Water Usage Optimization in Biofiltration Odor Systems

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ABSTRACT

The goal of this project was to maintain optimal pH in a biotrickling filtration system (BTF) while reducing water usage by using alkaline material to neutralize part of the sulfuric acid produced during operation. Normally pH is maintained using a continual stream of fresh water, called make-up water, into the BTF. However in cases where the site supply of make-up water is not sufficient to maintain optimum pH alone, alkaline addition would allow a BTF to function as well as if it had an adequate water supply to do so. Dosing a sufficient amount of alkaline material may achieve an even more aggressive reduction in water usage; however, the entire quantity of make-up water cannot be replaced with alkaline material due to system losses from evaporation and to prevent concentration of salts. It was important to achieve the water reduction without negatively impacting system performance. The goal was accomplished in May 2015 using a 3-stage 3.7 m (12 ft) diameter BTF operating at 283 m^3/min (10,000 ft^3/min) in Florida, using 50% caustic soda (sodium hydroxide) as the alkaline material in conjunction with a pH control system. Initial water usage at the site was 64 L/min (17 gpm) on average. After addition of caustic soda and utilizing pH control, the water usage dropped to an average of 19 L/min (5 gpm), a 70% reduction, while maintaining previous levels of hydrogen sulfide removal. A second trial was conducted in January 2016 using a 60% magnesium hydroxide slurry as the alkaline material. While there was a reduction in water usage, the magnitude of the reduction was less than expected for the amount of magnesium hydroxide used.

KEYWORDS: Sulfide oxidation, biofilter, pH, hydrogen sulfide, alkaline, odor

INTRODUCTION

The cost of water is a significant part of the operational costs of a biofiltration system and a target for improvement. A typical system may use from 53,000 liters (14,000 gallons) per day for smaller units to 120,000 liters (30,000 gallons) per day for larger units depending on loadings and limit of water supplied at the site. This amounts to 34 million liters (9 million gallons) of water consumed per year on the high end. For one municipality in Florida, the cost of water alone in operating a 3-stage biotrickling filter system (BTF) is roughly $67,000 per year. Optimizing the usage of water in these systems in order to lower operation costs and better use scarce water resources is an important goal in the sustainable design of these systems.

A biotrickling filter utilizes the capability of aerobic sulfur-oxidizing prokaryotes such as *Acidithiobacillus* to biologically oxidize inorganic sulfur compounds to sulfate (Friedrich et al., 2001). The input of fresh water into a biotrickling filter (BTF) system, called make-up water, is used to dilute the accumulation of acid produced by conversion of hydrogen sulfide to sulfuric acid. This dilution is important in maintaining a pH within the system that encourages the continued optimum activity of these bacteria. While *Acidithiobacillus* is acidophilic and grow in low pH environments (Khan et al., 2012), the complete absence of dilution would lead to accumulation of sulfate and extreme lowering of pH and decrease in removal efficiency (Lee et al., 2006). As hydrogen sulfide loading on a system increases, a larger quantity of sulfuric acid is produced, and a larger quantity of make-up water is required to sustain desired pH. Occasionally, the rate of supply of make-up water at a site is not sufficient to sustain desired pH. This can occur either at sites with limited access to water, or at sites that handle very high loadings where water demand reaches impractical levels. In these systems, performance can suffer as pH is lower than the optimal range.

RESULTS AND DISCUSSION

Addition of Sodium Hydroxide 50%

The first trial was conducted from May 15, 2015 at 1:41 PM to May 20, 2015 12:31 PM. From May 15 to May 18, the system was operated using the maximum site-available make-up water rate of roughly 64 L/min (17 gpm). From May 18 to May 19, the system was operated with addition of 50% caustic soda (sodium hydroxide) fed at a rate of 113 liters per day (30 gallons per day), and the rate of make-up water was adjusted using a fuzzy logic algorithm controlling an actuated globe valve attempting to control pH at 1.72. Fuzzy logic enables adjustment of the valve much like a human would by allowing the computer to reason with common-sense rules and vague input parameters (Kosko and Isaka, 1993). From May 19 onward caustic was removed, but the fuzzy logic controller was allowed to continue to adjust make-up water addition as necessary in attempt to maintain the pH 1.72 set-point. Prior to addition of caustic, the site available water rate was insufficient to achieve an average pH of 1.72, as seen in Figure 1.

