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Original Research Paper

A Long-term Study of a Lava Rock-based Biofilter for Hydrogen Sulfide, Ammonia and Volatile Organic Compounds (VOCs) Treatment at a Wastewater Treatment Facility

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ABSTRACT

Biofiltration is a sustainable technology in the US that utilizes microorganisms to biodegrade harmful airborne contaminants. Biofiltration can not only be more cost effective, but also more environmentally friendly than traditional technologies such as thermal oxidation and chemical scrubbing. The objective of this study was to follow the long-term operation of a lava rock-based biofilter for odour control at a wastewater treatment plant. The biofilter has operated well for over 14 years that we have followed the system. After 14 years of operation there are no visible signs of fungal growth or solid support breakdown. VOCs were removed at a rate of nearly 81% while ammonia and hydrogen sulfide removal was found to be almost 90% and 98%, respectively. This study demonstrates that lava rock can be used for a solid support media in wastewater treatment applications with excellent removal efficiencies, while maintaining its structural integrity over a decade or more of continuous use. This is the first study that has followed a biofilter operation for 14 years. When considering biofiltration as an odour treatment option, one should consider lava rock as a solid support option. The initial capital investment can be saved several times over by using a solid support that is able to hold-up over the years without replacement. Thus, it is practical to consider solid support materials that appear to have a larger capital cost when one considers a long media life expectancy and payback over decades.

INTRODUCTION

Biofiltration is an innovative form of biotechnology that has emerged in the United States for the treatment of off-gases containing odours, volatile organic compounds (VOCs), and hazardous air pollutants (HAPs) (Adler 2001, Amirhor & Gould 1997, Dawson 1993, Rao et al. 1996, Togna & Singh 1994). Its popularity resides in the fact that there are no caustic chemicals needed for operation, and the operation and maintenance are usually lower than comparable chemical scrubbing equipment. In 1957 the first patent for biofiltration-type technology was issued to Pomeroy in the United States. Biofiltration is a cost-effective and sustainable means of air decontamination. Biofiltration works as a biologically active filter by making use of a biofilm immobilized on a solid support medium, such as compost, soil, wood chips, ceramic, perlite, polystyrene, zeolite, and lava rock to mention a few (Banoventura & Johnson 1997, Boyette 1998, Devinny 1998, Devinny et al. 1999, Fouht 1992, Goldstein 1999, Jones & Banuelos 2000, Kleinheinz & Bagley 1998, Kleinheinz & Langolf 2006, Ottengraf & Konings 1991, Van Lith et al. 1997, Wade 1999).

While biofiltration is a cost-competitive technology for air treatment there is a significant capital investment with the construction of the system. Additionally, the replacement of media very 2-5 years is a significant investment and means operational downtime as the system media is emptied and replaced with new media. Additionally, there is a decrease in performance until the new media acclimates and removal efficiencies reach previous levels of treatment. The lifespan of the media in a biofilter is the largest operation and maintenance expense associated with biofiltration technology (Devinny et al. 1999).

Biofiltration technology is particularly effective for the removal of compounds with high water solubility and low molecular weights. Biofilters traditionally work most effectively with relatively low loading rates and high air flow rates.

Depending on the type of medium being used and the nature of the contaminant to be degraded, the biofilter medium may need to be inoculated with some sort of microbial suspension. Activated sludge is commonly used as an inoculum in many biofilters because of the variety of microorganisms present and their collective ability to degrade many different types of pollutants (Boyette 1998, Devinny et al. 1999). This is a particularly important issue when dealing with synthetic media like perlite, or natural media with low microbial content like lava rock (Kleinheinz & Langolf 2006).

The Neenah-Menasha Sewerage Commission owns and operates a 13 mgd wastewater treatment facility in Menasha, WI, which is adjacent to a residential area. Odour complaints intensified when the area residents learnt of a need for future plant expansion. These odor complaints prompted the Sewerage Commission to investigate odor control techniques.

