Control of Microbiologically Induced Corrosion of Collection System Infrastructure

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ABSTRACT

Hydrogen sulfide production by microorganisms has been identified as one of the major causes of wastewater infrastructure corrosion and deterioration worldwide. The control of hydrogen sulfide production in anaerobic biofilms was studied at a suction lift wastewater pump station and forcemain. In this field study, ozone injection was evaluated as a method for the inactivation of sulfate reducing bacteria and mitigation of hydrogen sulfide problems. Monitoring prior to injection indicated H_2S levels in excess of 200 ppm throughout the day in the forcemain discharge manhole. With the injection of ozone into the when the pump was operating, and into the wet well on a timed on/off cycle when the pump was off, the H_2S level in the discharge was reduced to a maximum of 45 ppm during spike events. The numbers of spike events were also significantly reduced. The H_2S levels were controlled to less than 2 ppm during spike events with the injection of ozone during pump operation only and oxygen when the pump was off. Good control of hydrogen sulfide levels in the pump discharge was achieved with only about two minutes of ozone injection in a 20 minute pump cycle.

1. INTRODUCTION

Corrosion of wastewater collection system infrastructure from microbiological reactions and physical and chemical processes within the collection system is a world-wide problem costing billions of dollars in infrastructure rehabilitation costs [1-3]. The primary cause of this problem is the ability of sulfate reducing bacteria (SRB) to generate hydrogen sulfide in the wastewater under anaerobic conditions, and the ability of sulfate oxidizing bacteria such as *Thiobacilli* that can survive under low pH conditions to oxidize hydrogen sulfide to sulfuric acid. Microbially generated hydrogen sulfide in the solution phase is transferred to the vapor phase by physical and chemical processes operative in the sewer environment, and the gas accumulates on the surfaces of the pipe, or are released to the atmosphere at wet wells and manholes.

There are about 20,000 wastewater systems in the U.S., and about 40% of them use concrete gravity sewers. There are in excess of 2 million wastewater pumping stations associated with collection systems, and these pumps are designed to accommodate future flow conditions and daily variations in flows. As a result the pumps operate in an on and off cycle allowing anaerobic conditions to develop in the forcemains. Thus, hydrogen sulfide corrosion affects not only the pipes, but also the forcemains, manholes, wet wells, mechanical and electrical components in the pump stations, and treatment plants. Corrosion problems can begin at a concentration as low as 0.1 ppm of sulfide (ppmS) in the wastewater. Severe corrosion of concrete materials may occur at a concentration of about 2 ppmS [4,5]. In a survey of 89 cities in 1984, 26 cities reported sewer collapses from hydrogen sulfide corrosion [6]. The cost of rehabilitation of corroded sewers and collection system components is expected to be in the billions of dollars. Los Angeles County alone estimated the cost to be in excess of $500 million [2].

Hydrogen sulfide emissions can create obnoxious odor problems and complaints from residents in the downwind area of a forcemain discharge manhole. It is denser than air, and has a half-life of 12 to 37 hours. Gases emitted in the vicinity of manholes can persist and accumulate in that location for several hours under stable atmospheric conditions. Under moderate wind conditions, the gas can be transported to downwind areas resulting in complaints from homeowners or other inhabitants. The odor is barely perceptible at about 0.13 ppm but noticeable at about 4.6 ppm. The odor is unpleasant at a concentration of about 27 ppm. The Occupational Safety and Health Administration (OSHA) has set a permissible limit of 20 ppm, and a peak exposure limit of 50 ppm for no more than 10 minutes. Inability to detect the odor due to olfactory paralysis can occur at prolonged exposure to concentrations of about 150 ppm. Inhalation of the gas at 500 - 1000 ppm concentration can cause rapid unconsciousness and death. Sewer gas may also contain organic sulfides such as methyl and dimethyl sulfide that are also toxic. Thus, it is important to prevent the production and accumulation of hydrogen sulfide in wastewaters to minimize the impact on infrastructure, personnel and the community at large.

1.1. Hydrogen sulfide production and corrosion of collection system infrastructure

Hydrogen sulfide is generated by sulfate reducing bacteria (SRB) such as from the genera *desulfovibrio* that utilize sulfate (SO_4^{2-}) as electron donor in the utilization of biodegradable organic constituents in the wastewater under anaerobic conditions. The presence of easily degraded organic matter such acetate, lactate, glucose, etc., can enhance the production of H_2S [7]. A biofilm of sulfate reducing bacteria is formed along the inner walls of the pipe and sulfide (S^{2-}), methane and carbon dioxide are produced in the biofilm under anaerobic conditions and transferred to the wastewater. The thickness of the biofilm will be a function of the depth of flow and flow velocity. Typically, pipes with small depth of flow to diameter ratios tend to have thicker films due to low flow velocities. This condition can typically occur during the initial period of operation when the tributary flows to the collection system are low. The series of biological, chemical, and physical transformations that take place after H_2S generation can be given by the following reactions:

$$SO_4^{2-} \xrightarrow{SRB} S^{2-} \qquad (1)$$

$$S^{2-} + H_2O \rightleftharpoons HS^- + OH^- \qquad (2)$$

$$HS^- + H_2O \rightleftharpoons H_2S(aq) + OH^- \qquad (3)$$

$$H_2S(aq) \rightleftharpoons H_2S(g) \qquad (4)$$

Long wastewater residence times in manholes or pipelines, high temperatures, and turbulence (e.g. discharge from forcemain into manhole) are conducive to the production and release of hydrogen sulfide into the vapor phase. The hydrogen sulfide gas along with carbon dioxide, collect on the un-wetted portions of the sewer and dissolve in the moisture on the surface. Sulfide oxidizing bacteria such as *Thiobacillus thiooxidans*, *Thiobacillus neapolitanus* and*,* *Thiobacillus Intermedius* convert hydrogen sulfide to sulfuric acid. Fungi that are operative in pH 2 to 8 range facilitate the colonization of the surface by the *Thiobacilli* [8]. The alkali in the concrete pipe reacts with the acid are produced, forming gypsum and ettringite precipitates that affect the structural integrity of the pipe. Low pH conditions are also conducive to deterioration of other pipe materials including ductile iron.

Corrosion of concrete sewers occurs by the reaction of sulfuric acid with the cementitious material of the concrete. Corrosion products such as calcium sulfate (gypsum) and ettringite are formed. Ettringite is expansive and can cause cracking and pitting of concrete, providing further areas where acid can penetrate and cause accelerated damage. The conversion of concrete to gypsum and ettringite will result in the loss of structural integrity, and failure can occur due to the loss of load bearing capacity. Corrosion rates ranging from 2.5 to 10 mm per year has been reported based on investigation in 34 different cities in the U.S. [6,9].

2. CONTROL OF HYDROGEN SULFIDE IN COLLECTION SYSTEMS

Microbiologically induced corrosion (MIC) and hydrogen sulfide odor problems can be controlled by (1) designing to minimize residence times in sewers and forcemains; (2) adding oxidizing chemicals or maintaining aerobic conditions by the addition of air or oxygen (e.g. Guiterrez et al, 2008); (3) adding chemicals such as nitrate or free nitrous acid for biological oxidation of sulfide from reaction (*1*) [10]; (4) adding iron salts to react with the sulfide to form insoluble precipitates; and (5) adding biocides to reduce the activity of sulfate reducing bacteria in reaction (*1*). Wastewater networks are typically designed for future development, and it is unlikely that sewer pipes will be designed for adequate depths of flow during the initial phase of operation. However, operation and maintenance strategies can be developed to minimize hydrogen sulfide generation in pump stations and pipelines. Strategies for H_2S emission control using chemical and biological methods have been reviewed recently [3,11].

2.1. Addition of oxidants, air or oxygen

Hydrogen peroxide, potassium permanganate, and chlorine can be used to oxidize the hydrogen sulfide in solution to sulfur or sulfate. Hydrogen peroxide will oxidize dissolved sulfide and decompose to produce oxygen. This will maintain aerobic conditions in the wastewater. However, hydrogen peroxide must be added at multiple points due to its low half-life. Potassium permanganate is added as a 6% solution, and will oxidize sulfide to sulfate. It's application is limited due to the high cost. Chlorine will oxidize sulfide or sulfate to elemental sulfur. However, it can react with many other constituents in the wastewater. It can generate chlorinated organic compounds and also cause biocidal action. These chemicals will continue to allow SRB to generate hydrogen sulfide, and once the feeding is stopped, the H_2S problem is likely to become severe.

Anaerobic conditions can be minimized by injecting (1) air or oxygen or by using (2) air aspirating pumps in the pump station [12]. Chemical and biological oxidation can reduce the sulfide concentrations in the wastewater. However, since it is difficult to penetrate the biofilm completely, sulfide generation by reaction (*1*) will continue to occur. . Complete oxygen penetration of the biofilm has been observed only when the biodegradable organic matter has been depleted in the wastewater. Pure oxygen is about five times more concentrated than the concentration of oxygen in air, and hence much higher dissolved oxygen concentrations can be maintained and this will reduce the anaerobic area available for the growth of SRB. However, SRB cannot be completely eliminated by air or oxygen injection, and SRB growth will resume if oxygen supply is stopped. The DIP system has unique features that allow the elimination of the wet well, and the generation of H_2S is minimized by reducing detention time by using a variable speed pump that can aspirate air.

2.2. Addition of nitrate

Nitrate addition to forcemains effectively prevents the accumulation of sulfide in the wastewater, but it does not have any long term effect on the SRB in the biofilm. It is postulated that sulfate oxidizing bacteria (SOB) use the nitrate to biologically oxidize sulfide to sulfate thereby preventing the accumulation of H_2S in the wastewater. Also, nitrate may be preferentially used by SRB. Sulfide production by SRB is resumed once nitrate feeding is stopped as the biofilm is still intact and active. In addition, in the gravity sewer beyond the forcemain discharge, SRB activity will occur when sulfate or oxidized sulfur is present and under anaerobic conditions, resulting in the renewed production of H_2S. The theoretical nitrate demand for sulfide oxidation to sulfur is estimated be 0.18-0.44 ppm of NO_3^-N per ppmS [13]. Actual dosage requirement will vary with wastewater characteristics including temperature, ionic strength, COD, and biomass activity. Values ranging from 0.6-4.5 ppm NO_3^-N per ppmS have been reported in the literature [14]. Nitrate is supplied as calcium nitrate. The cost of nitrate treatment can range from $1-5 per pound of S.