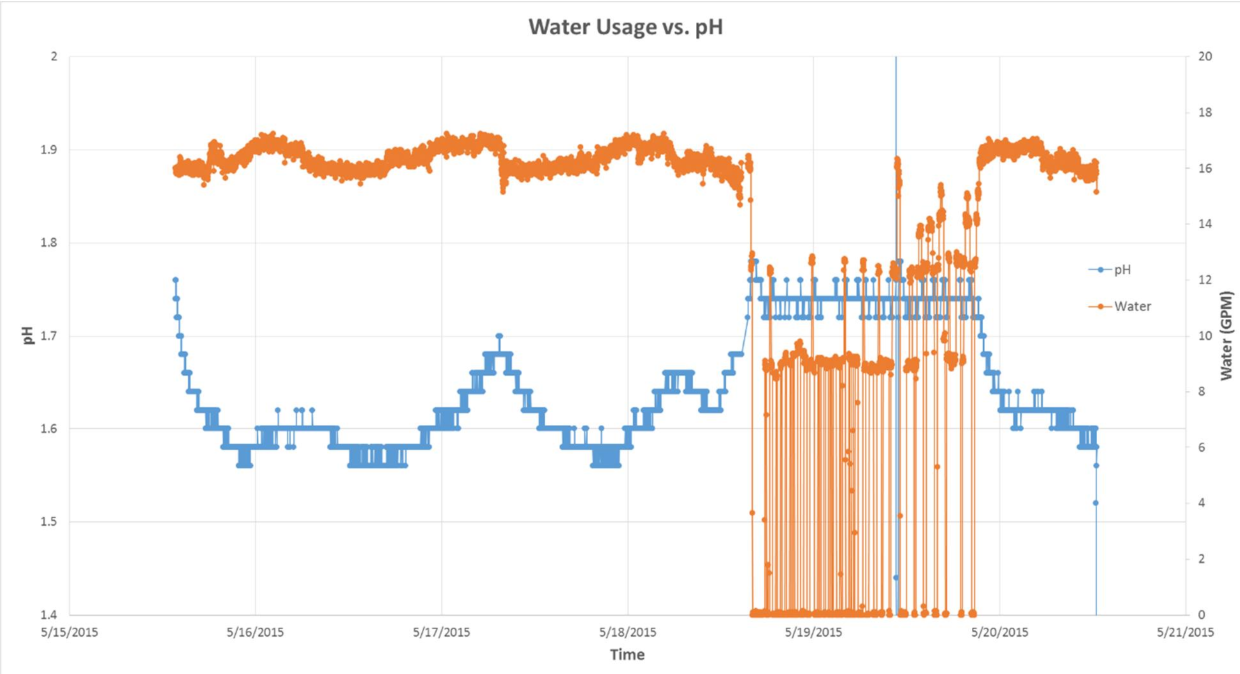

Figure 1. Water Usage vs. pH

Make-up water rate during the pre-caustic period averaged 61.7 L/min (16.3 gpm). The average pH was 1.61 with a high of 1.70 and a low of 1.56. Average H_2S loadings were 150 ppm. On May 18 caustic addition was initiated and the system was placed in automatic pH control. This allowed an actuated globe valve to throttle water in response to changing pH in attempt to keep pH at a user specified set-point and tolerance. Water usage dropped to 19 L/min (5 gpm) and pH was kept at average of 1.73 with a low of 1.70 and a high of 1.78. Average H_2S loadings were 130 ppm, slightly lower than the pre-caustic levels of 150 ppm, but comparable. It was important to establish that loadings were comparable during these two periods so that the reduction in water usage can be properly attributed to the caustic addition and pH control and not a drop in H_2S loading (Figure 2).

