APPLICATION OF BIOTRICKLING FILTER TECHNOLOGY TO TREAT OFF-GAS FROM STRIPPING TOWERS REMOVING HYDROGEN SULFIDE FROM GROUND WATER

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Control of hydrogen sulfide (H_2S) emissions from air degasifying towers at water treatment facilities is a high priority for municipalities across North America. H_2S emissions are controlled by the Clean Air Act of 1990 and its Amendments, and thus require removal from the air prior to being discharged into the environment. The primary regulatory driving force is that of odor nuisance; public health impacts become a concern only at higher H_2S concentrations. Unfortunately, H_2S has a very low odor detection threshold, and as a result it has to be removed to concentration levels much lower than what is required by the Clean Air Act.

The use of H_2S degrading microorganisms to treat off-gas from degasifying (stripping) towers is an important and developing application of cell immobilization technology. Biotrickling filter technology utilizes immobilized microbial cells that are attached to a medium inside the reactor. The H_2S is then biologically oxidized (degraded) with microorganisms to odorless compounds. Since the process relies completely on biological means, it is environmentally-friendly and has a low operating cost compared to physical/chemical alternatives such as chemical scrubbers.

A full-scale biotrickling filter 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 and high H_2S loadings (> 250 g H_2S/m^3.hr) on the biotrickling filter's performance. The biotrickling filter uses structured synthetic EcoBase™ media that has a life expectancy of more than ten years.

The biotrickling filter inlet and outlet H_2S concentrations were continuously measured and recorded with OdaLogs over a 9 month period. The residence time for the BF reactor was varied between 2.4 and 9.8 s, and the H_2S concentration varied between 50 and 350 ppmv for the duration of the test period.

At an average empty bed residence time (EBRT) of 2.8 s, the biotrickling filter removed more than 99% of the H_2S at volumetric loading rates up to 272 g/m^3.hr. The H_2S removal efficiency was 97% at volumetric loading rates greater than 472 g/m^3.hr at the same EBRT.

The results show that the biotrickling filter could effectively remove H_2S under very high volumetric loading rates (> 250 g/m^3.hr) and short residence times (< 2.8 s). The significance of this finding is that it is possible to economically treat off-gas from air stripping towers with biotrickling filter technology. Biotrickling filters are an environmentally-friendly technology and provide benefits over existing chemical scrubber technology such as very low operating cost, low maintenance requirements, and elimination of the use of hazardous chemicals at a similar reactor foot print.

Keywords: biotrickling filter, air stripping, off-gas treatment, hydrogen sulfide removal, biological emissions control, odor control.

Introduction

In many parts of the United States, groundwater containing high concentrations of hydrogen sulfide (H_2S) is used as a source of water supply for drinking water treatment plants. Due to possible health effects, unpleasant taste and odors, the dissolved H_2S has to be removed from the groundwater before it could be used for human consumption. This is commonly achieved with degasifying towers during which the H_2S is stripped from the water and transferred to the air. The presence of H_2S in air presents another challenge; it requires that the air be treated before it could be discharged into the environment.

H_2S emission control from air degasifying towers is regulated by the Clean Air Act of 1990 and its Amendments. The primary driving force is that of odor nuisance; public health impacts become a concern only at higher H_2S concentrations. H_2S has a very low odor detection threshold (0.5 – 20 ppbv) (Chan, 2006), thus it has to be removed to concentration levels much lower than what is required by the Clean Air Act.

Chemical scrubbers are the most commonly used technology for the removal of H_2S from degasifying tower off gas streams. It uses a packed-bed tower design and utilizes chemicals such as caustic (NaOH) and hypochlorite (OCl^-) to remove the H_2S from the air, and dissolve and further oxidize it in the water phase. Although chemical scrubbers are effective in removing H_2S from air, their drawbacks include high operating costs, generation of halomethanes that are known air toxics, and they use hazardous chemicals that pose serious health and safety risks (Cox et al., 2002).

The removal of H_2S from air with chemical scrubbers could be described by the following chemical reactions (MAP 25, 2004).

$$H_2S + 2\ NaOH \leftrightarrow Na_2S + 2\ H_2O$$

$$Na_2S + 4\ NaOCl \leftrightarrow Na_2SO_4 + 4\ NaCl$$

The net result is the production of sodium sulfate (Na_2SO_4) and sodium chlorite (NaCl) that are removed from the scrubber with the blow down water.

Figure 1 shows a schematic of a typical groundwater H_2S stripping tower along with a chemical scrubber.