2.3. Iron salts

The addition of iron salts does not eliminate SRB activity. Ferrous (Fe(II)) or Ferric (Fe(III)) salts will react with the sulfide generated in reaction (*1*). In the case of Fe(II), ferrous sulfide (FeS) precipitate is formed thereby limiting speciation of sulfide species into H_2S . Fe(III) will react with sulfide to form FeS and elemental sulfur. In either case, SRB activity by reaction (*1*) will continue to produce H_2S if chemical feeding is stopped. Yuan et al [15] indicate that the use of Fe(III) will reduce sulfate reduction and methane production by 60% to 80%. The dosage of iron salts required depends on the wastewater composition. Iron can react with phosphate or other ligands in the wastewater, and these reactions will remove nutrients needed for biological treatment. If oxygen is present in the wastewater, some of the Fe(II) added will be oxidized to Fe(III). The addition of iron salts is a comparatively inexpensive and a widely used method to control H_2S (Hvitved-Jacobson et al, 2002). However, as observed by the City of Los Angeles, it is difficult to reduce H_2S to satisfactorily low [16]. Pilot studies indicated have shown a reduction of 63% to 79% of H_2S gas in when a combination of Fe(II) and Fe(III) salts were used.

2.4. Inhibition of SRB activity

Biological activity can be inhibited by the addition of sodium hydroxide to raise the pH of the wastewater to 9 or higher. Under these conditions much of the sulfide generated will remain in solution. This is a costly process that will affect subsequent wastewater treatment operations. Ozone is a powerful oxidant that can also be used as a biocide against SRB in forcemains and gravity sewers. The extent of inhibition of SRB activity will depend on the wastewater characteristics, the ozone dose and contact time provided. Ozone will also react with organic and inorganic constituents in the wastewater, and hence the ozone dosage required and its effectiveness in eliminating SRB activity will vary widely. Ozone has a short half-life, and any unreacted ozone will decompose to oxygen. This will allow further reduction in H_2S concentration from biological and chemical oxidation of sulfide.

This paper will discuss the results from a field study on the effects of injection of ozone and oxygen into the forcemain during pump operation, and its effect on hydrogen sulfide control. This process was developed by Envirozone Corporation (Carthage, Missouri), and involves the injection of a gas containing ozone and oxygen into the pump discharge during pump operation. Ozone injection may be conducted for several days depending upon the forcemain length and wastewater characteristics. Ozonation can be discontinued once the gas phase H_2S level is reduced to low levels, and thereafter, pure oxygen may be injected. Control of H_2S can be achieved by oxygen alone or by injection of ozone when needed. This field study investigated the use of a combination of ozone and oxygen for minimizing hydrogen sulfide problems in forcemains using this technology.

3. METHODOLOGY

3.1. Field study location

The field studies were conducted at the Job Corps Lift Station of the City of Manhattan, located on Fort Riley Boulevard, Manhattan, Kansas. This facility has two 430 gpm pumps that alternate in operation, and discharge wastewater into an 8 inch ductile iron forcemain that is 2.4 miles long. The pump running time at the lift station is about 2.2 minutes. The pump cycle time varies with the wastewater inflow, but averages about 20 minutes. The forcemain discharges into a manhole that is adjacent to homes in a residential neighborhood, this manhole has been a source of complaints due to the high concentration of H_2S in its vicinity. This manhole also receives flow from a gravity sewer that collects wastewater from portions of the Staag Hill residential area.

3.2. Sample Collection and Analytical Methods

Wastewater sampling was conducted at the lift station wet well and at the forcemain discharge manhole during discharge from the forcemain. The samples were tested for dissolved sulfate, sulfide, COD, suspended solids, pH, and dissolved oxygen using analytical protocols and procedures presented in the “Standard Methods for the Examination of Water and Wastewater”. Dissolved oxygen and temperature measurements were made at the site immediately upon collection of the samples. The remaining parameters were analyzed for immediately after the samples were brought back to the laboratory. Hydrogen sulfide gas concentration was continuously monitored in the wet well and the forcemain discharge manhole using a portable Odalog monitor (App-Tek International, Brendale, Australia). Samples were collected in triplicate each time at each location, and analyzed to obtain representative concentrations for each parameter. For COD, duplicates were run for each sample from a location, and the values were averaged. For each sampling time there were three readings for each parameter. BOD determinations were made on samples collected during the first six weeks. Bacterial seed from the local wastewater plant was used in the BOD determinations. However, due to high dissolved oxygen concentrations from ozone and oxygen injections, the BOD readings were inconsistent and discontinued.

