Biofiltration of H$_2$S with Reclaimed Water as a Nutrient/Moisture Source at Loading Rates from 10 to 300 g H$_2$S m$^{-3}$ h$^{-1}$

*Peter Fox and †David Locher

PO Box 5306, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ, 85287 USA
*corresponding author  Phone: 480-965-1734, Fax: 480-965-0557 E-mail: Peter.Fox@asu.edu
†Phone: 480-965-3589 E-mail: David.Locher@asu.edu

Abstract  A biofilter was evaluated with two different media under field conditions using reclaimed water as a nutrient source. Evaluation with a single media demonstrated that H$_2$S could be efficiently removed at volumetric loading rates of up to 200 g H$_2$S m$^{-3}$ h$^{-1}$. After an extended period of high loading rates, the performance began to deteriorate at loading rates greater than 150 g H$_2$S m$^{-3}$ h$^{-1}$ possibly due to nutrient limitations. The reclaimed water served as a nutrient source even though the primary form of nitrogen was nitrate. The reclaimed water successfully supplied nutrients at the majority of loading rates observed in the study and this was verified by stoichiometric calculations. The biofilter was converted to a dual media filter and consistent performance was also observed with the dual media filter at loading rates up to 150 g H$_2$S m$^{-3}$ h$^{-1}$. The biofilter was successfully operated at loading rates higher than previously reported under field conditions. The use of nitrate in reclaimed water as a nitrogen source was successful and demonstrated the potential to eliminate the need for a separate nutrient source at a water reclamation plant.

Keywords – Biofiltration, Reclaimed Water, Hydrogen Sulfide, Dual Media

Introduction  One of the major concerns for wastewater treatment plants in residential areas is odor emissions. One of the most cost effective removal techniques available for odor control appears to be biological treatment. Several concerns have existed regarding the use of biofiltration for odor control (Devai and Dulane, 2000). One of the major concerns is that the size of a biofiltration system will exceed the size of alternatives such as chemical control systems. Kim and Deshusses (2003) reported that a full-scale chemical scrubber was successfully converted to a biofilter. Effective treatment was observed with gas contact times as low as 1.6 seconds (Gabriel and Deshusses, 2003). The H$_2$S removal efficiency was greater than 98% with inlet concentrations as high as 30 to 50 ppm. The corresponding volumetric elimination rates of H$_2$S were 95 to 105 g H$_2$S m$^{-3}$ h$^{-1}$. In comparison to other systems, Kim and Deshusses (2003) cited exceptional performance since other biofilters were have reported removing lower concentrations of H$_2$S at higher contact times (Smet et al., 1998, Koe and Yang, 2000). Their explanation for the excellent performance was a combination of high mass transfer rates and optimum operating conditions. The high mass transfer rates could be a result of a high surface area combined with very high gas linear velocity (1.8 m/s) (Alonso et al, 1998). The optimal operating conditions include no nutrient deficiencies, sufficient CO$_2$ for growth and no air short circuiting.

A literature review of air pollution control biofilters for odor control was completed in 2005 by Iranpour et al. The literature review summarized laboratory studies of biofilters for the removal
of \( \text{H}_2\text{S} \) and reported volumetric elimination rates ranging from 12-130 g \( \text{H}_2\text{S} \) m\(^{-3}\) h\(^{-1}\) with removal efficiencies exceeding 99\% and gas contact times ranging from 23-200 s. The literature review did not report ranges of volumetric elimination rates in field systems but did report concentrations ranging up to 200 ppm being successfully removed.

One of the challenges associated with using biofilters for odor control at publicly owned treatment works (POTWs) is the variability in odor causing compounds and their concentrations (Yang and Allen, 1994). The headworks ventilation air is often a mixture of \( \text{H}_2\text{S} \) and other reduced sulfur compounds (carbon disulfide, dimethyl sulfide and methyl mercaptan). At most POTWs, \( \text{H}_2\text{S} \) is the major component and concentrations can vary by a factor of 10 depending on the time of day. The concentration of \( \text{H}_2\text{S} \) at the Hyperion Wastewater Treatment Plant in Los Angeles where extensive evaluation of biofiltration has been done ranges from 5 to 50 ppm. In addition to varying concentrations, full-scale biofilters are subject to extensive variations in temperature, discontinuous pollutant supply and relative humidity.

The objective of this study was to evaluate the removal of \( \text{H}_2\text{S} \) under field conditions with a biofilter using a novel biomass attachment media and treated wastewater effluent as the moisture and nutrient source. The major form of nitrogen in the treated wastewater effluent was nitrate. The novel biomass attachment media was first evaluated as a monomedia and then it was combined with second media for provide a dual media biofilter. Varying influent concentrations and temperatures were documented and mass balances were completed to determine the suitability of treated wastewater as a nutrient source.