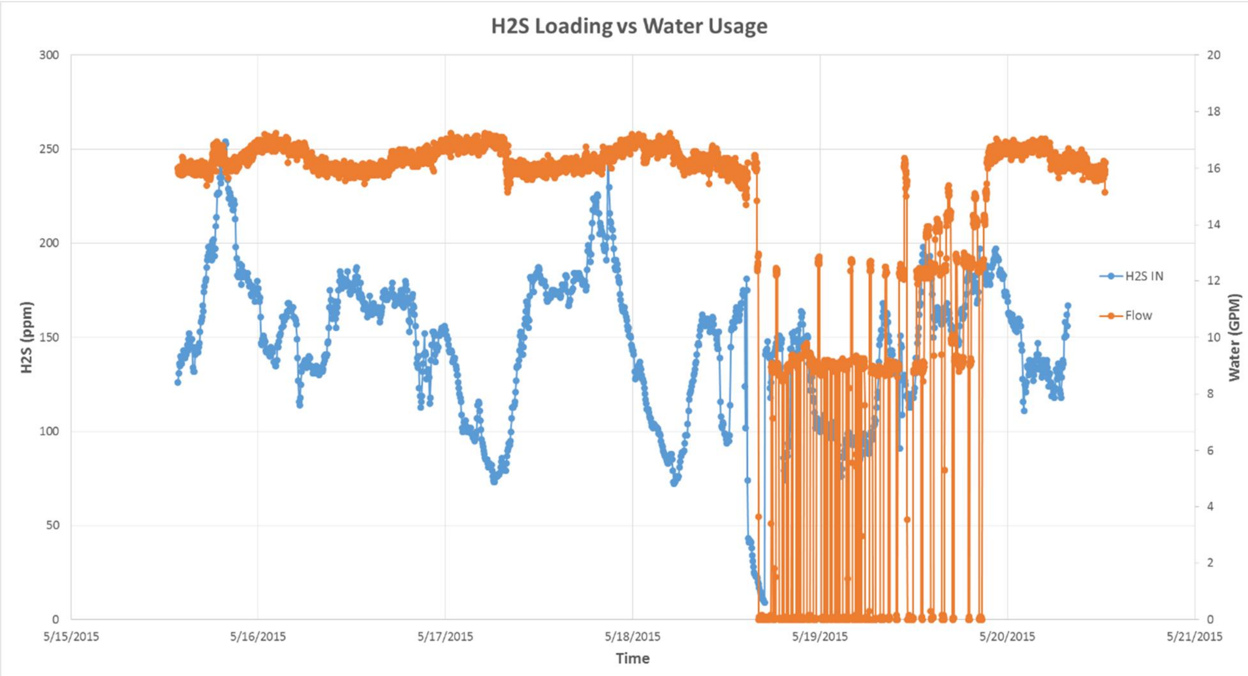

Figure 2. H_2S Loading vs Water Usage

On May 19 the caustic soda feed was removed from the system while the pH control was allowed to continue to operate. A steady drop in pH can be observed as soon as caustic is removed from the system (Figure 1). The impact on water usage is immediately observable as without the additional neutralization provided by the caustic the pH control logic commanded the valve to 100% open in attempt to bring the pH back up to the 1.72 set point. Even at maximum flow, the site-available flow rate of was not sufficient to maintain the 1.72 set point and as a result, the valve remained open and water usage was pushed to maximum site available flow for the remainder of the experiment (Figure 1).

The final parameter that was evaluated in this experiment was the inlet H_2S vs outlet H_2S before, during and after the caustic addition. It was important to establish that the addition of caustic would not have a negative impact on the biology of the BTF, and that the reduction in water would not decrease the performance of the BTF. As can be seen from Figure 3, H_2S removal was maintained during the experiment without any large fluctuations in performance during or after caustic addition. The one caveat to this is the brief and small rise in outlet H_2S on May 18, which was a result of a depleted nutrient reservoir. As soon as the nutrient reservoir was replenished, the outlet H_2S dropped to previous levels, and was maintained until the end of the experiment.