Dissolved sulfide was analyzed using The Methylene Blue Method (Standard Methods, 1992) was used for the analysis of dissolved sulfide. Samples were fixed at the site to prevent the loss of dissolved hydrogen sulfide. Aluminum chloride was added to flocculate and settle the solids. After decanting some water, zinc acetate and sodium hydroxide was added to fix the sulfides. Further sample preparation and photometric analyses were done in the laboratory. Sulfate was measured using the Turbidimetric Method (Standard Methods, 1992). Suspended solids measurements were made for samples from the wet well and the forcemain manhole.

Hydrogen sulfide gas in the manhole and wet well were measured continuously using Odalog H_2S monitors. The Odalogs were hung about two feet above the water surface in the manhole, and about 2-4 ft higher than the high water level in the wet well. The Odalogs were in place from 1 to 7 days at a time, and was then replaced with a new dry unit. The Odalogs were brought to the laboratory, and the stored data were downloaded.

3.3. Initial wastewater and hydrogen sulfide data

The study period was from July 28, 2008 to January 1, 2009. During this period, the sulfate concentration in the wet well ranged from 62 mg/L to 105 mg/L with an average value of 90 mg/L. The study was begun during summer high temperatures when H_2S production is likely to be high and competed winter when ambient temperatures were low. The wastewater temperature ranged from 24^o C on July 2 to 19.5^o C on October 5.The forcemain discharge temperatures are slightly lower than the wet well temperatures due to mixing with the stagnant colder wastewater in the forcemain. The DO, COD, dissolved sulfide, and sulfate data for the wet well and the forcemain prior to the beginning of treatment with ozone are shown in Table 1.

Table 1. Initial data for water quality parameters

Location	*COD mg/L*	*Dissolved oxygen, mg/L*	*Sulfate mg/L*	*Sulfide mg/L*
Wet well	262	247	67.8	0.077
Forcemain discharge	228	1.53	64.3	5.20

The COD values ranged from 66 mg/L to 326 mg/L. There is sufficient easily biodegraded organic matter to serve as carbon source and facilitate sulfate reduction. The wet well dissolved oxygen (DO) values ranged from 1.2 mg/L to 4.1 mg/L initially and increased to about 8 mg/L when ozone was injected into the wet well. The sulfate concentration ranged from about 62 mg/L to 105 mg/L with an average value of about 90 mg/L. Sulfate concentrations are sufficiently high enough to cause sulfide production in the forcemain. Anaerobic conditions during long pump cycle times can also result in degradation of sulfate by SRB to sulfide and H_2S gas in the wet well. The dissolved sulfide concentrations in the wet well ranged from 0.02 mg/L to 0.14 mg/L. Sulfide was present in the wastewater from anaerobic activity in the wet well, or from the anaerobic action in the pipe discharging into the wet well. The hydrogen sulfide gas concentrations were measured in the pump station wet well and the forcemain discharge manhole. In the wet well H_2S concentrations ranged from zero to a maximum of 50 ppm. A high H_2S peak of 50 ppm was observed on 12/16/2008 indicating that regardless of winter conditions, H_2S generation can occur causing nuisance conditions. Figure 1 shows the H_2S levels as measured by the Odalog. It is clear that H_2S levels are in excess of 200 ppm (Odalog limit) at levels that can cause injury to maintenance personnel, and also elicit complaints from residences nearby.

4. RESULTS AND DISCUSSION

Ozone and ozone/oxygen injection trials were conducted in three stages. In the first stage of the study (OI #1), ozone alone was injected into the pump suction line only when the pump was on. In the second stage (OI #2), ozone was injected into the wet well for 10 minutes in a 20 minute cycle, 24 hours of the day, followed by ozone injection into pump suction line when the pump came on. The third stage of the study was similar to the second except that ozone was injected into the wet well only for 4 minutes of the 20 minute cycle. In the fourth stage of the study, ozone was injected into the forcemain when pump was running, and when pump was idle, oxygen was injected into the forcemain at a location downstream of the check valve.