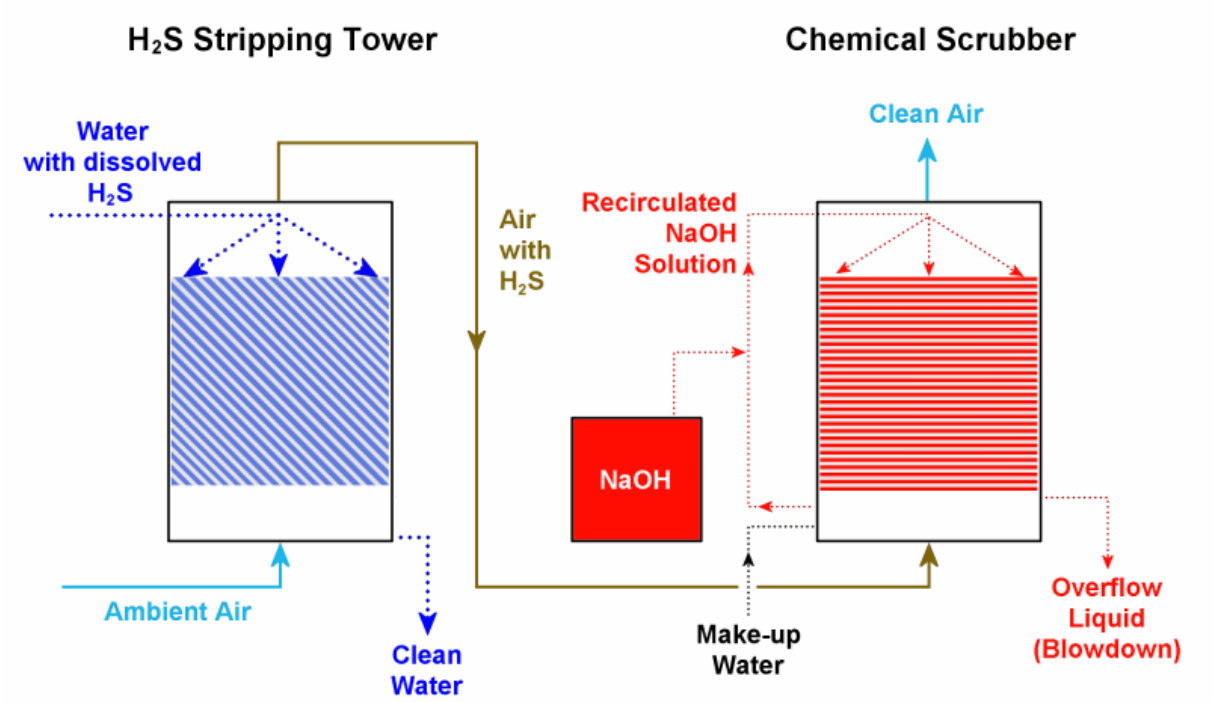

Figure 1: Groundwater Treatment with Air Stripping Tower Followed by Chemical Scrubber

Biotrickling Filters for H_2S Removal

During the past decade, biotrickling filters have become increasingly popular for the treatment of H_2S and other municipal odors, especially at wastewater treatment plants and pump stations. Although primarily used in the wastewater industry, biotrickling filters are well-suited for treatment of off gas coming from ground water stripping towers.

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 2) (le Roux et al., 2009). The odorous 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).

The biochemical reaction that describes the oxidation of H_2S is as follows:

$$H_2S + 2\ O_2 \rightarrow H_2SO_4$$

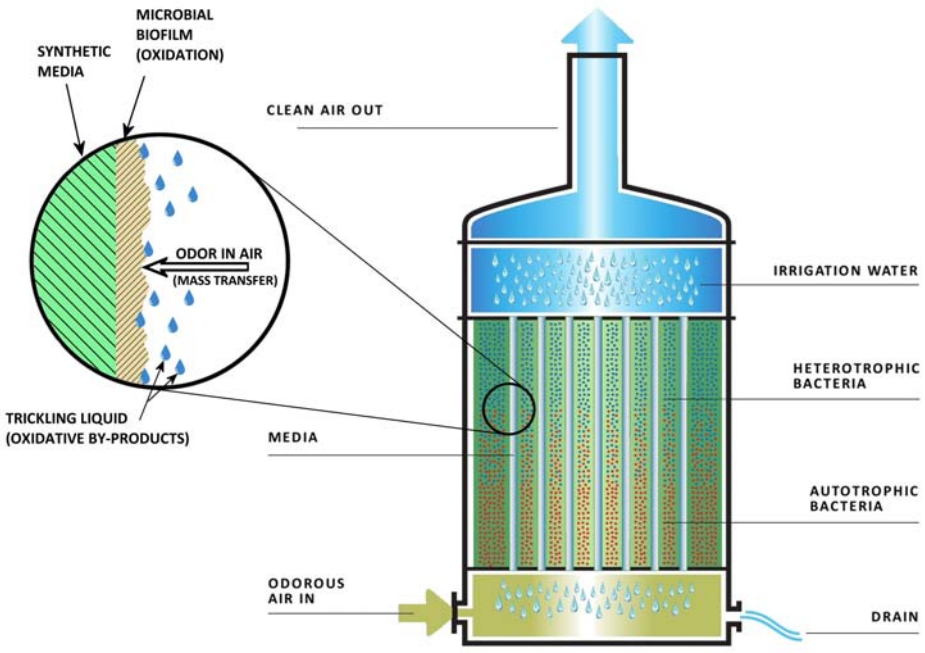

Figure 2: Schematic Presentation of the Operation of a Biotrickling Filter.

The biotrickling filter process relies completely on biological means, thus it is environmentally-friendly and has a very low operating cost. Figure 3 shows a flow schematic of the use of a biotrickling filter to remove H_2S from degasifier off gas.

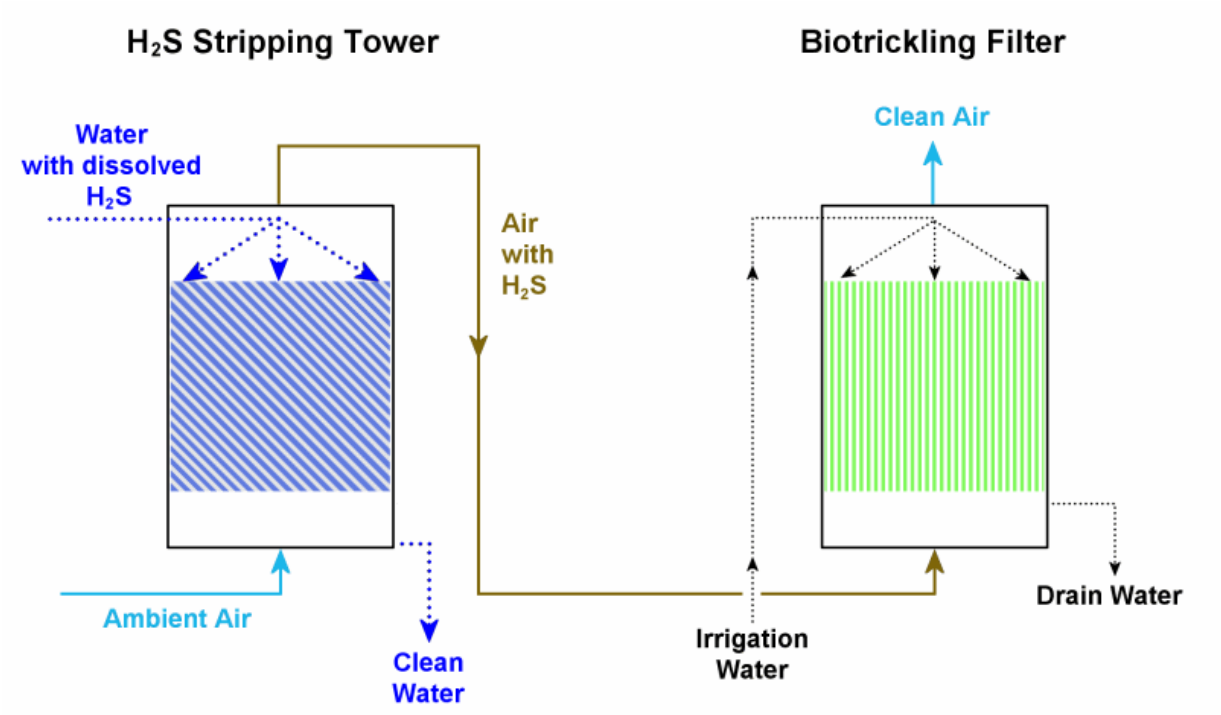

Figure 3: Application of H_2S Stripping Tower Followed by Biotrickling Filter

One of the disadvantages of the original biotrickling filter design is the fact that it required long empty bed residence times (up to 5 - 7 times that of chemical scrubbers), thus often making it capital cost prohibitive for the treatment of large airflows.