In the early 1990s the Commission identified the main source of odours to be from the screw pumps, headworks (grit and screening area) and biosolids dewatering operations. These odours are primarily related to hydrogen sulfide, ammonia and volatile organic compounds (VOCs). Chemical masking agents were being used at the time with limited success. Two options were considered for permanent odor treatment: chemical scrubbing and biofiltration.

Preliminary cost investigations determined that chemical scrubbing could cost as much as $1,000,000 with annual operating costs of $150,000/year. Biofilters, however, may have similar capital costs but much lower operating cost of approximately $45,000 annually. The potential for cost savings prompted the Commission to select biofiltration as the technology of choice.

Construction of a full-scale biofilter, using lava rock as the media, placed in two existing 30.48-m diameter biosolids storage tanks sized at 1,260 m^3/min (cmm) was completed in January, 2001. The system has been in continuous service since start-up.

The objective of this study was to evaluate the long-term use of a lava rock-based biofilter for the treatment of odours at a wastewater treatment plant. Specifically, this study evaluated the removal of VOCs, H_2S, and ammonia in the biofiltration system of a >10 year period. By using lava rock in this system the facility was able to maintain adequate odor removal and lower the cost of operation of a full-scale biofiltration unit.

EXPERIMENTAL METHODS

Biofilter design: The biofilter was constructed in two existing unused 30.48-m diameter steel tanks with an existing concrete floor/foundation and aluminium cover. Odorous compounds were collected from throughout the facility and piped to the biofilter via 91.44-cm diameter stainless steel ducting. The headworks, grit screen, belt presses in the biosolids dewatering area, and solids dumpster were covered and foul air collected for odor treatment. A variable speed fan supplying approximately 1,260 cmm of air delivered it to the biofilters. This study focuses on the operation of one of the biofilter units with approximately 630 cmm of air being delivered continuously. Foul air is brought to the system and discharged below the bed to provide an upflow current of air in the system.

Fig. 1 shows the basic design of the system. Each existing steel tank was retrofitted to hold 1.2192 meters of lava rock media. Lava rock media was 3.81centimeters and obtained via rail from a supplier in Colorado. Stainless steel grating was used to support the rock. PVC piping was used to distribute the foul air throughout the tank floor. A spray system using non-potable (reuse) water is used to keep the lava rock moist. The moisture is applied via an inline spray nozzle that acts as the humidification system and an overbed water system. Approximately 75.71 (L/min)/unit is provided to keep the lava rock moist. All drainage is collected and

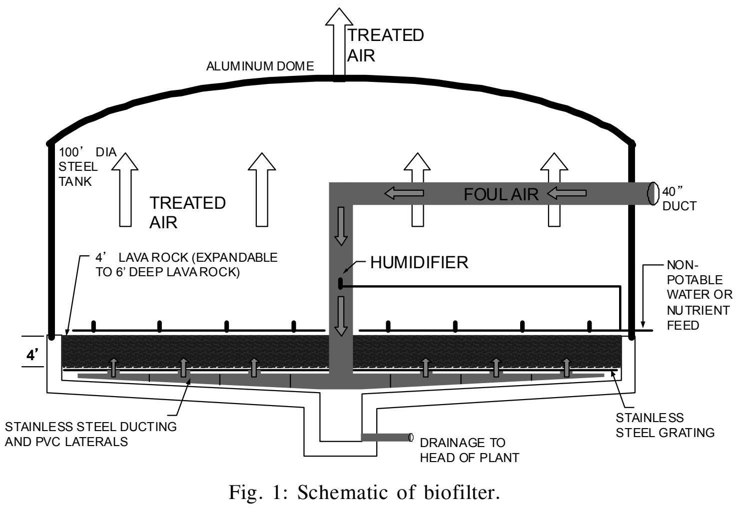

Fig. 1: Schematic of biofilter.

returned to the headworks for treatment.