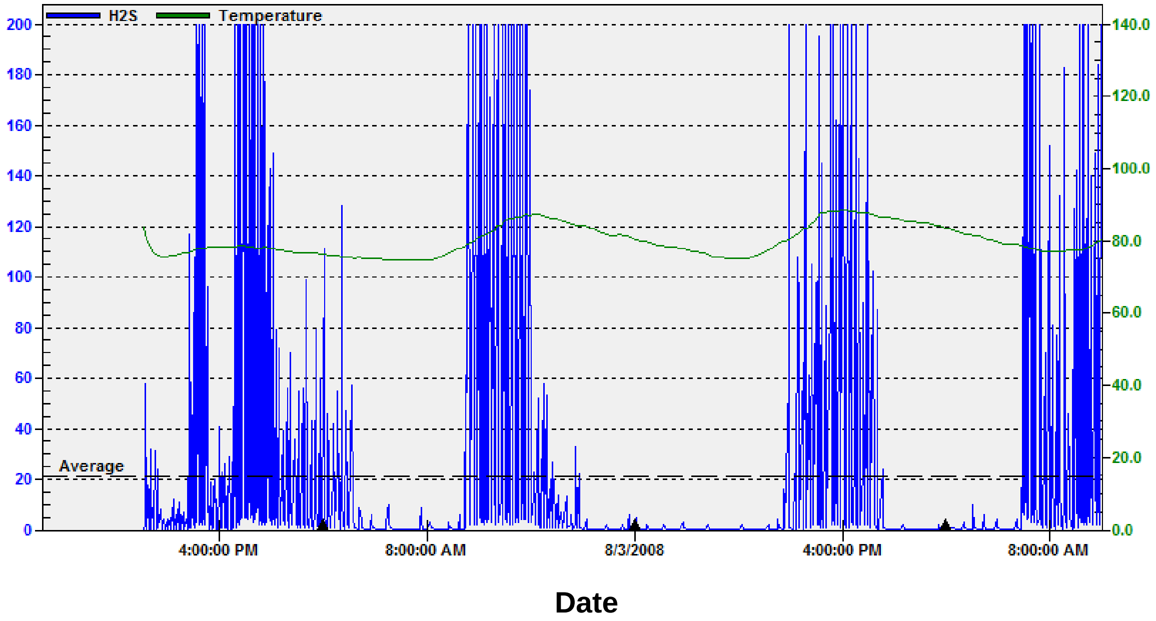

Figure 1. H_2S concentration in forcemain discharge prior to treatment

This pump station is a suction lift station, and hence the wastewater pumps are located at the high point in the hydraulic grade line. Continuous injection of ozone into the pump suction line would create vapor lock problems during pump operation. The suction side of each pump was tapped, and tubings were connected from the ozone generator to the tap. The pump operation begins with the vacuum pump turning on, and when sufficient suction head is created the wastewater pump turns on. The controls were set up such that ozone injection occurs with a time delay of 10 seconds after the wastewater pump start occurs into the pump suction. This was done to prevent premature gas injection and potential vapor lock that could affect pump priming and suction. The pump capacity is 430 gpm, and the flow velocity in the 8” pipe is calculated to be 2.75 ft/s. This velocity is insufficient to fully resuspend settled solids in the forcemain. The forcemain had not been cleaned by pigging or by running two pumps to create high velocities in the line during the life of the pump station. As a result, considerable amount of settled solids and biofilm is to be expected in the line.

Oxygen was generated from air using a pressure swing adsorption system to supply 90% top 95% oxygen at 60 psi pressure and 60 SCFH flow rate to the ozone generator. The flow rate is 60 SCFH. An oxygen monitor assures that the ozone generator is receiving oxygen of at least 89% purity. The ozone generated for injection was 1 g/min at about 60 psi pressure. A monitor was installed to monitor for leaks, and controls were set up to shut the system off at ambient concentration of 0.3 ppm.

4. 1. Ozone injection study (OI #1)

Ozone injection was begun on August 4, 2008. Ozone was injected into the forcemain only when the pump was running. The pump running time was only about 2 minutes and 12 seconds out of a total cycle time of 20 minutes, and this limited the quantity of ozone that could be injected into the system. Hydrogen sulfide concentrations in the forcemain discharge manhole after one month of operation is shown in Figure 2. It is clear that there are many episodes of high H_2S spikes, though during some periods the magnitude was reduced slightly.

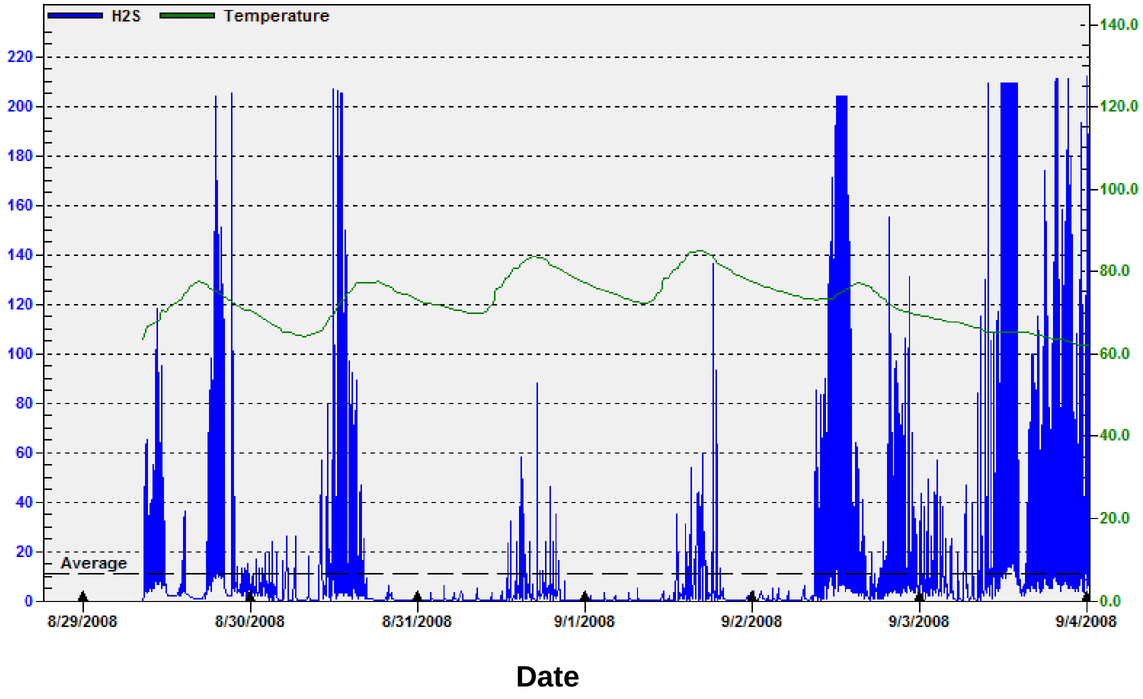

Figure 2. H_2S concentration in forcemain discharge after 1month of O_3 injection

