 s EBRT Data

The airflow to the System was set at approximately 475 cfm, which corresponds to an EBRT of 9.9 s. The system was operated at this airflow for minimum three weeks prior to the start of the data collected from May 21 till May 28 (see Figure 3). The H_2S concentration during the data collection period varied between 75 and 250 ppmv and the outlet air H_2S concentration varied between 0.0 and 1.8 ppmv (on May 27, 2009, see Figure 3). The average H_2S removal for the data period displayed in Figure 3 is 99.92%.

Odor samples were collected on May 27, 2009 and the results are reported in Table 1. It is clear from the data in Table 1 that the System removed 96.9% of the odor (based on Detection Threshold odor data) and 99.9% of the H_2S, at a mass loading of 76 g H_2S/m^3.hr.

Figure 3 – Reactor inlet and outlet H_2S concentration at 10 s EBRT

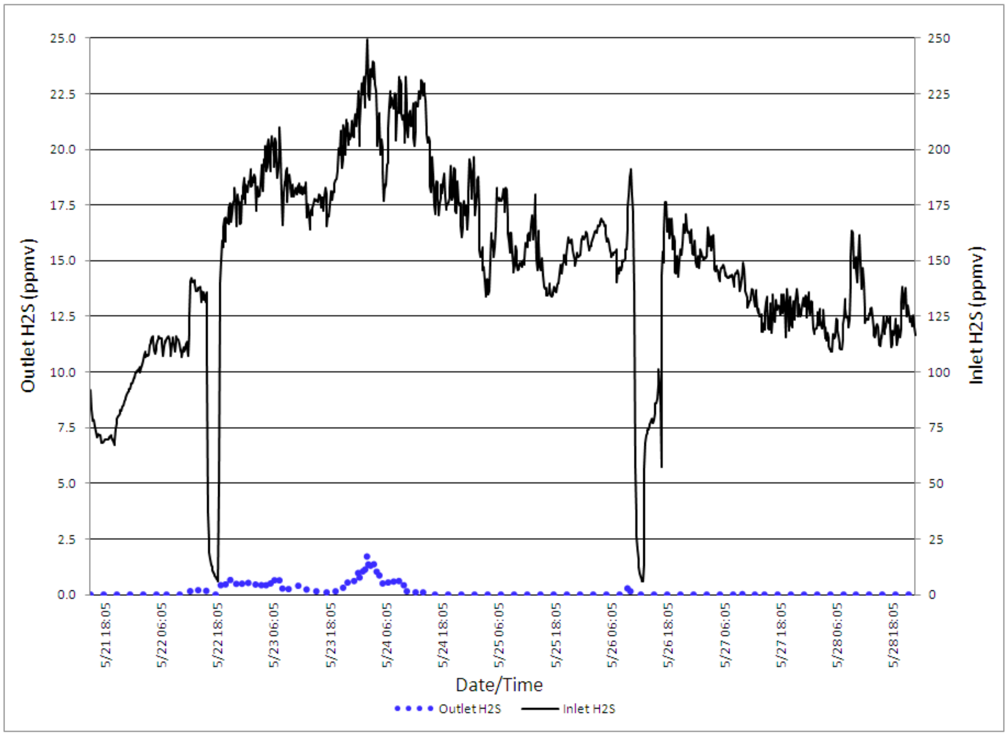


Table 1 – Results of odor samples collected on May 27, 2009

Description	Detection Threshold (OU)	Odor Removal (%)	H_2S on 5/27 (ppmv)	H_2S Removal (%)	Mass Loading (g H_2S/m^3.hr)
Inlet air sample	78,000		144 – 148[1]		76
Outlet air sample	2,400	96.9	0.16[2]	99.9	

[1] H_2S range during inlet sample collection (0 – 1,000 ppmv OdaLog)

[2] H_2S range during outlet sample collection (0 – 2 ppmv Low Range OdaLog)

7 s EBRT Data

The airflow to the System was increased 475 to 675 cfm on May 30, 2009 to reduce the EBRT to approximately 7 s. The system was operated at this airflow until June 11 at which time odor samples were collected for which the results are reported in Table 2.