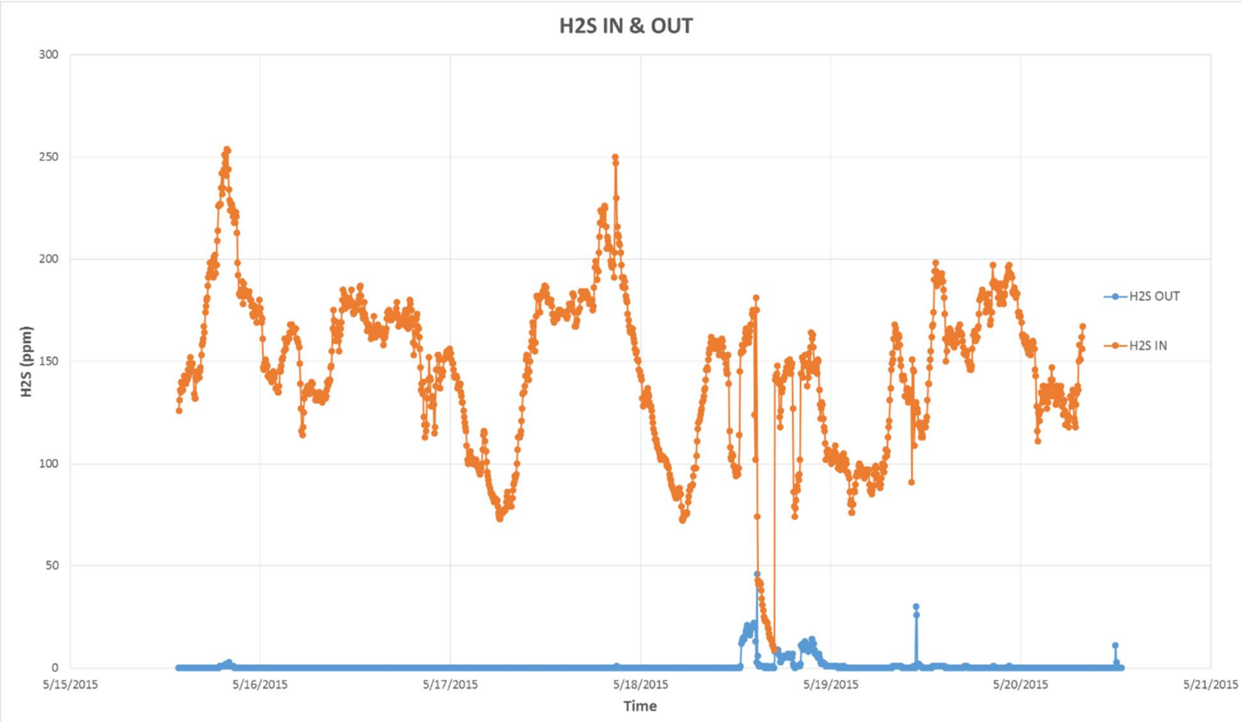

Figure 3. H_2S In and Out

Table 1. Operation Summary for Sodium Hydroxide

Start Date/ Time	End Date/ Time	Caustic Feed Rate (LPD/ GPD)	Make-up Water Rate (LPM/ GPM)	Average pH	Minimum pH	Maximum pH	Average Influent H_2S (PPM)
5/15/2015 1:41 PM	5/18/15 12:31 PM	0	64/17	1.61	1.56	1.70	150
5/18/2015 12:31 PM	5/19/2015 9:31 PM	113/30	19/5	1.73	1.70	1.78	130
5/19/15 9:31 PM	5/20/15 12:31 PM	0	64/17	1.62	1.52	1.68	150

Addition of Magnesium Hydroxide 60%

The second trial was conducted in the period between January 7, 2016 1:00 PM to January 17, 2016 12:00 AM using magnesium hydroxide as the alkaline material and pH set point of 1.70. Feed rate of magnesium hydroxide was derived from the equivalent alkalinity of magnesium hydroxide slurry to 50% sodium hydroxide. 1.00 kg of NaOH is equivalent in alkalinity to 0.73 kg of $Mg(OH)_2$ and volume ratio of 0.60 to 1.00. The volumetric equivalent of 113 L (30 gal) of sodium hydroxide in magnesium hydroxide is approximately 68 L (18 gal). However, total feed was set at 95 liters per day (25 gallons per day) fed at 66 mL/min; the additional margin was to accommodate the anticipated incomplete dissolution of the slurry when dosed. Data on pH and flow in a period of roughly 24 hrs before the trial was captured and used as a baseline before addition of magnesium hydroxide. The system was in automatic pH control and allowed to utilize the water resources necessary to attempt to maintain the pH set-point. Water usage was 59.4 L/min (15.7 gpm) on average during this period and pH was on average 1.69. Magnesium hydroxide feed was started on January 8, 2016 at 3:00 PM and continued until 3:11 PM January 14, 2016. There is a break in recorded data starting on January 13, 2016 5:57 AM as the data logger device ran out of memory and ending on and January 15, 2016 3:11 PM when the device was replaced. This discontinuity displays as a gap in charted data below (Figure 4).