4. 2. Ozone injection into wet well (OI #2 and OI #3)

In the second phase of the study oxygen and ozone were injected into the wet well when the pump was not in operation. Ozone was injected for 10 minutes and oxygen alone was injected during the remaining 10 minutes in a 20 minute cycle. Injection into the wet well was stopped when pump start occurred, injection of O_3 and O_2 was stopped, and ozone alone was injected into the pump suction. The O_3/O_2 injection into the wet well was restarted when the pump stopped running. Ozone and oxygen injection into the wet well was begun on 9/9/08. Subsequent data for H_2S in the forcemain discharge showed substantial reductions in H_2S levels as seen in Figure 3. The occasional spikes in H_2S peaks were reduced to about 15 ppm to 45 ppm. However, there was strong odor of ozone in the wet well, and as a result the next phase of the study was initiated with a reduced ozone injection period. In stage three of the study (OI #3), the wet well injection period was changed on September 26 to 4 minutes injection time for ozone and 16 minutes for oxygen. However, at this lower ozone dosage the hydrogen sulfide concentration spikes in excess of 200 ppm began to occur. Ozone and oxygen injection into the wet well was completely stopped on October 15 due to problems with the ozone diffuser getting tangled up in debris in the wet well causing the diffuser to be only partially submerged. To prevent undesirably high concentrations of ozone in the wet well, injection into the wet well was discontinued.

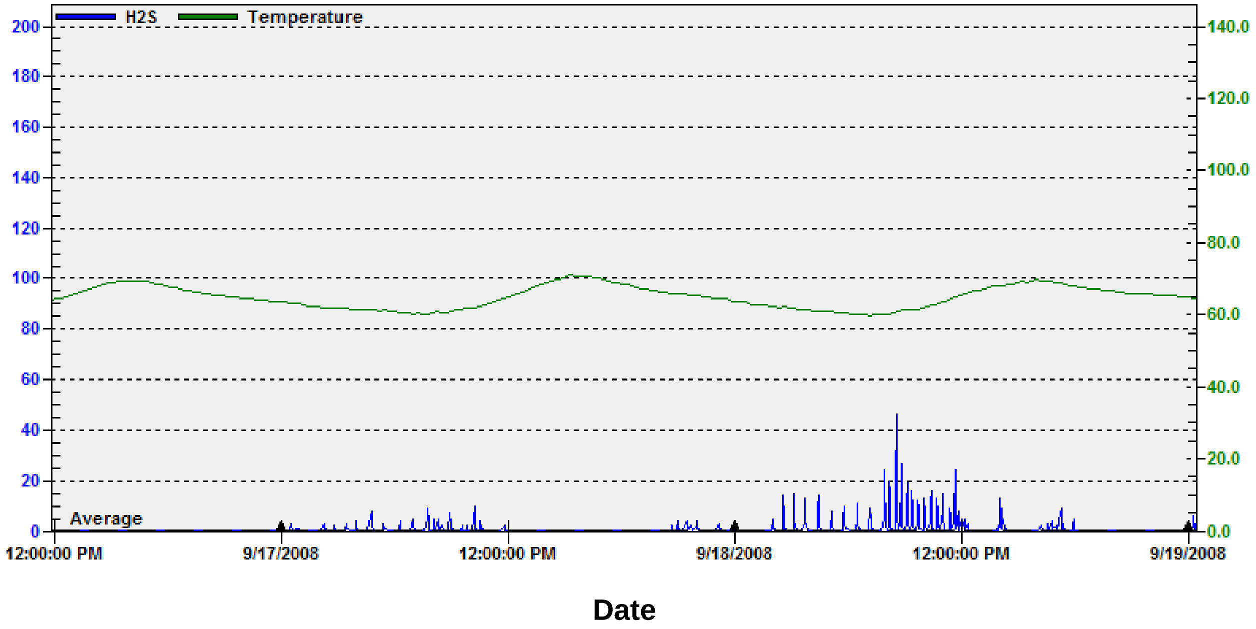

Figure 3. H_2S concentration in forcemain discharge after O_3/O_2 injection into wet well

4.3. Oxygen and ozone injection into forcemain (OI #4)

In this phase of the study ozone was injected into the forcemain when the pumps were running, and ozone injection was stopped when the pump went off. However, during the period the pump was turned off, oxygen was injected into the forcemain at the rate of 60 SCFH and at a pressure of 80 psi at a point downstream of the check valve. When the pump came on, the oxygen discharge would be automatically stopped, and ozone would be discharged into the pump suction line. The tap for ozone injection and the control system was installed, and operation in this mode began on October 24, 2008. The effects of this change in operation was noticeable within a week of operation. Figure 4 displays H_2S readings from the Odalog in the forcemain manhole for one week following this injection procedure. It is seen that H_2S concentration was reduced to 1 ppm in most cases with an occasional spike to 2 ppm. During a major portion of the time the H_2S concentration was zero. This excellent control was maintained for more than a month of further operation and monitoring. This type of operation is required for a suction lift station. However for other lift stations, it is possible to obtain good control of H_2S problems with ozone injection alone.