Table 2 – Results of odor samples collected on June 11, 2009.

Description	Detection Threshold (OU)	Odor Removal (%)	H_2S on 6/11 (ppmv)	H_2S Removal (%)	Mass Loading (g H_2S/m^3.hr)
Inlet air sample	140,000		222 – 225[1]		169
Outlet air sample	6,000	95.7	0.57 – 0.92[2]	99.7	

[1] H_2S range during inlet sample collection (0 – 1,000 ppmv OdaLog)

[2] H_2S range during outlet sample collection (0 – 2 ppmv Low Range OdaLog)

The System removed 95.7% of the odor (based on Detection Threshold odor data) and 99.7% of the H_2S, at a mass loading of 169 g H_2S/m^3.hr (see Table 2).

5 s EBRT Data

The airflow to the System was increased on June 12, 2009 from 675 to 950 cfm to reduce the EBRT to approximately 4.8 s. The system was operated at this airflow until June 24 at which time odor samples were collected for which the results are reported in Table 3.

Table 3 – Results of odor samples collected on June 24, 2009

Description	Detection Threshold (OU)	Odor Removal (%)	H_2S on 6/24 (ppmv)	H_2S Removal (%)	Mass Loading (g H_2S/m^3.hr)
Inlet air sample	83,000		187 – 220[1]		212
Outlet air sample	8,300	90.0	5.4 – 7.4[2]	96.9	

[1] H_2S range during inlet sample collection (0 – 1,000 ppmv OdaLog)

[2] H_2S range during outlet sample collection (0 – 2 ppmv Low Range OdaLog)

On June 11 the System removed 90% of the odor (based on Detection Threshold odor data) and 96.9% of the H_2S, at a mass loading of 212 g H_2S/m^3.hr (see Table 3). However, H_2S results obtained during the period June 21 through June 22 (see Figure 4), showed that the System consistently removed more than 99% H_2S during which the inlet air H_2S concentration varied between 125 and 180 ppmv. However, on the day the odor samples were collected there was an increase in inlet H_2S from about 150 ppmv to as high as 220 ppmv, suggesting that the System was still "acclimating" to the concentration, which explains the less than 99% H_2S removal on June 24.

3 s EBRT Data

The airflow to the System was set at 1,650 cfm on July 1, which corresponds to an EBRT of 2.8 s. The system was operated at this airflow for approximately four weeks to provide sufficient acclimation time to the short EBRT. The reactor inlet and outlet H_2S concentration for the period August 7 till August 13 is shown in Figure 5. The inlet H_2S concentration varied between 55 and 110 ppmv (average 73.3 ppmv), and the outlet concentration was between 0.0 and 0.5 ppmv (average 0.01 ppmv) as measured with 0 – 50 ppmv OdaLog) representing an H_2S removal efficiency of greater than 99.9%.

Mass Loading

Since the inlet H_2S concentration for the period July 24 – 29 varied between 200 and 350 ppmv, and for the period August 8 – 13 varied between 55 and 80 ppmv, the data was used to calculate the reactor H_2S Load (Load = inlet H_2S concentration x airflow/media volume) and Elimination Capacity (Elimination Capacity = (inlet – outlet) concentration x airflow/media volume) (Revah et al., 2005). Figure 6 shows a H_2S Load vs. Elimination Capacity for the System at 2.8 s EBRT. A second order polynomial was fitted through the data using multiple linear regression analysis (EXCEL 2007 Version) (see Figure 6). The formula was used to determine the maximum H_2S Load for which 99% and 95% H_2S removal were still achievable, and it was calculated to be 247 and 524 g H_2S/m^3.hr, respectively. These loadings are approximately 2.5 to 5.2 times higher than previously reported data where polyurethane foam cubes (M+W Zander, Germany) media was used (Gabriel et al., 2003).