A chemical feed pump was provided to allow for the addition of nutrients if needed. This provided approximately 1 L of concentrated liquid 10-10-10 fertilizer to the biofilters daily. The fertilizer feed was injected into the overhead water system. The biofilter exhaust exits the biofilter through the hatch openings on the aluminium covers. At a flow rate of 1,260 cmm the units are sized to have an approximate empty bed residence time of 1.4 minutes. With a lava rock media of approximately 50% the true residence time is approximately 0.7 minutes. The actual construction cost of the system including the lava rock was $1.1 million dollars.

The only source of inoculum was 37,850 litres of reuse water that was applied to each biofilter at the time of startup. The biofilters are covered so the majority of microbial input through operation is likely from the overhead water system.

Air stream analysis: The influent air was measured via a 10.16-cm sample port installed just prior to the biofilter and effluent air monitoring was measured above the biofilter bed as the air exited the top of the biofilter. The air stream was monitored for VOCs using a Graywolf Sensing Solution (Shelton, CT) Photoionization Detector (PID) on a TG-502 sensor platform. The data were logged in realtime by a handheld tablet or PDA and 5 readings were composited over a 3 minute period to form one single composite reading. The limit of detection was 0.1 ppm and a range of analysis is 0.1 to 10,000 ppm. Ammonia (NH_3) was monitored by a Graywolf TG-502 air monitoring system equipped with an electrochemical ammonia sensor with a limit of detection of 0.1 ppm and a range of 0.1 ppm to 100 ppm. Hydrogen sulfide (H_2S) was monitored by a Graywolf TG-502 air monitoring system equipped with an electrochemical ammonia sensor with a limit of detection of 0.1 ppm and a range of 0.1 ppm to 100 ppm. The TG-502 sensing system was calibrated quarterly per the manufacturer specifications.

The TG-502 sample probe also recorded temperature and relative humidity of the air at the time of sampling. Flow rate of the influent air stream was measured via a Fieldpiece (Melrose, MA) STA2 anemometer with a measuring range of 0.45-45 mph (meters per hour). Pressure drops across the bed were determined by manometer measurements in inches of water column recorded before and after the filter bed.

Lava rock microbial and physical analysis: Quarterly lava rock samples were collected from a depth of 15.24-cm and 0.3048 meter of bed depth using a sanitized shovel. These samples were placed in sterile bags and placed in a cooler at <4C until they can be returned to the laboratory. All analysis was conducted within 8 hours of collection. These lava rock samples were visually inspected for deterioration and heterotrophic microbial counts, moisture content, and pH were determined. Microbiological counts were performed by methods described in Kleinheinz & Bagley 1998. Moisture content and pH were determined using standard methods for environmental sampling (American Public Heath Association, 1998) and were performed on a composite sample of four randomly collected sample throughout the biofilter bed.

RESULTS AND DISCUSSION

As shown in Fig. 2 and Table 1, microbial levels over the 14 years of this study were consistent with respect to the seasons of the year. Since ambient temperature in Wisconsin can reach -30°C in January, it is not surprising that microbial numbers would be lower during the winter. Microbial levels were found to be the highest in July, 2012 at 7.2E7 CFU/g of lava rock. The low value was observed January, 2008 at 1.0E2 CFU/g of lava rock. The mean microbial concentration found on the lava rock was 6.7E6. Observational results showed good biofilm formation around the lava rock with little or no visible fungi present. This is also evidenced by an average pressure drop across the column of 1.5 cm of water column. The greatest drop was 1.9 cm of water column and the least was 1.25 inches of water column at startup.

There was no pH adjustment added to the system throughout its operation, but the pH was able to maintain itself between 7.3 and 8.3. The lava rock appears to have a buffering capacity in regard to pH. With ammonia being a predominant odor constituent and hydrogen sulfide a minor component there appears to be no problem with the accumulation of acidic compounds in the biofilter bed.