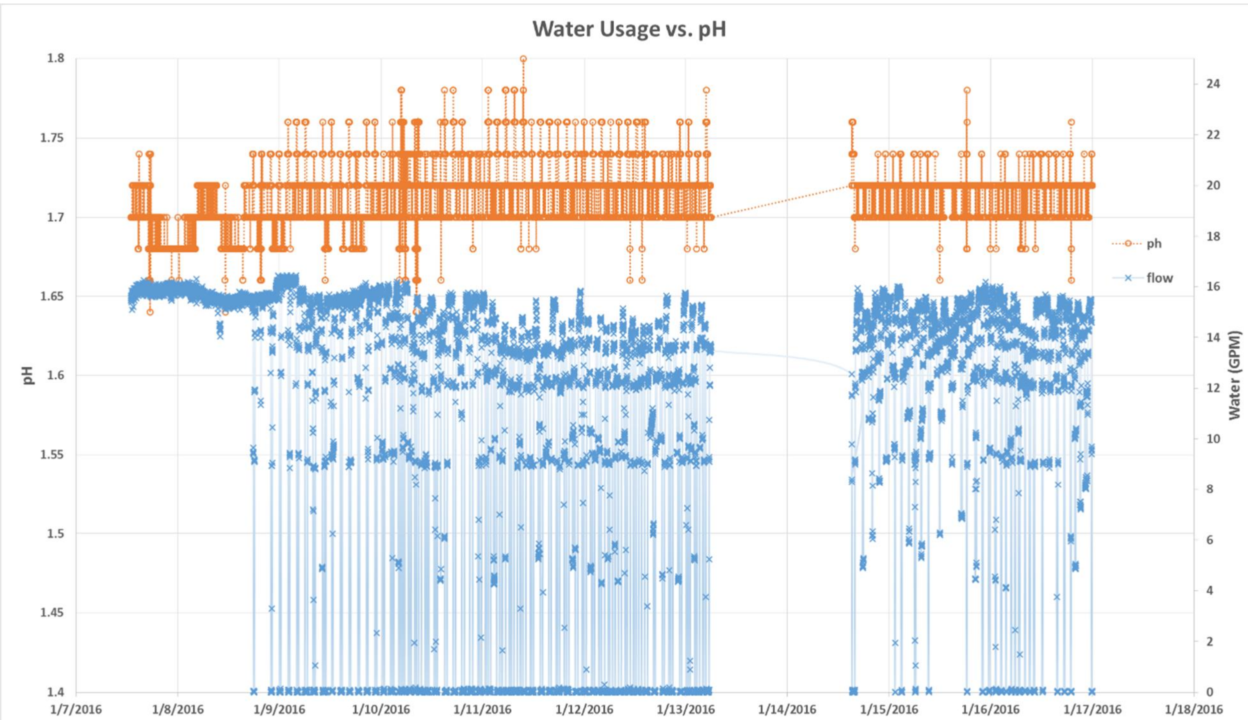

Figure 4. Water Usage vs. pH (Magnesium Hydroxide)

Water usage averaged 35.2 L/min (9.3 gpm) during the magnesium hydroxide phase, a 40% reduction. Average pH was maintained at 1.71. While a clear reduction in water is apparent from the pre-trial average of 59.4 L/min, this is a smaller reduction than anticipated from the results seen in the sodium hydroxide trial. In theory with the same molar concentration of hydroxide ions added to the system, a similar percentage reduction in water usage should be observed. Even with the additional margin of 27 liters per day, magnesium hydroxide failed to achieve a similar water reduction. It is hypothesized that the slow dissolving nature of the magnesium hydroxide slurry is mainly responsible for these challenges.

In addition to achieving a smaller reduction in water usage, pH control was less tight during the magnesium hydroxide phase. While average pH was successfully maintained at 1.71, there were far more instances of short peaks, many in excess of 1.75, which were not observed either during the sodium hydroxide trial or prior to adding magnesium hydroxide. It is important to note that the majority of deviations are upward deviations above the set-point and not downward deviations. This observation in conjunction to the smaller reduction in water usage support the hypothesis that the magnesium hydroxide slurry is incapable of dissolving as quickly as sodium hydroxide to accommodate the on-the-fly adjustment algorithm used to control pH. These peaks may occur if the logic determines that the make-up water valve needs to be opened if pH drops below the set-point, but after the valve is opened residual undissolved magnesium hydroxide dissolves causing overshoot from the intended set-point.