4.4. Effects on wastewater quality in forcemain discharge

In addition to the inhibition of SRB activity, ozone and oxygen injection can promote the oxidation of organic matter, thereby reducing organic load to the wastewater treatment plant. The COD profiles in the forcemain discharge manhole (FDM) are shown in Figure 5. During the initial OI #1 phase of ozone injection, COD in the forcemain discharge in part due the action of ozone on the biofilms and other material in the forcemain. The suspended solids concentrations also increased noticeably during this period. Once oxygen and ozone injection into the wet well began, COD levels in the forcemain discharge decreased compared to the wet well CODs. In stage four of the study (OI #4), the injection of ozone during pump operation and injection of oxygen when pump was not operating, caused substantial decrease in the COD values. During the November to December period, the COD decreased by about 40%.

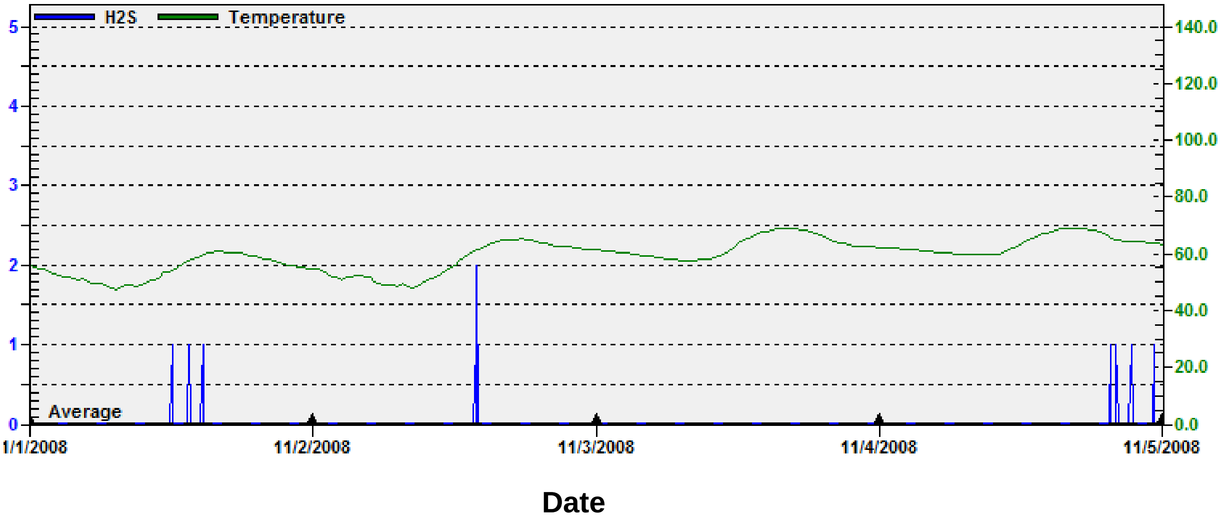

Figure 4. H_2S concentration in discharge after O_3/O_2 injection into forcemain

The DO profiles after ozone treatment are shown in Figure 6. The DO values ranged from 0.41-1.8 ppm in the forcemain discharge prior to the start of the study. During August, when ozone was being injected only when the pump was on, the DO level increased marginally due to the short injection time. In the second and third phases of the study when ozone and oxygen was being injected into the wet well, the DO level increased dramatically in the wet well, but was