Figure 4 – Reactor inlet H_2S concentration and H_2S removal efficiency at 5 s EBRT

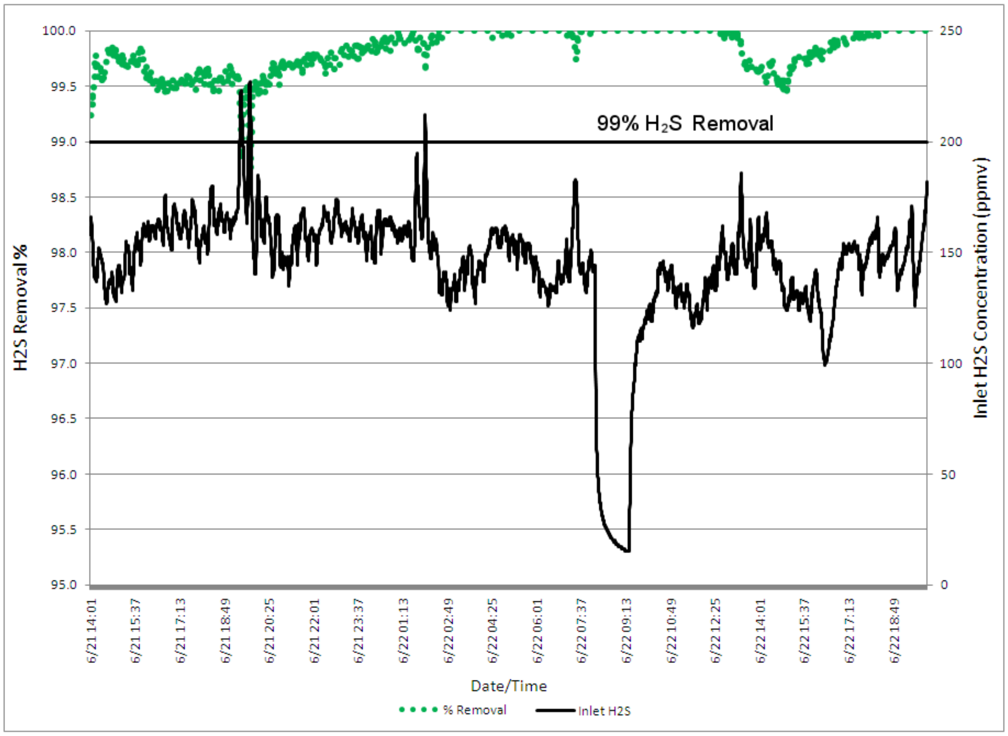