**Methods**  A modular biofilter with novel biomass attachment media was operated at the Arrowhead Water Reclamation Facility in Glendale, Arizona for a period of six months. The modular biofilter was 0.679 m\(^3\) in volume and contained a proprietary media from Ecoverde (Phoenix, Arizona, USA). For the first three months of operation, a single type of structured synthetic polypropylene media with 95\% void space was used in the biofilter. This media has the unique properties of providing a high specific surface area for growth while still maintaining uniform air and water flow patterns. The media is installed in sheets preventing an exact calculation of the surface area for microbial attachment since growth can occur on multiple surfaces, however the estimated specific surface area is greater than 1,000 m\(^2\)/m\(^3\). After three months of operation, the media in the biofilter was changed to a dual media filter such that the top 75\% of the biofilter contained the proprietary media used during the first three months and the bottom 25\% of the biofilter contained a more traditional cube media. The cube media had a void fraction of 87.8\% and a specific surface area of 432 m\(^2\)/m\(^3\). The use of two different media was done in an attempt to provide a more robust biofilter. One type of media (cube media) is known to provide faster start-up times while the other type of media is capable of treating at higher loadings once the biomass becomes established.

Effluent from the secondary clarifier of the Arrowhead Water Reclamation Facility was applied to the biofilters using spray nozzles and allowed to flow down the filters by gravity. The filters were operated in an upflow mode and the airflow treated by the filters was from the headworks of the Arrowhead Water Reclamation Facility. Initially the filters were operated at a flowrate of 2.83 m\(^3\)/min during an acclimation period of 21 days. The gas contact time in the filters was 14s during the acclimation period. After the acclimation period was completed, the influent flowrate
was increased to 4.24 m$^3$/min resulting in a gas contact time of 9.6s. After the initial operation of the filter with a single media for 3 months, the media was changed to a dual filter media. During the final three months of operation with the dual media and initial gas flowrate was set at 3.4 m$^3$/min corresponding to a gas contact time of 12s. After acclimation, the gas flowrate was increased to 4.24 m$^3$/min which was identical to the gas flow rate used during the first three months.

The filters were equipped with probes to continuously monitor H$_2$S and temperature in the influent and the effluent air (Figure 1). Measurements of H$_2$S and temperature were automatically taken every 10 minutes and recorded using an Odalog L2 Model SL-200 certified by APP-TEK International (Brendale, Australia). In addition, the pH of water draining from the filters was monitored using a Model 10E-PH Transmitter from Pulse Instruments (Van Nuys, CA, USA). The pH measurements were logged every 15 minutes. The H$_2$S and pH data was downloaded from the data loggers weekly. The flowrate of reclaimed water was 166 l/d throughout the majority of the experiment and the water flowrate was metered using an Elster C700 Water Meter (Ocala, FL, USA).

![Biofilter diagram](image)

Figure 1. Biofilter at Arrowhead Water Reclamation Facility

The Arrowhead Water Reclamation Facility produces Arizona Class A+ water for reuse. Therefore, the water is nitrified and denitrified and nitrate is the major form of nitrogen. Average nitrogen concentrations for the influent were obtained from plant operating data. The ammonia concentrations were less than 0.05 mg/L and the nitrate concentrations ranged from 3.6 to 5.8 mg-N/l during the study. The effluent pH ranged from 7.4 to 8.1 and alkalinity averaged...
180 mg/L as CaCO$_3$. Stoichiometric calculations were completed to determine the nutrient requirements and alkalinity consumption in the biofilter.

**Results and Discussion** The mass removed versus mass input in g H$_2$S m$^{-3}$ h$^{-1}$ for the first acclimation period is presented in Figure 2. The data is plotted for six different time periods. A 45 degree line represents complete removal of the input H$_2$S. After 16 days of acclimation (10/12-10/28), the system began to consistently remove the input H$_2$S. The clear improvement in removal is observed as the time of operation increased. The airflow was increased to 150 cfm on 11/2/10 after 21 days of operation. The higher loadings observed on from 11/2 to 11/11 are a result of the increased airflow rate and efficient removal of H$_2$S was observed. It is interesting to note that the system efficiently removed H$_2$S at a loading rate as high as 117 g H$_2$S m$^{-3}$ h$^{-1}$ immediately after acclimation. This value is higher than others reported in the literature for field systems (Gabriel and Deshusses, 2003). During acclimation the concentration of influent H$_2$S varied diurnally by approximately one order of magnitude. The lowest concentration observed was 10 ppm and the highest concentration was 211 ppm. Diurnal temperature variations were also significant since the filters were placed on top of a covered sedimentation basin and exposed to full sunlight. The minimum temperature of 12°C was observed after acclimation at the 150 cfm on 11/10/10. The maximum temperature of 30°C was observed at the outlet on 10/19/11. The system was surprisingly resilient considering the wide variations in operating conditions.

