Georgia-Pacific

Georgia-Pacific Crossett LLC
Consumer Products

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February 29, 2016

John Bailey, P .E.
Technical Assistance Manager
Water Division
Arkansas Department of Environmental Quality
5301 Northshore Drive
North Little Rock, AR 72118-5317

Reference: Georgia-Pacific Crossett LLC - Crossett Paper Operations
NPDES Permit # AR0001210, AFIN 02-00013
Request to Run Trial of Added Oxygen to the Primary Clarifier

Dear Mr. Bailey:

As we discussed, Georgia-Pacific Crossett LLC, Crossett Paper Operations (GP) intends to initiate a trial to apply oxygen prior to the primary clarifier as described in the wastewater treatment system schematic that was an approved part of our recent (October 31, 2015) permit modification application.

GP presently applies hydrogen peroxide and an organic iron catalyst immediately upstream of the primary clarifier to oxidize sulfide in the wastewater. This reduces the potential for emissions of hydrogen sulfide from the primary clarifier. Additionally, since hydrogen peroxide decomposes into water and oxygen, this also provides an added boost of oxygen to the wastewater. Oxygen also rapidly oxidizes sulfide. Adding oxygen through this means and by aeration in the aeration basin is already part of our process, and is also necessary for proper degradation of organics.

In order to implement this trial, we will install an oxygen supply system (from either an oxygen generator system or liquid oxygen supply tank) in the primary treatment area and dissolve the oxygen in a portion of the clarifier influent stream. This oxygenated stream will be reinjected back into the primary clarifier influent. As shown on the approved wastewater system schematic, the oxygen will be added in lieu of or in addition to the peroxide system in place.

GP presently adds oxygen in this manner prior to the primary clarifier at our Toledo, OR and Big Island, VA paper mills. There are several benefits of adding oxygen in this manner: (1) it reduces the potential for odors, (2) it increases the settling efficiency significantly of the primary clarifier by raising the oxidation-reduction potential in the settling zone, (3) the dewatering characteristics are much improved since the settled sludge is more aerobic and (4) it meets immediate oxygen demands of some readily degraded substances. Additionally, the use of oxygen may reduce or eliminate the use of peroxide at this application point, thereby significantly reducing chemical costs and reducing safety risks from handling 50% hydrogen peroxide.

We've also attached a technical paper that illustrates that the use of oxygen in this manner has been practiced elsewhere and with excellent results.

Our intention would be to run this trial for a period of 12 months. We would begin this trial as soon as we procure and install the equipment (which would likely be in March 2016). During the trial period, if we determined that we would like to make the oxygen system a permanent installation, we will contact you to determine next steps. Given the potential benefits associated with the trial, we request that ADEQ provide any feedback at its earliest convenience.

If you have any questions or need additional information prior to this, please feel free to contact me at (870) 567-8670 or by email at sarah.ross@gapac.com.

Sincerely,

Sarah M Ross

Sarah M. Ross
Environmental Manager
Crossett Paper Operations

LARGE-SCALE OXYGEN INJECTION FOR ODOR CONTROL AT PRIMARY CLARIFIERS AT THE TRINITY RIVER AUTHORITY OF TEXAS

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ABSTRACT

The Trinity River Authority of Texas owns and operates the 162-MGD Central Regional Wastewater Treatment Plant in Grand Prairie, Texas. The plant is an advanced secondary facility consistently producing nitrified effluent with BOD and TSS concentrations less than 5 mg/L each and an ammonia nitrogen concentration less than 0.5 mg/L. In addition to providing high quality effluent, the Authority is committed to being a good neighbor to the commercial, recreational, and residential areas surrounding the plant. As such, the Authority has committed significant funds and manpower to minimize the emission of odors from the plant.

In projects spanning more than 20 years, the plant has eliminated or minimized emissions from major odor sources such as the preliminary treatment areas, influent junction boxes, primary clarifier weirs, and sludge processing areas. The plant eliminated use of its sludge-only landfill except for screenings and implemented beneficial reuse of all its sludge. The next phase of odor control would include the management of odors from aerated grit units and the quiescent areas of the primary clarifiers. Covering the primary clarifiers could involve literally acres of covers and the collection and treatment of well over 150,000 cfm of foul air.

As an alternative to the covering of the primary clarifiers and collection and treatment of the air, the Authority, with Alan Plummer Associates, Inc., conducted "full-scale pilot studies" to investigate the feasibility of using pure oxygen for odor control. Pure oxygen has been used for odor control in pressure lines in collection systems and in receiving streams to boost oxygen concentrations during critical low-flow periods. Use of pure oxygen for odor control at a wastewater treatment plant, however, is a new application.

Following the success of the pilot study, the Authority conducted a second bench-scale study to identify optimum dosage rates and injection points. This study identified the reaction rate of sulfide oxidation for the wastewater stream and provided a basis of design. The system began operation in June 2007. Following startup, the Authority conducted performance testing to identify the reduction in hydrogen sulfide, reduced sulfide, total odor (dilution to threshold) and other parameters.