Magnesium hydroxide feed was ended on January 14, 2016 3:11 PM. The system was allowed to continue in automatic pH control to observe if water usage would rise to pre-trial levels without alkaline additive; data was collected from this point until January 16, 2016 11:59 PM. While water usage did rise, it was not to the expected pre-trial levels of 59.4 L/min. Water usage on average during this period was 47.7 L/min (12.6 gpm) despite identical pre-trial H_2S loadings (Figure 5). Furthermore this low water usage without alkaline additive is atypical of this system in particular and has not been observed in months of background data collected. A possible explanation relates to the slowly dissolving nature of the magnesium hydroxide slurry. There may be additional residual neutralization occurring from undissolved material dosed into the sump of the BTF allowing water reduction even after magnesium hydroxide feed was halted.

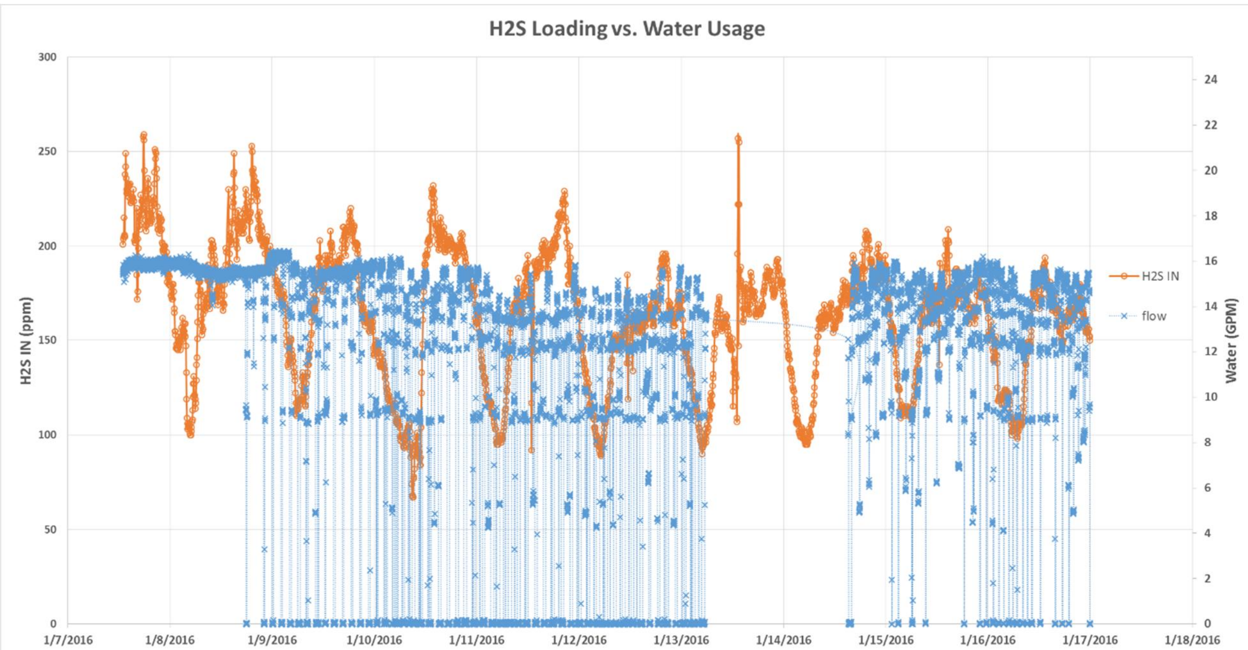

Figure 5. H_2S loading vs. Water Usage (Magnesium Hydroxide)