Moisture content in the biofilter was variable with respect to season and possible uneven water over the surface of the biofilter bed. While there was no obvious dry areas of the biofilter bed it is clear that some samples had less moisture than others. It is unclear if this is an artifact of sample variability, watering, or some other factor. However, the mean moisture content of 28.7% appears to be sufficient to maintain a health microbial population and and pH on the solid support.

As shown in Table 2, throughout the fourteen years cov-

Table 1: Microbial and physical parameters monitored during operation (n=58).

Parameter	Mean	Standard Deviation	Range
Heterotrophic microbes (CFU/g)	6.7E6	1.0E7	1.2E2-7.2E7
pH	7.3	0.61	7.3-8.3
Moisture content (%)	28.7	5.6	17.0-39.7

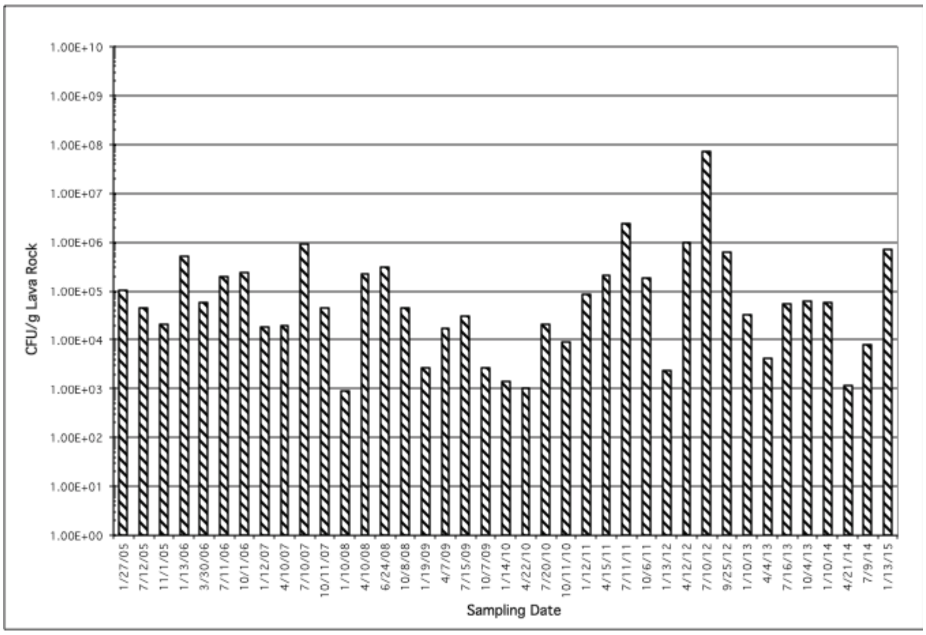

Fig. 2: Microbial counts from lava rock throughout the study. Each data point is the mean of two samples. Error bars are not visible.

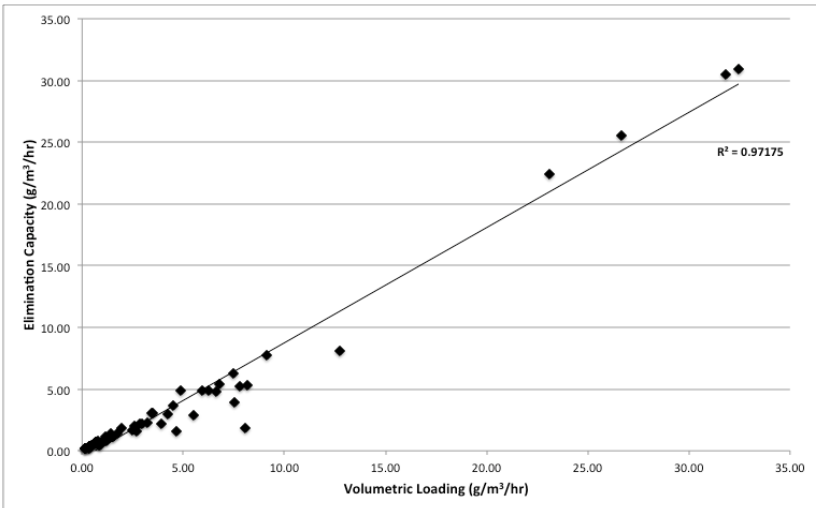

Fig. 3: VOCs volumetric loading vs. elimination capacity (g/m^3/hr).