KEYWORDS

Odor control, oxygen, dissolved oxygen, DO, downflow bubble contactor, Speece cone, aeration.

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INTRODUCTION

Oxygen has been injected into force mains in wastewater collection system for many years. The injection of oxygen into wastewater streams *within treatment plants* specifically for odor abatement, however, has been done in only very limited applications. Previous papers (Jordan and Perkins, 2003) have detailed evaluation and pilot testing for pure oxygen injection into a raw wastewater stream at the Authority's CRWS plant to minimize the release of odorous compounds from preliminary and primary treatment areas. Following the success of this pilot study, a full scale, permanent oxygen injection facility was designed. During the design phase, it was necessary to perform additional bench scale testing to determine the optimum oxygen dosage for the wastewater stream. This paper provides a brief background on the previous pilot testing, and details results of the bench scale testing. Design related issues and equipment selection are also discussed.

HISTORY OF ODOR CONTROL AT TRA CRWS

TRA has pursued odor abatement at the CRWS plant on a step-by-step basis (using both direct and indirect approaches) since the plant's Phase I expansion was completed in the 1970s. Each step has focused on controlling the most significant odor sources (and/or the most economically-addressed odor sources) remaining in each stage. The need to proactively continue this odor abatement program has been recently affirmed due to a number of significant developments in the area surrounding the plant. The Authority strives to invest in technologies and improvements that will provide a tangible benefit to residents near the collection and treatment facilities, while not placing an undue burden on its customer cities not situated near the plant. It is conservatively estimated that the Authority has invested over $10 million over the last 30 years in capital construction costs for odor control systems.

Currently, the CRWS plant uses eight organic media biofilter cells to treat approximately 60,000 cfm of foul air and five inorganic media bioscrubbers to treat approximately 11,000 cfm of foul air from liquid and solids treatment process. Foul air is pulled from covered units including the weir areas of eight primary clarifiers, six gravity thickeners, four influent junction boxes, two influent pump stations, three grit basins, and four sludge tanks.

Following completion of the Stage V Odor Control Improvements project, the Authority began master planning future odor control work at the plant. The Master Plan showed that the largest remaining odor sources were ten aerated grit basins and the quiescent areas from eight primary clarifiers. It was estimated that traditional cover and scrub techniques for controlling odors at these sources would cost over $50 million over the life of the system. Other methods of odor control were investigated, resulting in the selection of high purity oxygen injection.

OXYGEN INJECTION PILOT STUDY

Pure oxygen has been used for odor control in pressure lines in collection systems and in receiving streams to boost oxygen concentrations during critical low-flow periods. Use of pure

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oxygen for odor control at a wastewater treatment plant, however, is a new application. Since injection of high purity oxygen within a treatment plant force main with limited hydraulic residence time was an unproven concept, a full-scale pilot study was performed to investigate the feasibility and effectiveness of using pure oxygen for odor control.

Pure Oxygen Injection System

For the purpose of the pilot study, the Authority awarded a turnkey equipment and materials supply bid to an oxygen supplier. Subject to restrictions by the Authority, the supplier designed and installed the oxygen feed system for this study. The system furnished included a 6,000 gallon liquid oxygen (LOX) tank, two vaporizers, pressure regulator and flow meter, and a diffuser (sparge element). The LOX tank, vaporizers, flow meter and associated controls were located near Pump Station 6 (one of two main influent pump stations into the plant).

Liquid oxygen was stored in the 6,000-gallon bulk storage tank at a pressure of 100 psig. LOX under pressure went to the vaporizers, where ambient air temperatures boiled the LOX, releasing gaseous oxygen (GOX) for injection. Vaporizers were alternated as needed to maintain the GOX flow. GOX flowed from the vaporizer, through a regulator and flow meter, to the injection point at the discharge elbow of the 40 mgd pump in the pump station. Injection was made using a 316 stainless steel sparge element inserted into the flow.

After the pump discharge, flow traveled through a steel force main to the influent box of the aerated grit basins. Flow traveled through the aerated grit basins and into rectangular primary clarifiers. At the point of injection, pressure in the force main was approximately 31 psig. Total contact time from injection through the aerated grit basins and primary clarifiers was approximately 97 minutes at the tested flow rate (40 mgd), although contact time within the force main was only five minutes.

Results of the Pilot Study

The pilot study measured dissolved oxygen, liquid sulfide, gas sulfide, oxidation-reduction potential, wastewater temperature, and pH over an eight-week period.

<u>Total Sulfide:</u> Prior to oxygen injection, liquid total sulfide showed an average decrease of 13% between the influent pump station and the aerated grit basin influent box. With oxygen injection, the average decrease rose to over 60% reduction of total sulfide. This reduction in total sulfide was also evident throughout the liquid process train. Prior to oxygen feed, total sulfide was detectable throughout the sample area. During oxygen injection, total sulfide downstream from the aerated grit basin dropped to below detectable limits in most cases and was lowered significantly when measurable concentrations were detected.