This study focused on the use of a biotrickling filter to remove H_2S from a municipal air stream, and in particular, investigation of the effect of short empty bed residence time (EBRT) on the biotrickling filter performance.

Objectives

The objectives of this study was 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 4). 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 4 for details on the System.

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.

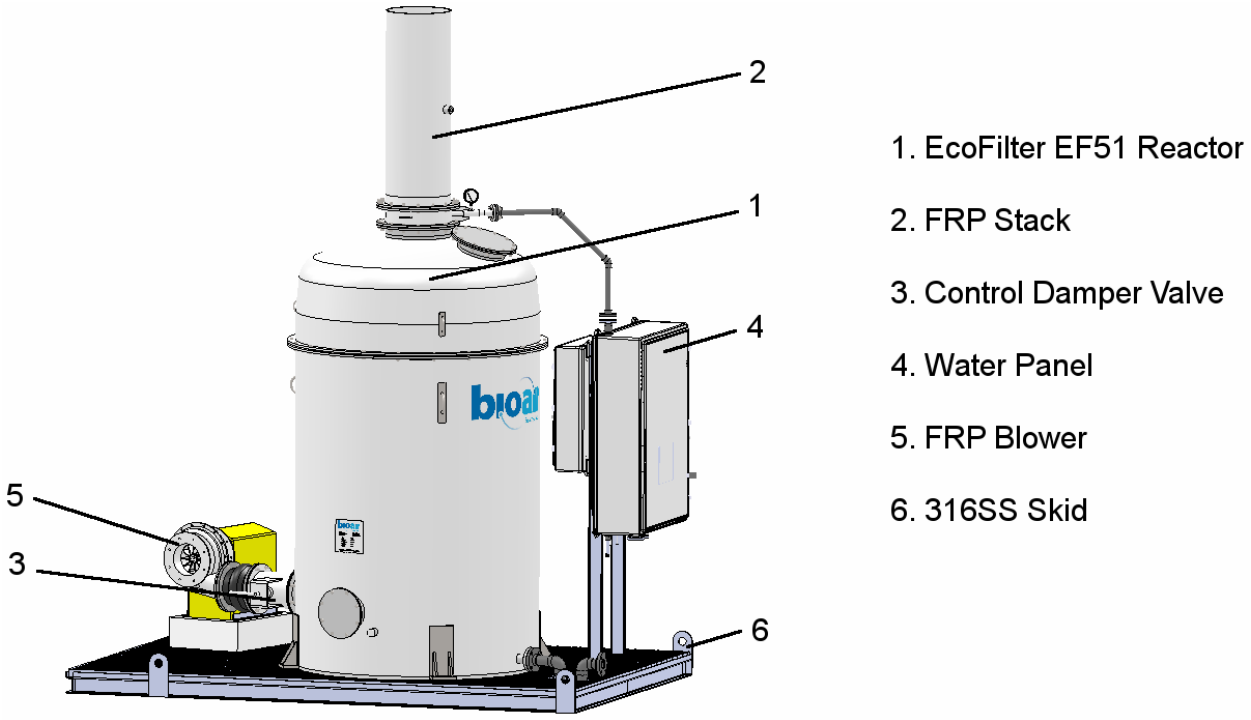

Figure 4: Skid mounted EcoFilter EF51 biotrickling filter.

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 in Jacksonville, FL. The odor source was from the gravity belt thickeners located in the biosolids building. The H_2S concentration in the air stream varied between 50 and 350 ppmv.

Results and Discussion

The biotrickling filter 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 5). 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. The average H_2S removal on May 27 was 99.9% and the mass loading 76 g H_2S/m^3.hr.