Figure 5 – Reactor inlet and outlet H_2S concentration at 2.8 s EBRT

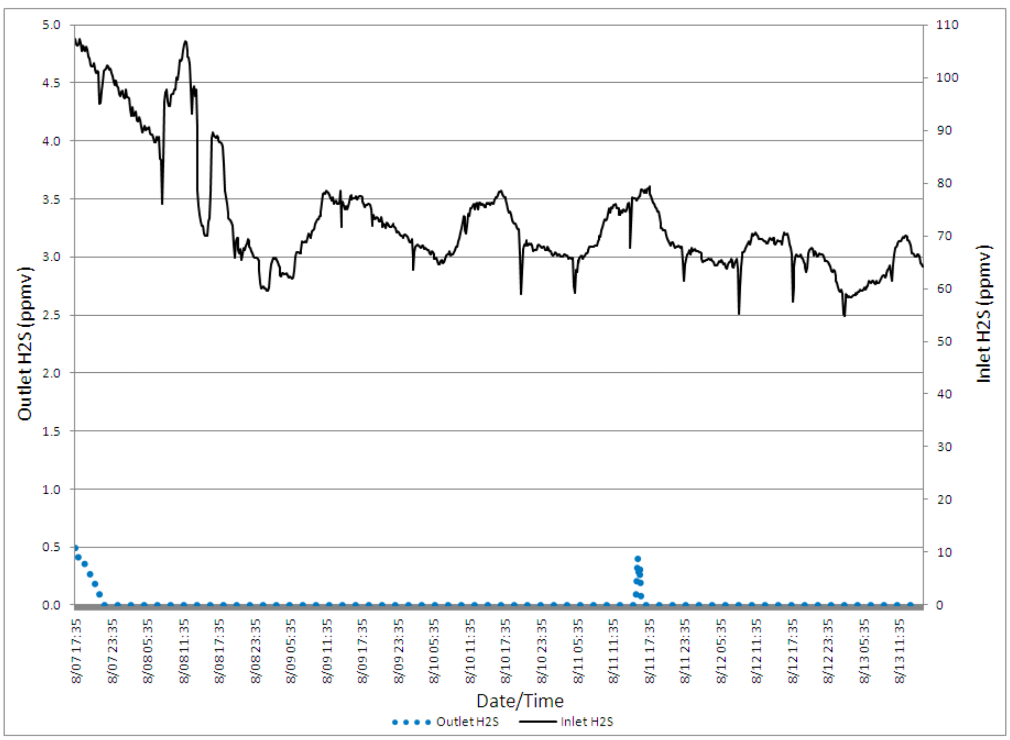
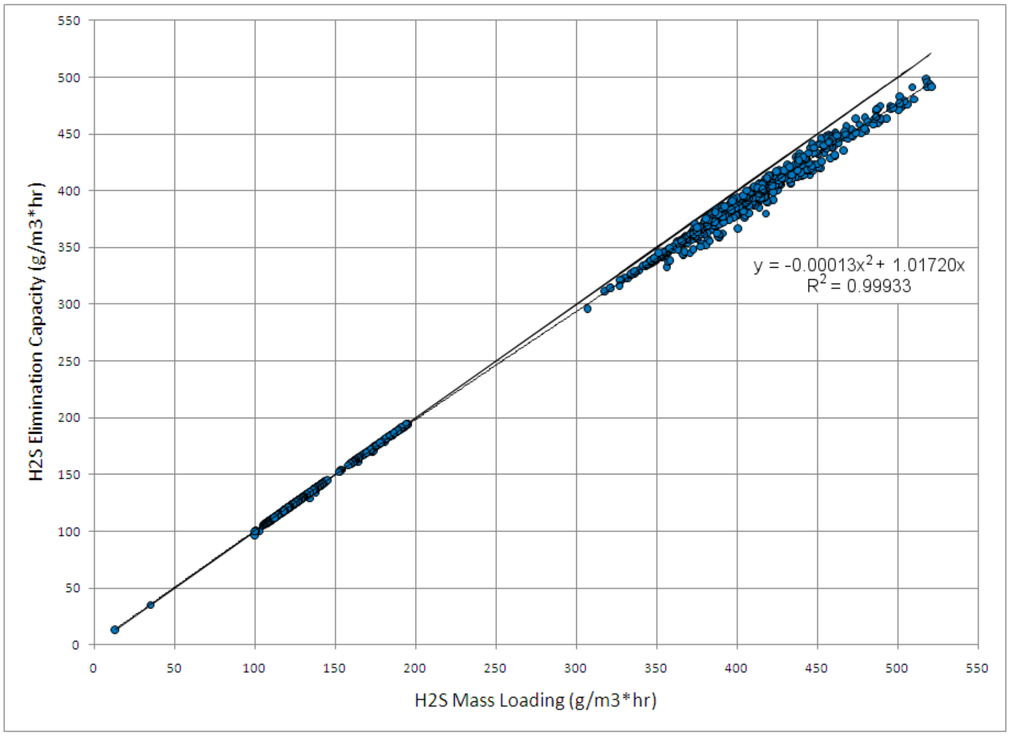