<u>Dissolved Sulfide:</u> Prior to oxygen injection, liquid dissolved sulfide showed a slight decrease of 5% between the influent pump station and the aerated grit basin influent box. With oxygen injection, the average decrease was over 68% (reduction in dissolved sulfide). As with total sulfide, the reduction in dissolved sulfide was evident throughout the liquid process train. Prior to oxygen feed, dissolved sulfide was detectable in most sample locations. During oxygen

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injection, dissolved sulfide downstream from the aerated grit basin dropped to below detectable limits for all but one sample.

Dissolved Hydrogen Sulfide: Dissolved hydrogen sulfide is dependent upon the dissolved sulfide concentration and the pH of the raw wastewater. A simple correction factor (based on the pH of the raw wastewater) is used to determine the dissolved H_2S concentration in the raw wastewater. As the pH of the raw wastewater was generally between 6.8 and 7.2 for the duration of the study, results of dissolved H_2S measurements closely follow dissolved sulfide results.

Dissolved Oxygen (DO): Increases in dissolved oxygen were observed during oxygen injection, although the effects were not as dramatic as expected. Prior to oxygen injection, increases in DO were observed to occur in the aerated grit basins (due to the coarse bubble diffusers) and immediately following the three cascades at the grit basin effluent channel (presumably a result of oxygen dissolution due to turbulence).

During oxygen injection, DO increases were observed in the aerated grit basin influent box (from approximately 0 mg/L to around 8 mg/L), and higher DO concentrations were measured at the influent area of the primary clarifier. Unfortunately, DO concentrations decreased rapidly in the primary clarifier and were generally below detection limits at the downstream end of the primary clarifier, as was the case prior to oxygen injection.

Oxidation-Reduction Potential (ORP): Generally, ORP increased as a result of oxygen injection. Prior to oxygen injection, the ORP ranged from –90 mv to –200 mv depending on location. During oxygen injection, ORP ranged from –60 mv to –150 mv. Most significantly, ORP increased slightly between the pump station influent box and the aerated grit basin influent box prior to oxygen injection. During oxygen injection, the ORP increased approximately 30% between the pump station and the aerated grit basin influent box.

Water Temperature and pH: Injection of oxygen impacted neither water temperature nor pH, as would be expected.

Gas Phase H_2S Concentration: Surface H_2S concentrations generally showed an average decrease as a result of oxygen injection. The most significant decrease occurred in the primary clarifier, where decreases were over 80%.

Dispersion Modeling: Dispersion modeling of the results from the pilot study showed that the area of odor impact from the plant decreased by 96% with oxygen injection to the primary clarifiers and with odors controlled at the aerated grit basins.

Recommendations

Based on the success of oxygen injection for controlling odors at the primary clarifiers, it was recommended that the Authority inject oxygen for odor control at the primary clarifiers. As the oxygen injection did not sufficiently decrease odor at the aerated grit basins, it was recommended that the aerated grit basins be demolished and be replaced with vortex grit removal basins with a bioscrubber for odor control.

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PRELIMINARY DESIGN

Preliminary design of the oxygen injection facility involved determining the optimum oxygen dosage, selecting injection equipment, and selecting the best method of supplying oxygen. For this phase of the project, high purity oxygen is to be injected at the south treatment train (the pilot study was conducted on the north treatment train).

Existing Facilities

Wastewater flow enters the WWTP through influent Junction Boxes 1E and 1F. Raw wastewater flows into the Pump Station 6 influent box, where the flow is currently split between Pump Station 6 and Pump Station 6A. Pump Station 6A lifts wastewater to the south primary treatment train. A discharge header combines flow from either two or three pumps (depending on operational intent) and sends the flow into parallel 72-inch diameter mains. These 72-inch force mains exit the pump station and flow though Meter Vault 1A and into Headworks Building B (HWB).

This flow passes through HWB, through a division box, and into four 165-foot diameter primary clarifiers. Inside HWB, flow travels through three bar screens inside an enclosed room. After leaving the barscreens, flow travels through three vortex grit removal units and leaves the building via a drop structure. This drop structure discharges into a 96-inch pipeline that supplies the primary clarifier division box. This division box acts as standpipe, splitting flows to each of the four circular primary clarifies via 48-inch pipes.

Oxygen Requirements

Determining the dissolved oxygen concentration at the injection point is dependent on the following (adapted from Rush 2002):

- required DO concentration at the "system" endpoint; in this case the weir plates on the effluent launder of the primary clarifiers are the system endpoint
- oxygen uptake rate for the wastewater
- oxygen necessary for chemical oxidation of dissolved hydrogen sulfide and other compounds present in the wastewater
- loss of oxygen due to turbulence
- DO concentration of the incoming wastewater

In order to prevent formation of hydrogen sulfide, a positive DO of 1.0 mg/L was required in the wastewater up to the existing launder covers on the primary clarifiers.

Oxygen uptake rates (OUR's) for the wastewater were recorded during a three week period in October 2004. Wastewater samples were taken from the influent area of PS6A and included recycle flows (filter backwash) from the WWTP. The OUR average was approximately 10 mg/L/hr. This value was used for determining the design DO. The total hydraulic residence

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time calculated at design flows is approximately 134 minutes at the design flow of 108 mgd. This results in an oxygen consumption of 22.3 mg/L between PS6A and the Primary Clarifier effluent launder.