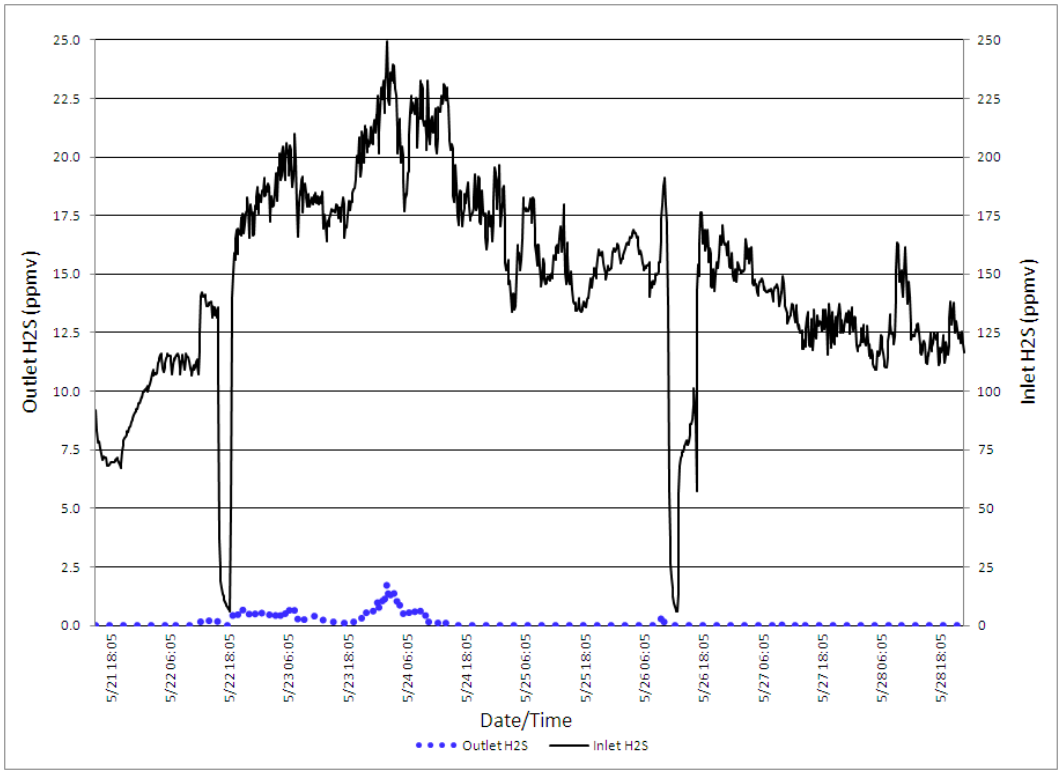

Figure 5: Reactor inlet and outlet H_2S concentration at 10 s EBRT. Average H_2S removal for duration of data shown is 99.92%.

Several experiments were performed at 7 s and 5 s EBRT during the period May 27, 2009 and July 1, 2009. On July 1, 2009, the airflow to the System was set at 1,650 cfm, which corresponds to an EBRT of 2.8 s, the results of which is reported below.

2.8 s EBRT Data: The System was operated at 1,650 cfm airflow for approximately four weeks to provide sufficient acclimation time. The reactor inlet and outlet H_2S concentration for the period August 7 till August 13 is shown in Figure 6. 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) resulting in a H_2S removal efficiency of greater than 99.9%.