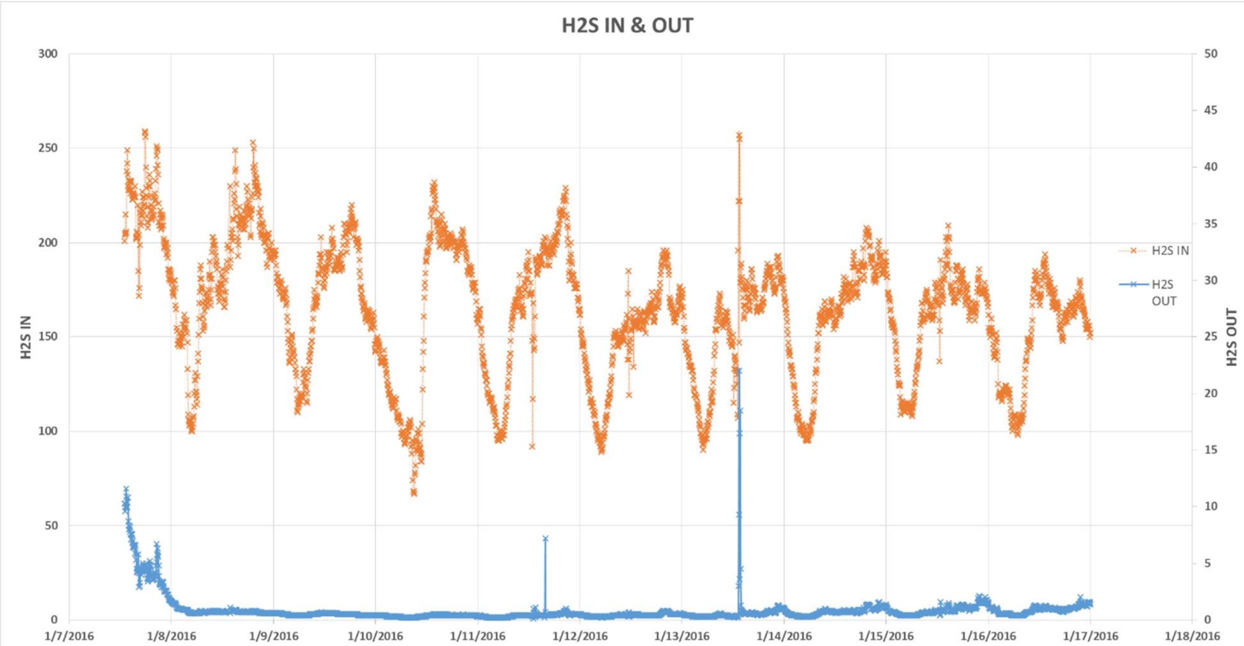

Figure 6. H_2S In and Out (Magnesium Hydroxide)

CONCLUSION

Optimizing water usage in biofiltration systems using fuzzy logic pH control and alkaline addition is a large step forward in the sustainable design of these systems, and has tangible economic and environmental benefits. The pH control system allows the water usage to be adjusted automatically without user intervention while a set dosage of alkaline material assists in a known capacity to partially neutralize sulfuric acid produced. These two combined techniques reduce water expenditures and allow operation of a BTF at site with otherwise insufficient water. While water usage reduction is the goal, the entire balance of water cannot be replaced with an alkaline additive. A sufficient average level of water flow must still be maintained for several reasons: to counter evaporation, flush the media beds and prevent accumulation of ions from alkaline dosing that may precipitate unwanted solids and clog the beds.

Proof of concept for this method was successfully demonstrated using 50% sodium hydroxide as the alkaline material. The main advantage of sodium hydroxide is the high solubility and reaction of the hydroxide ion when dosed. In addition there is far less risk in fouling the media bed. Due to the success of using sodium hydroxide, magnesium hydroxide was tested as an alternative. Magnesium hydroxide is a desirable alkaline source for this application due to its non-hazardous rating. However solubility of magnesium hydroxide is much less than sodium hydroxide, 0.0009 g/100 mL at 18°C (Lide, 1994, pp. 4-77) compared to 42 g/100 mL at 0°C (Lide, 1994, pp. 4-105) for sodium hydroxide. Results indicate that magnesium hydroxide has an effect in reducing water usage but the magnitude of the effect is much less than sodium hydroxide most likely as a result of the decreased solubility of the slurry. The initial benefit of a lower volume of magnesium hydroxide required is offset by poor solubility and the need to dose more to achieve the similar results. While magnesium hydroxide may be used these challenges must first be overcome. Additional research is underway to address these challenges.

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