Oxygen necessary for the chemical oxidation of hydrogen sulfide varies depending on the alkalinity of the wastewater. Under neutral or acidic conditions, stoichiometric dosage rate is approximately 0.5 pounds of oxygen (O_2) per pound of sulfide. Under alkaline conditions, the stoichiometric dosage rate is approximately 1.9 pounds of oxygen (O_2) per pound of sulfide. As oxygen will interact with other oxidizable compounds, the practical dosage is typically taken as 5 pounds of oxygen per pound of hydrogen sulfide (5.0 mg/L O_2 per 1.0 mg/L H_2S). Average H_2S concentrations were measured at an average of 1.3 mg/L. At 5 mg/L O_2 per 1.0 mg/L H_2S, 6.5 mg/L of dissolved oxygen is necessary.

Loss of dissolved oxygen due to turbulence at the headworks building vortex grit chambers and weir gates was evaluated. Water with DO below the saturation concentration for water in air (around 8 mg/L at typical temperatures) will tend to increase in DO in order to reach equilibrium with the atmosphere. Likewise, supersaturated solutions tend to decrease in DO in order to reach equilibrium. Using stream reaeration equations, DO increase or decrease can be estimated for the turbulent water flow and waterfall at the headworks building. For the recommended process, DO in the wastewater entering the headworks building will be slightly below saturation concentrations for water at atmospheric conditions. It is expected the DO in the wastewater will increase due to the waterfall at the effluent weir gate, although a conservative assumption will be that there is no increase in DO.

The DO of the wastewater in the influent box at Pump Station 6 was recorded at an average of 3.2 mg/L and fluctuated between 1.1 and 5.2 mg/L during the pilot study. A conservative assumption is to assume the incoming DO in the system is at 0 mg/L.

The total DO required at the point of injection is the sum of the above, or 29.8 mg/L O_2. The actual oxygen required will depend on variations of the above factors, the purity of the oxygen, and the efficiency of the dissolution mechanism. For instance, assuming 99.5 percent purity for oxygen and 90 percent efficiency, the actual DO required at the discharge header of PS6A will be 33.3 mg/L for the above conditions.

The amount of oxygen that can be dissolved in water is determined using Henry's Law, which states that the saturation concentration of a gas in water is directly proportional to the partial pressure of the gas. Using high purity oxygen, the partial pressure of oxygen will be nearly equal to the pressure at which the oxygen gas is introduced to the wastewater. For instance, at atmospheric pressure using pure oxygen, the saturation concentration of oxygen in water is 39.5 mg/L, compared to 8.3 mg/L at atmospheric conditions (at 25°C). For the design system flow rate of 108 mgd and a DO of 35 mg/L, approximately 15.8 tons per day of pure oxygen will be dissolved. This number will increase depending dissolution efficiency.

Laboratory Reaction Rate Study

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Although it is fairly certain that maintaining a positive DO through the system will prevent sulfide odors, construction of such a system was beyond the construction budget for the project. Providing a DO of 35 mg/L would require 2 injection installations – one at PS6A for initial oxidation of sulfide, and one downstream of the headworks building to provide a positive DO through the primary clarifiers. DO upstream of the headworks building could not be increased above saturation because the turbulence in the headworks building would cause oxygen to come out of solution ("off gas"), reducing efficiency and possibly creating a hazardous atmosphere.

During the preliminary design phase of this project, a bench scale laboratory test was made to determine the sulfide oxidation rate of sulfide in wastewater from the TRA CRWS WWTP. The reaction rate was then used to determine how quickly sulfide are oxidized and the amount of time before hydrogen sulfide begins to form again. This allowed for optimizing the location of the oxygen injection point in the system and the appropriate design DO at the injection point.

<u>Description of Lab Test:</u> A batch reactor was constructed to determine the reaction order and reaction rate constant of sulfide in wastewater in the presence of elevation dissolved oxygen concentrations. During the test, high purity GOX was dissolved into one liter of wastewater from the Headworks Building influent area to obtain a DO of approximately 43 mg/L. The supersaturated wastewater was combined with three liters of wastewater with a DO of 0 mg/L, for an initial DO of approximately 11 mg/L. Sodium sulfide crystals were added to raise the sulfide concentration in the wastewater to approximately 6 mg/l. The reactor was continuously stirred while liquid samples were withdrawn regularly for determination of total sulfide concentration, dissolved sulfide concentration, and hydrogen sulfide concentration. Samples were analyzed immediately using Standard Methods for the Examination of Water and Wastewater Methylene Blue Method 4500-S^{-2}D, as applied in the LaMotte Chemical Testing Kit. The LaMotte kit is a portable, wet chemical field-testing kit, which uses a comparative, color (methylene blue) endpoint for the determination of total sulfide concentrations ranging from 0.1 to 18 mg/l. DO, ORP, pH, and temperature were also recorded using a YSI 556MPS meter. The data obtained were plotted to determine the reaction rate order and reaction rate constant. After the total sulfide concentration fell to below detectable limits, the reactor was allowed to sit for approximately two hours while DO and ORP were recorded.