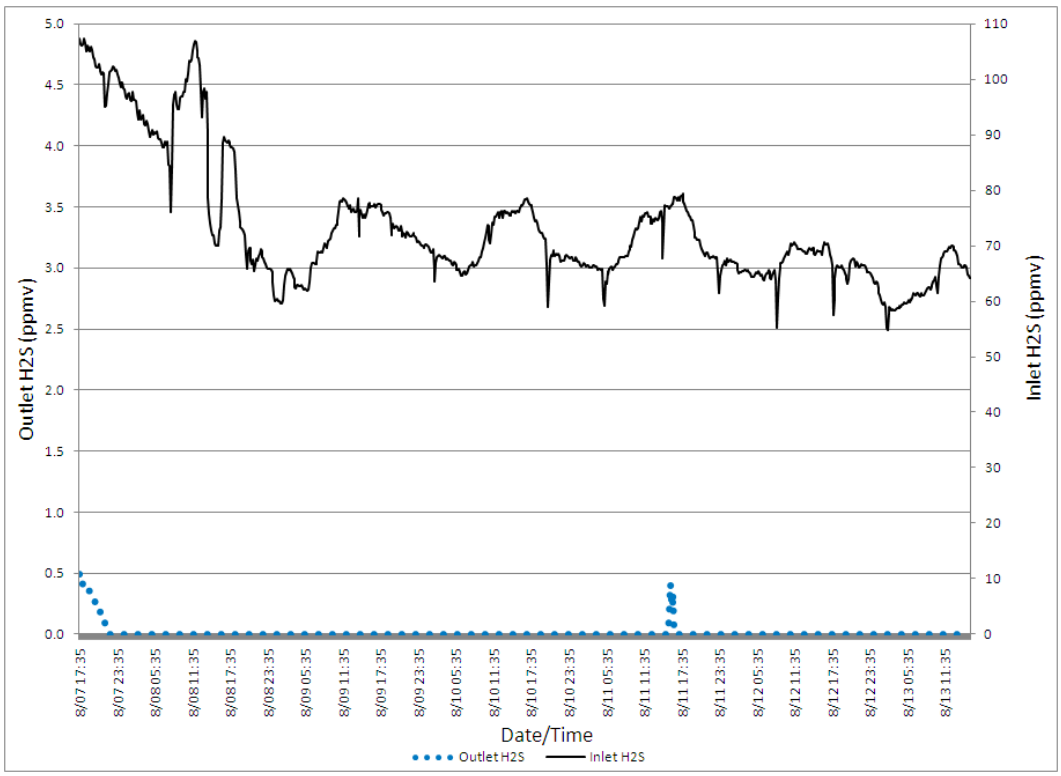

Figure 6: Reactor inlet and outlet H_2S concentration at 2.8 s EBRT.

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 7 shows the 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 7). The formula was used to determine the maximum H_2S Load for which 99% and 95% H_2S removal were achievable, and it was calculated to be 247 and 524 g H_2S/m^3.hr, respectively. These loading 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).

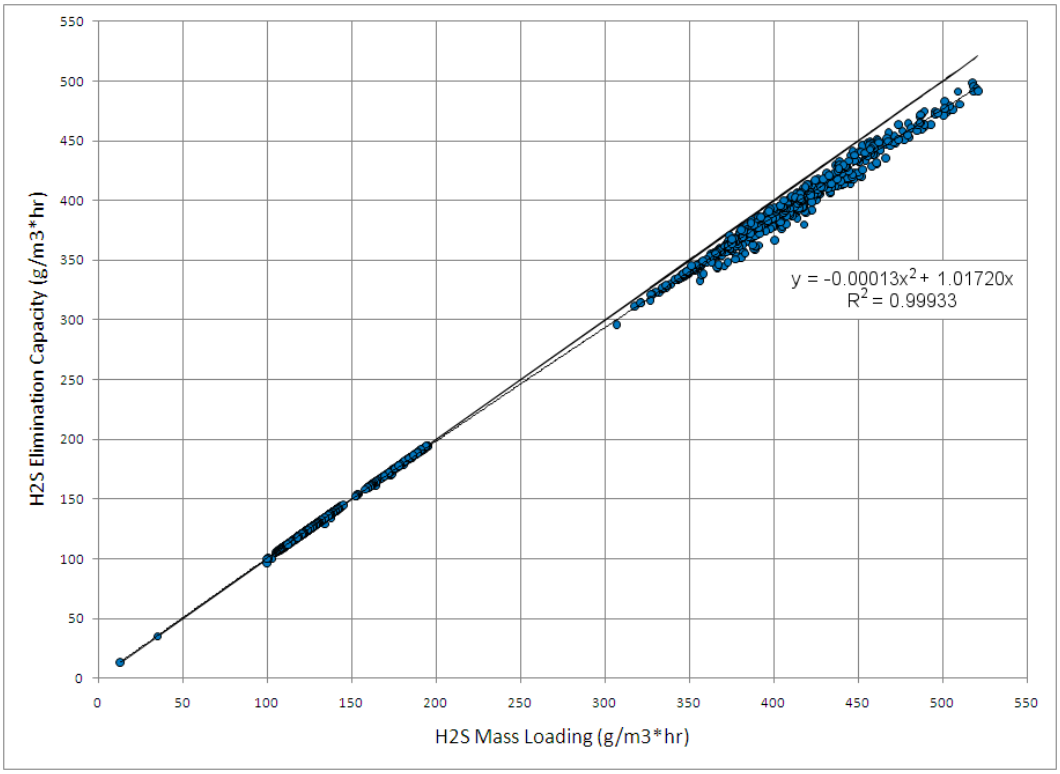

Figure 7: H_2S Mass Loading vs. Elimination Capacity at 2.8 s EBRT.

Conclusions

The results showed that it is possible to treat air streams contaminated with H_2S with the EcoFilter biotrickling filter technology at 2.8 s EBRT. The biotrickling filter system reduced the H_2S from an average concentration of 73.3 ppmv to less than 0.01 ppmv, which equates to a removal efficiency of 99.98%.

Another key finding from this research was the fact that the biotrickling filter 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 was 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 biotrickling filters could be used to treat H_2S from degasifier off gas 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 but at a capital cost similar to that of chemical scrubbers.

Acknowledgement

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