ered in this study VOCs were removed at a rate of nearly 81% (Fig. 3) with a mean influent of 26.1 (±38.7) ppm. There was an excellent relationship (R^2=0.97) between loading rates and elimination capacity (Fig. 3) with elimination capacity of over 30 g/m^3/hr. This suggests that the biofilter is capable of much more in terms of loading and removal efficiency should situations change at the facility. The typical loading of VOCs was far under the capacity of the system and during a period of plant upgrades the VOCs spike, but yet the biofilter was able to keep-up with odor control.

Ammonia removal was found to be almost 90% (Table 2) over the life of the study with a mean influent concentration of 5.0 ppm (±6.5) and an effluent concentration of 0.5 ppm (±0.9). There was an excellent relationship (R^2=0.96) between loading rates and elimination capacity (Fig. 4) with elimination capacity of over 0.6 g/m^3/hr. Again, this rela-

Table 2: Chemicals monitored during operation (n=58).

Parameter	Overall Removal	Influent Mean (ppm)	Effluent Mean (ppm)	Volumetric Loading Mean (g/m3/hr)	Elimination Capacity Mean (g/m3/hr)	Range (ppm)
VOCs	80.9%	26.1 (±38.7)	4.9 (±6.4)	4.8 (±7.2)	3.9 (±6.9)	2-168
H_2S	97.7%[a]	1.1 (±1.2)	0.1 (±0.3)	0.1 (±0.1)	0.1 (±0.1)	0-7
Ammonia	89.8%	5.0 (±6.50)	4.3 (±5.14)	0.2 (±0.1)	0.2 (±0.1)	1-19

[a]Very low concentrations of H_2S.

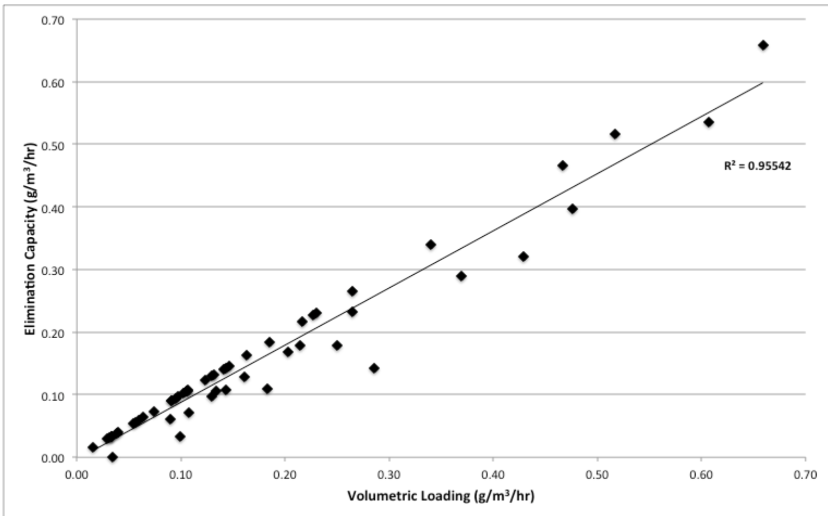

Fig. 4: NH_3 volumetric loading vs. elimination capacity (g/m^3/hr).