<u>Results:</u> The lab test was run four times, three of which provided useful data. Raw data in Table I below was used to determine the reaction rate.

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Table I - Reaction Rate Data

Test No.	Elapsed time, min	Total Sulfide, mg/L	Dissolved Sulfide, mg/L	Dissolved H_2S, mg/L
1	0	1.3	0.4	0.1
	5	0.2	0.0	0.0
	10	0.2	0.0	0.0
	15	0.1	0.0	0.0
	22	0.0	0.0	0.0
	138	0.0	0.0	0.0
2	0	2.6	1.5	0.2
	5	1.0	0.2	0.0
	10	0.3	0.0	0.0
	15	0.3	0.0	0.0
	20	0.2	0.0	0.0
	25	0.1	0.0	0.0
	120	0.0	0.0	0.0
4	0	6.5	4.5	0.5
	5	2.3	1.6	0.2
	10	1.7	1.0	0.1
	15	1.6	0.8	0.1
	20	0.8	0.3	0.0
	25	0.4	0.1	0.0
	30	0.3	0.0	0.0
	35	0.2	0.0	0.0
	40	0.1	0.0	0.0
	76	0.0	0.0	0.0

Results from test number 3 (not shown) were irrational and were discarded. Results from test number 1 contained too few data points to draw meaningful conclusions. Tests 2 and 4 were used to determine the reaction rates specific to this wastewater.

Results were plotted using saturation, zero, first, and second order reaction rate equations. The test results showed that the sulfide oxidation generally followed a first order reaction of the form:

$$C_{A_t} = C_{A_0} e^{-kt}$$

where

C_{A_t} = Sulfide concentration at time t;

C_{A_0} = Initial sulfide concentration at time t=0;

t = Time, minutes; and

k = Sulfide oxidation rate, min^{-1}

= 0.10 min^{-1} for total sulfide

= 0.14 min^{-1} for dissolved and hydrogen sulfide

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Shown below are plots showing the reaction rate data from test number 4 for total and dissolved sulfide. Data from test 2 is consistent with these plots. The decease in total DO is shown in Figure 1. The total and dissolved sulfide reaction rates are shown in Figures 2 and 3, respectively.