Figure 6 – H_2S Mass Loading vs. Elimination Capacity at 2.8 s EBRT



CONCLUSIONS

The results showed that it is possible to treat municipal odors with the EcoFilter biotrickling filter technology at EBRTs less than 3 s. The System was able to reduce the inlet H_2S concentration from an average of 73.3 ppmv to less than 0.01 ppmv, which represent a removal efficiency of 99.98%. This is significant because most commercially available biotrickling filters require between 8 and 12 s EBRT, which results in a reactor volumetric size of 3 to 4 times than what would be required if an EcoFilter system is used for the same application.

Another key finding from this research was the fact that the System was able to remove 99% of the H_2S at a volumetric loading rate of 247 g H_2S/m^3.hr at 2.8 s EBRT. This loading rate is approximately 2.5 times higher than that reported for similar research conducted at EBRT between 1.6 and 2.2 s during which the loading rates were as high as 110 g H_2S/m^3.hr (Gabriel et al., 2003). The significance of this finding is that for applications where the H_2S concentration is very high, i.e. greater than 130 ppmv, the EcoFilter reactor volumetric size is approximately 2.5 times less than that required for similar type commercially available systems.

It is clear from this research that the EcoFilter biotrickling filter could be used to treat municipal wastewater odors, especially those with high H_2S concentrations, at EBRTs similar to that of chemical scrubbers. This is significant because biotrickling filters use no hazardous chemicals and have very few moving parts, thus resulting in very low operating cost compared to chemical scrubbers, but with similar capital cost.

ACKNOWLEDGMENT

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REFERENCES

Card, T. (2001) *Odours in Wastewater Treatment: Measuring, Modeling and Control*. Editors Stuetz, R. & Frechen, F.B. International Water Association: London.

Clark, J. (2004) *Control of Odors and Emissions from Wastewater Treatment Plants.* WEF Manual of Practice No. 25, Chapter 1. Water Environment Federation: Alexandria, VA.

Cox, H.H.J; Deshusses, M.A.; Converse, B.; Schroeder, ED; Iranpour, R. (2002) *Odor and Volatile Organic Compound Treatment by Biotrickling Filters: Pilot-scale Studies at Hyperion Treatment Plant*. Water Environment Research 74(6): 557-563.

Deshusses, M.A. (2005) *Application of Immobilized Cells for Air Pollution Control*. Applications of Cell Immobilisation Biotechnology, p. 507-526, V. Nedovic and R. Willaert (Editors), Springer-Verlag, Germany.

Gabriel, D.; Deshusses, M.A. (2003) *Performance of a Full-scale Biotrickling Filter Treating H_2S at a Gas Contact Ttime of 1.6 - 2.2 Seconds*. Environmental Progress 22: 111-118.

Gabriel, D.; Deshusses, M.A. (2003) *Retrofitting Existing Chemical Scrubbers to Biotrickling Filters for H_2S Emission Control*. Proc. Natl. Acad. Sci. U.S.A. 100(11): 6308-6312.

le Roux, L.D.; Johnson, M.E.; So, M.J.; de los Reyes III, F.L. (2009) *Biotrickling Filters for Municipal Odor Control – The Next Step*. Odor and Biosolids Management: Bridging to the Future Conference & Expo, San Marcos, TX, August 27 – 28, 2009.

Revah, S.; Morgan-Sagastume, J.M. (2005) *Methods of Odor and VOC Control*. Biotechnology for Odor and Air Pollution Control, p. 50, Z. Shareefdeen and A. Singh (Editors), Springer-Verlag, Germany.

U.S. Environmental Protection Agency. (1989) *Assessment of Needed Publicly Owned Wastewater Treatment Facilities in the United States*. Publication No. 430/9-89-001, U.S. EPA, Washington, DC.