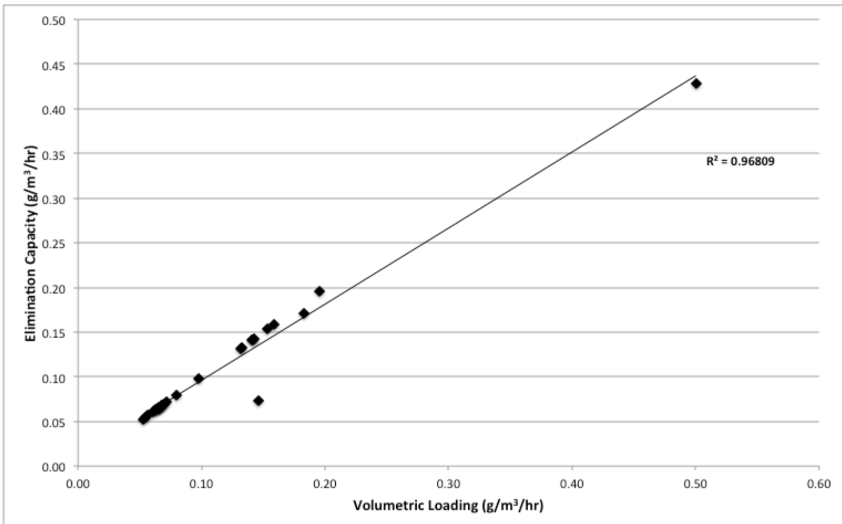

Fig. 5: H_2S volumetric loading vs. elimination capacity (g/m^3/hr).

tionship demonstrates that the capacity of the biofilter has not been reached and that increases in loading rates would be handled by this system.

While hydrogen sulfide was in relatively low levels its overall removal throughout the study was nearly 98% with a mean influent concentration of 1.1 ppm (±1.2). There was an excellent relationship (R^2=0.97) between loading rates and elimination capacity (Fig. 5) with elimination capacity of over 0.4 g/m^3/hr. Again, this relationship demonstrates that the capacity of the biofilter has not been reached and that increases in loading rates would be handled by this system. The hydrogen sulfide results also suggest that.

This study demonstrates that lava rock can be used for a solid support media in wastewater treatment applications with great success because of its typical surface terrain and pores (Fig. 6) . In the case of this site, the biofilter oversized relative to constructing the unit from the ground up as the site made use of two old sludge holding tanks onsite. Having said that, the EBRT is only 42 seconds and the results of the monitoring suggest that the biofilter has excess capacity. As with other studies, it has shown that lava rock can have excellent removal efficiencies (Kleinheinz & Langolf 2006), while maintaining its structural integrity over a decade or more. One limitation of lava rock is that it is not readily available in bulk all over the United States. Thus, the cost per m^3 of bed area can be very different in different regions of the country. Based on this study and others it is clear that lava rock can play a significant role in biofiltration into the future in a broad array of applications.

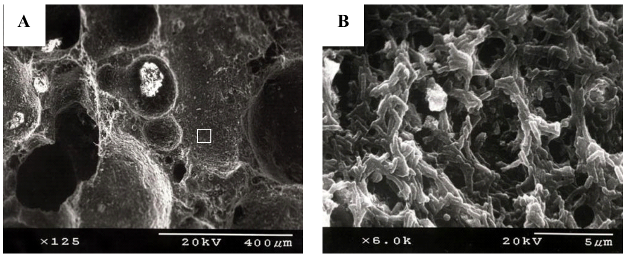

Fig. 6: SEM analysis: A) Scanning electron micrograph of the surface of lava rock displaying typical terrain and pores, magnification 125×; B) Biofilm formation on biofilter lava rock at 6000× in area designated by rectangle in image A.

CONCLUSIONS

This is the first study that has followed a biofilter operation for 14 years. Typical biofilter media has a 2-5 year life expectancy and its replacement is considered and operations and maintenance cost. When considering biofiltration as an odor treatment option, one should consider lava rock as a solid support option. The initial capital investment can be saved several times over by using a solid support that is able to hold-up over the years without replacement. Thus, it is practical to consider solid support materials that appear to have a larger capital cost when one considers a long media life expectancy and payback over decades.

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