Figure 1 - Total Sulfide and Dissolved Oxygen Data Points

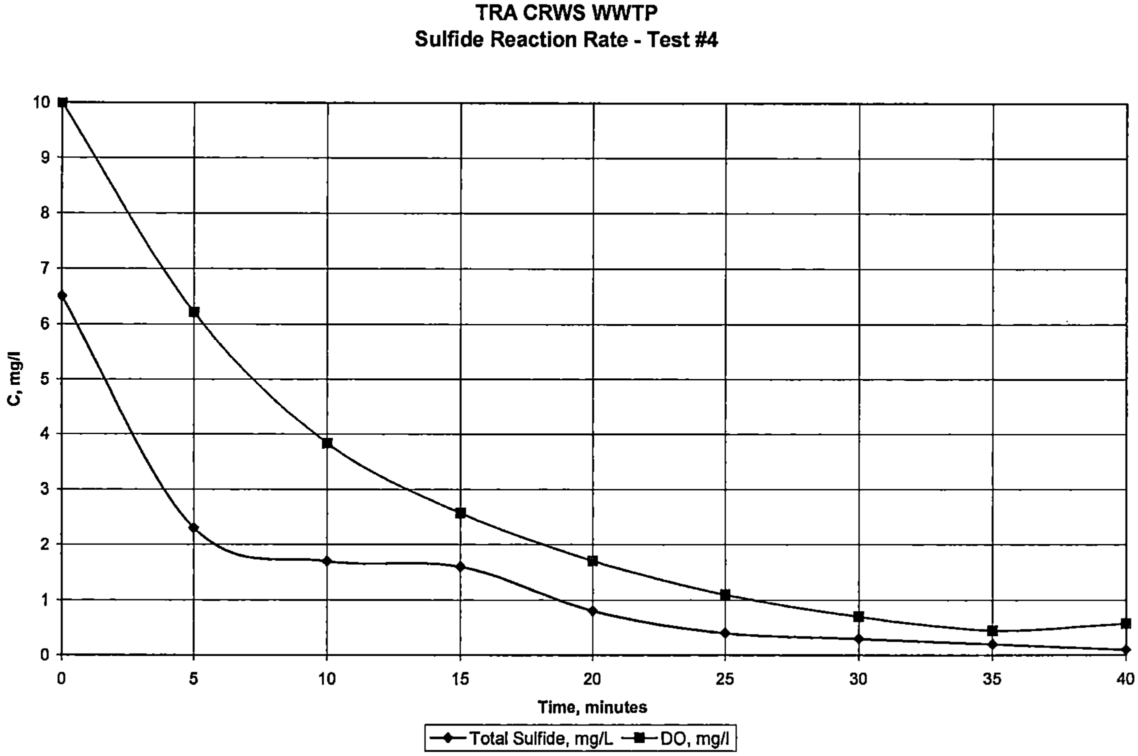

Figure 2 - Total Sulfide Reaction Rate

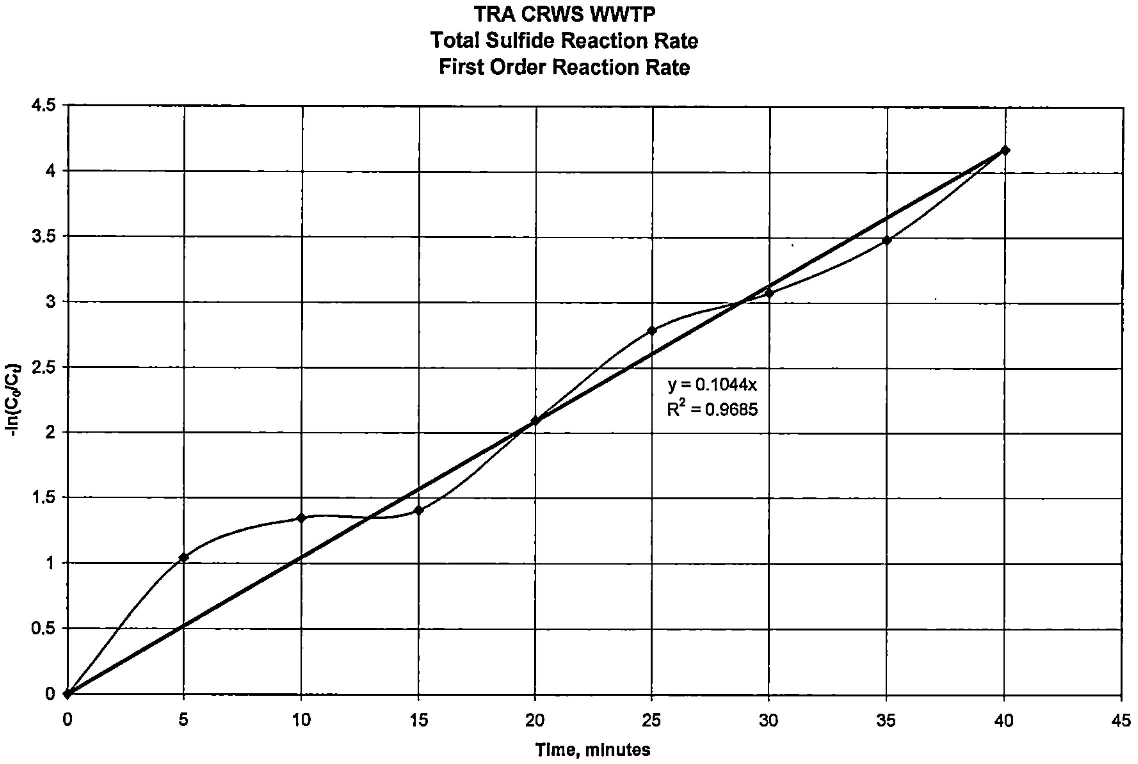

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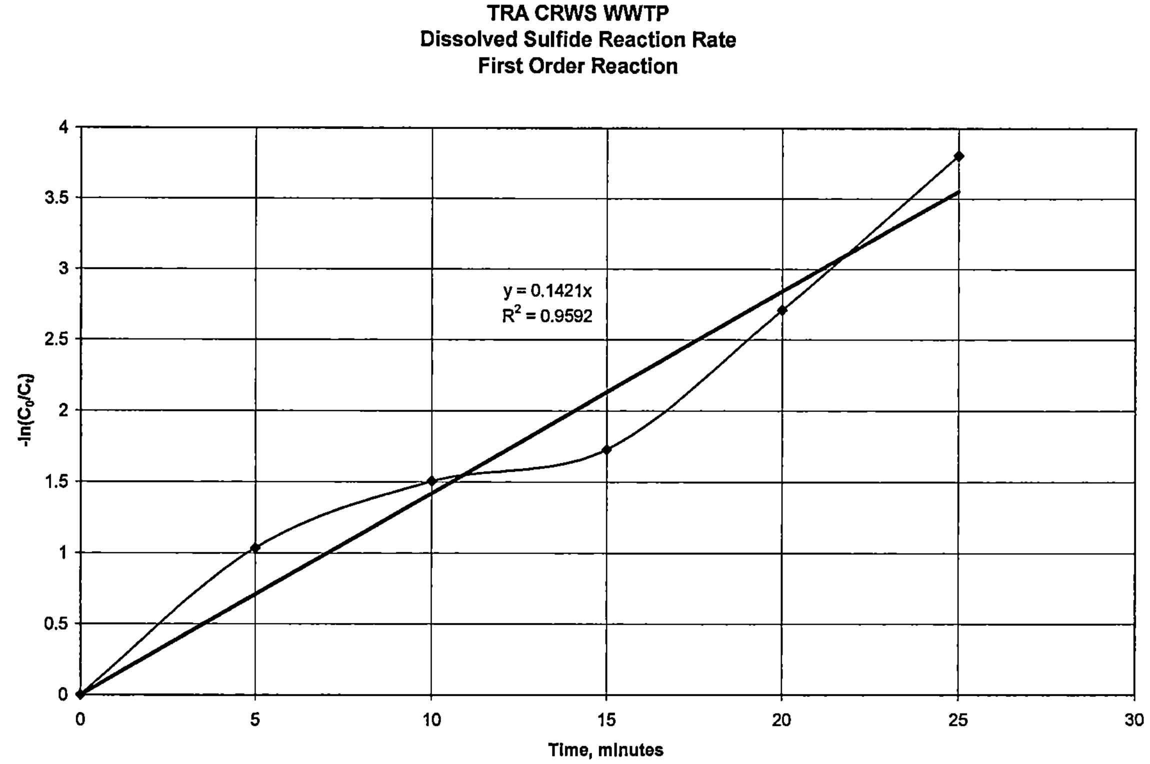
Figure 3 - Dissolved Sulfide Reaction Rate