![Figure 2](image-url)  
Figure 2. Mass removal rate as a function of mass input rate for the first acclimation period.

Figure 3 contains mass removed versus mass input data in g H$_2$S m$^{-3}$ h$^{-1}$ for the days (11/11/10-12/17/10) which is when the largest variation in H$_2$S loadings occurred. During 11/12/10-11/16/10 (red dots) and 11/23/10-11/29/10 (light blue dots) problems with power supply or the fan caused the less efficient removal at loading rates above 75 g H$_2$S m$^{-3}$ h$^{-1}$. During the period of 11/16/10-11/19/10 the loadings exceeded 200 g H$_2$S m$^{-3}$ h$^{-1}$ yet complete H$_2$S removal was observed as influent H$_2$S concentrations exceeded 300 ppm. The large variations in loadings
were due to maintenance issues at Arrowhead Water Reclamation Plant and were not typical of normal operating conditions. During the period of 11/19/10-11/23/10 the influent \( \mathrm{H}_2\mathrm{S} \) concentration reached 485 ppm and the loading exceed 300 g \( \mathrm{H}_2\mathrm{S} \) m\(^{-3}\) h\(^{-1}\) (Figure 4.) During 11/19/10-11/23/10 the removal efficiency began to clearly decrease at loadings above 150 g \( \mathrm{H}_2\mathrm{S} \) m\(^{-3}\) h\(^{-1}\). The decrease in removal at higher loadings might have been from nutrient limitations. The mass transfer capacity of the system might have also been reached, but efficient removal at loadings greater than 200 g \( \mathrm{H}_2\mathrm{S} \) m\(^{-3}\) h\(^{-1}\) was observed during the previous time period. Since removal as observed at high loadings previously, it is possible that continued operation at high loadings was not sustained as nutrients became exhausted. The system relies on nitrogen in the plant effluent which is sufficient at average loadings approximately 1/3 less than what was observed during the period of 11/19/10-11/23/10.

![Figure 3. Mass removal rate as a function of mass input rate following acclimation during periods of high loading.](image-url)
After the filter media was modified to become a dual media filter, the acclimation period was similar to that observed with the single media filter and greater than 99% removal was observed after 21 days of operation. Removal efficiencies greater than 99% continued as the mass loadings rates were consistently less than 100 g H₂S m⁻³ h⁻¹. The significant diurnal variations in H₂S that causes the large variation in loading rates also continued throughout the study. Towards the end of the experimental period with the dual media filter, the loadings exceeded 100 g H₂S m⁻³ h⁻¹. The mass removed and mass in for the high loading period are presented in Figure 6. Greater than 99% removal is observed at loadings up to 120 g H₂S m⁻³ h⁻¹ and greater than 95% removal was observed at loadings over 150 g H₂S m⁻³ h⁻¹.
The stoichiometry of the microbial oxidation of sulfide to sulfate was determined using classical thermodynamic analysis of the half reactions with nitrate as the nitrogen source. From this analysis it was determined that the nitrogen requirement is 0.014 gN/gS. Based on the stoichiometry, the nutrients in the reclaimed water can sustain removal of an average loading of 75 g H₂S m⁻³ h⁻¹. This is the average loading over a 24 hour period and the system has been observed to maintain removal efficiencies at loadings up to 200 g H₂S m⁻³ h⁻¹. However, the system would not be able to sustain removal at such high loading rates and nutrient limitation could have affected performance with the single media filter at high loading rates. Nutrient limitations are most commonly observed at high loading rates (Son et al. 2005, Morgenroth et al, 1996).

The effluent pH was almost always in the range of 2 to 2.3. This pH is ideal for the sulfide oxidizing organisms and it also indicates that all the alkalinity in the applied water was exhausted. From the stoichiometric reaction, there are 0.046 of acid equivalents produced per gram of sulfur removed. Based on the alkalinity of the wastewater, an average minimum loading of 19 g H₂S m⁻³ h⁻¹ is sufficient to neutralize the alkalinity and reduce the pH.

Conclusions

The novel filter media evaluated for the biofiltration of H₂S was capable of efficiently removing H₂S at loading rates up to 200 g H₂S m⁻³ h⁻¹. The volumetric elimination rates observed were higher than those previously reported for a biofilter evaluated in the field (Iranpour et al, 2005). At higher loading rates, detectable effluent concentrations that could be potentially exceed odor thresholds were observed.
The dual media filter performance was similar to the single media performance and excellent removal was observed at loading rates up to 150 g H₂S m⁻³ h⁻¹.

Diurnal variations in concentration, loading and temperature did not adversely affect performance. Influent concentrations up to 485 ppm were observed in the study.

Reclaimed water was successfully used as a nutrient source with nitrate as the major nitrogen source. The alkalinity in the reclaimed water was consumed. Nutrient limitations might have occurred during an extended high loading period with the single media filter.

References