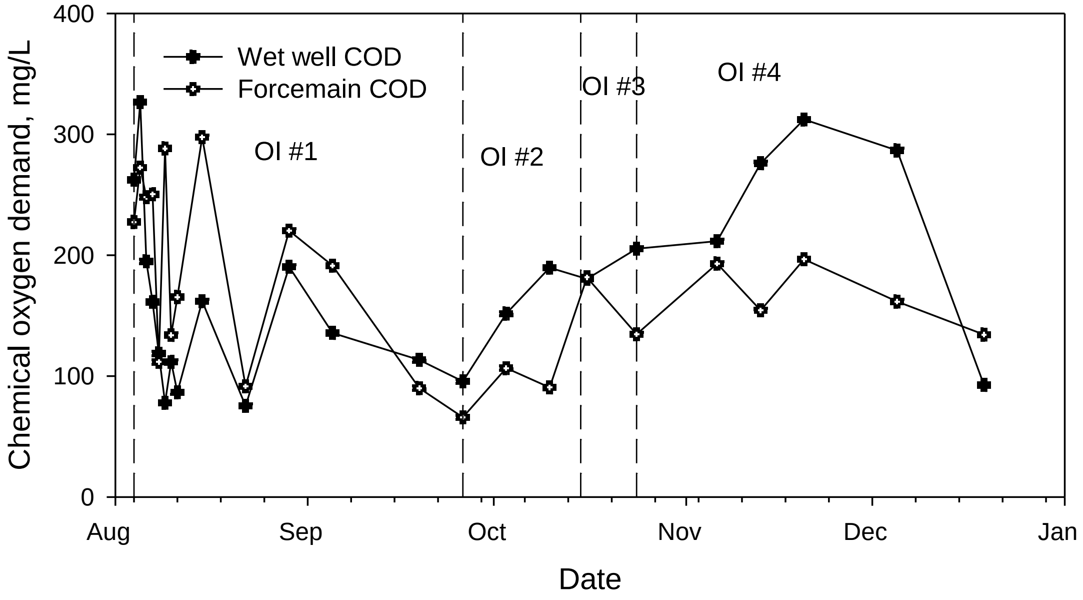

Figure 5. COD concentrations in the wet well and forcemain discharge

somewhat lower in the forcemain discharge. During the fourth stage (OI #4), oxygen was being injected into the pump discharge line continuously, and the DO level increased to about 25 ppm in the forcemain discharge manhole. The DO level can be controlled by controlling the pressure and the oxygen output rate from the oxygen generator.

The dissolved sulfide concentrations are shown in Figure 6. The sulfide concentrations were about 5 mg/L prior to the beginning of treatment, and during the first phase (OI #1). However, as ozone and oxygen were injected into the wet well (OI #2), the dissolved sulfide concentration is close to zero, confirming the low H_2S levels noted in Figure 3. In stage four (OI #4) dissolved sulfide concentrations in forcemain discharge are essentially zero confirming the Odalog readings of 1 to 2 ppm H_2S gas phase concentration.

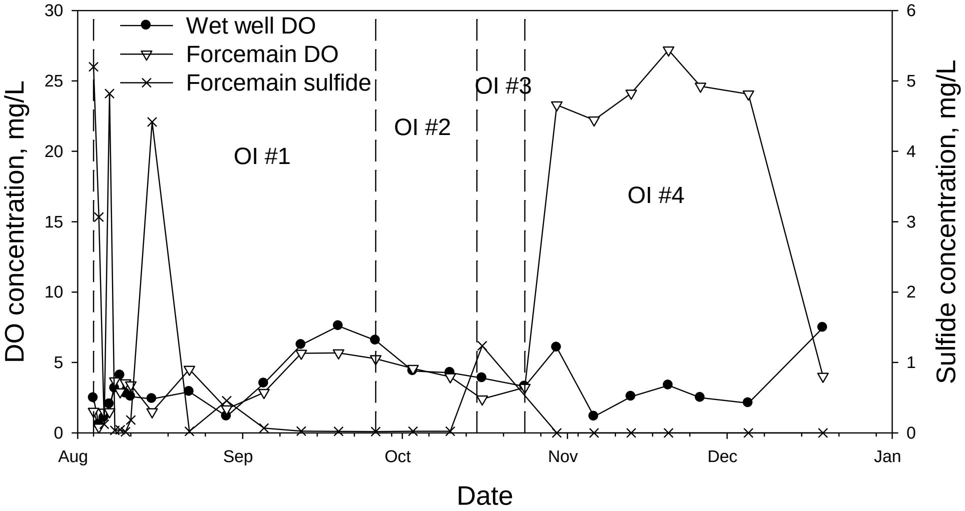

Figure 6. DO and sulfide concentrations in forcemain discharge

5. CONCLUSIONS

H_2S is a toxic gas with an unpleasant odor, and can be fatal if individuals are subjected to high concentrations for prolonged time periods. Sulfate and COD are used by sulfate reducing bacteria to generate sulfides in the wastewater under anaerobic conditions. Control of sulfides is important in preventing sulfuric acid generation leading to infrastructure corrosion. The sulfate concentrations were reasonably constant in the wet well to the pump station. Sulfate concentrations in the wastewater were sufficiently high to cause sulfide production in the forcemain during long pump cycle times. The COD levels were typically higher during the day, and the increased COD concentrations resulted in higher levels of H_2S in the wet well and the forcemain discharge manhole.

A field study was conducted to study the effects of ozone and oxygen on hydrogen sulfide control in wastewater collection systems to reduce corrosion and odor problems. Prior to the ozone injection study, H_2S levels were in excess of 200 ppm in the forcemain discharge manhole. High concentration levels were distributed throughout the day. High H_2S concentrations were present particularly in the noon and evening periods of the day somewhat coinciding with increased human activity and waste discharge during those periods. The high H_2S concentration spikes were present during weekdays and weekends.

The ozone injection study was conducted in four phases. The process of ozone injection during the short period only when the pump was running could not control H_2S production meaningfully. Ozone and oxygen injection to the wet well was successful in reducing H_2S levels to less than 45 ppm. The injection of ozone when pump was running, and the injection of oxygen when the pump was off resulted in excellent control bringing H_2S levels close to zero with occasional spikes to 2 ppm level in the discharge forcemain. This process can be implemented easily and economically due to the ease of ozone production and ozone injection into the waste stream.

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