The following general conclusions are drawn from the data:

1. Generally, a first order reaction was observed.
2. An initial DO as low as 10 mg/L provided a reduction in sulfide for up to two hours.
3. Approximately 80% reduction in total sulfide was seen in the first ten minutes following the addition of oxygen.
4. Reduction of dissolved hydrogen sulfide to below detection limit (0.1 mg/l) varied from as low as five minutes to over fifteen minutes.
5. Although the ORP did not rise above –50 mv during the test, sulfide did not re-form after they fell to below detectable limits.

Conclusions from Laboratory Study: The following conclusions were made based on the lab test results for this project:

1. Sufficient reduction of hydrogen sulfide may be possible with a lower DO than originally thought.
2. A single injection point downstream from the headworks building does not allow for a sufficient hydraulic detention time to reduce hydrogen sulfide sufficiently prior to entering the center well of the primary clarifiers.
3. An injection point located to provide at least 15 minutes of detention time would provide sufficient time to reduce hydrogen sulfide in the wastewater.

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4. A single injection point inside Pump Station 6A would likely provide a sufficient DO and detention time to significantly reduce hydrogen sulfide in the wastewater prior to entering the primary clarifiers.
5. Odors may be present in the primary clarifier influent well due to the short hydraulic detention time between PS6A and the primary clarifiers.

Based on the laboratory study it was recommended that the project have a phased approach. The first phase involved permanent facilities for raising the dissolved oxygen concentration at the pump station to 11 mg/L. If necessary, the second phase will boost the dissolved oxygen concentration after the headworks facility by 24 mg/L, for a total DO of 35 mg/L. Projected capital costs for both phases was $8 million; phase 1 construction bid price was $3.3 million, resulting in a potential savings of $4.7 million if phase 2 is not necessary. Field performance verification will be conducted following startup to determine the effectiveness of the first phase.

Equipment Selection – Oxygen Injection

Selection of the appropriate equipment for oxygen injection is critical for achieving efficiency. Generally, lower capital costs for equipment result in lower efficiency and therefore higher operational costs, and so a long term economic evaluation must be made to compare different alternatives. During preliminary design, several vendors were invited to present their proposed method of injecting oxygen. The two alternatives evaluated were oxygen injection using downflow bubble contactors and using multiple injection points.

<u>Sidestream Injection by Downflow Bubble Contactors:</u> A downflow bubble contactor draws a sidestream of wastewater from the mainstream flow, superoxygenates the water with oxygen, and returns the highly oxygenated sidestream to the mainstream. Wastewater is superoxygenated by injecting high purity oxygen into pressurized wastewater within the contactor. A "swarm" of oxygen bubbles is formed within the contactor through which the wastewater must pass. This causes significant contact between the oxygen bubbles and wastewater at high pressure, raising the DO of the liquid. DO is controlled by adjusting the oxygen feed to the contactor. Downflow velocities in the wastewater are such that the buoyant velocity of the bubble is greater than the downward velocity of the water, which retains bubbles for prolonged periods causing highly efficient transfer and absorption of oxygen. The increasing diameter of the contactor reduces the downward wastewater velocity providing high efficiencies because bubbles are prevented from leaving the contactor. Since there is no path for oxygen to escape from the contactor vessel while operating, 100% efficiencies are theoretically possible.

Since the sidestream dissolved oxygen concentration follows Henry's Law and Dalton's Law of Partial Pressures, high purity oxygen and relatively high pressures are used to raise the DO in the contactor to very high levels.

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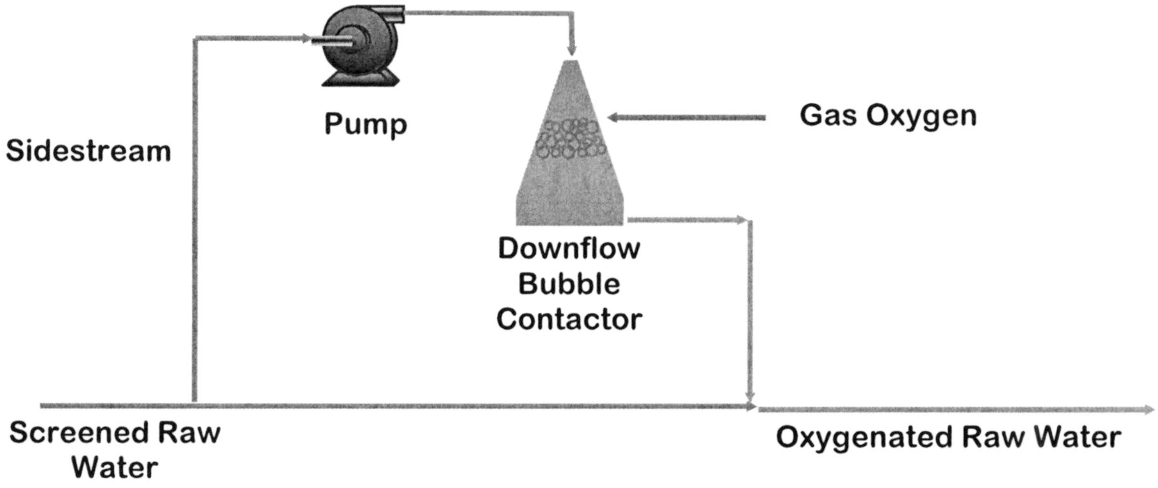
Pressures in the contactor vessels can be achieved by static head or pumping. The long term costs must be evaluated to determine if it more cost effective to construct a below grade structure (higher capital costs) to use static head, or if it is more cost effective to raise the pressure in the contactor by pumping (higher energy costs). A combination of these methods may be most effective. Existing pressures in a force main may also be used, but the DO achievable will be a function of the existing pressure.

Figure 4 - Downflow Bubble Contactor Typical Schematic



Multiple Injection Points: Under this scenario, oxygen could be injected at multiple locations to achieve relatively low DO at each injection point. Injection could be by supersonic mixer, inline diffuser, venturi injector, and proprietary injection equipment supplied by an oxygen vendor. DO addition is made at rates that match the uptake, satisfying the demand in stages rather than by superoxygenaton.

The initial injection point is at the pump discharge in Pump Station 6A, and would provide only enough DO to oxidize sulfide and maintain a slightly positive DO through the headworks building. A sidestream pump would pull screened wastewater from the PS6A wetwell, pass the wastewater through a supersonic mixer where oxygen is injected, and return the flow to the force main discharge in PS6A. Approximately 50 to 70 percent of the total oxygen required would be introduced at this point.

Oxygen would also be introduced by an inline sparger between PS6A and the metering vault. Approximately 30 to 50 percent of the required oxygen would be injected at the sparge element. A venturi injector would be placed between the meter station and the headworks building to trim the DO in the lines (relieving any non-dissolved oxygen or adding additional oxygen).

Following the headworks building, a proprietary sidestream oxygen dissolution system would provide the necessary DO for the clarifiers. Overall efficiency of the system is expected to be around 65 percent, although this is a unique installation and expected efficiencies may not be achievable.

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Evaluation of Alternatives: A controlling factor in the evaluation of equipment was the necessity to have little or no loss of DO at the headworks building. This enclosed structure has the first open water surfaces after the pump station. Oxygen gas coming out of solution in this building has the potential for creating an oxygen enriched atmosphere. Enriching the atmosphere (above 23.5%v/v) could increase flammability of materials inside the pump station and create a fire hazard.

Equipment was also compared based on capital and annual operating costs. For multiple injection points, it was estimated that life cycle costs over 20 years would have a present day cost of $12.7 million. Life cycle costs for the downflow bubble contactors were estimated at only $9.8 million. Downflow bubble contactors, manufactured by Eco Oxygen Technologies LLC, was the specified equipment.

Equipment Selection – Oxygen Supply

Generally, high purity oxygen is available in bulk delivery by truck in 20 ton increments for onsite storage or can be generated on site using vacuum pressure swing adsorption (VPSA) technology. Both methods were evaluated for use on this project.

On Site Liquid Oxygen Storage: LOX may be stored on site using insulated cryogenic tanks. These tanks can be stand-alone or can be mounted on a trailer. Delivery is by tractor-trailer, either to fill on site tanks or to swap trailers. Cryogenic tanks are insulated, ASME pressure code vessels generally kept at an internal pressure of 100 to 150 psi. LOX flows under pressure to vaporizers, where ambient temperatures "boil" the LOX, forming GOX under pressure. A regulator controls the GOX flow from the vaporizers to the injection point.

Bulk oxygen systems require no additional energy to produce oxygen. Typically, bulk LOX is purchased on a per ton basis. Equipment (cryogenic tanks and vaporizers) may be leased or purchased. Leased equipment allows for a low capital cost with a recurring monthly lease expenditure. When the equipment is leased, the vendor takes responsibility for maintaining the equipment. Generally, vendors require a five-year commitment for leasing oxygen storage systems, which would commit the Authority to one oxygen vendor for the duration of the lease period.

On Site Generation by VPSA: Vacuum pressure swing adsorption is the generation of relatively high purity oxygen (typically 93 percent purity) on site. Air is compressed into the generator tank, which contains a molecular sieve (usually a zeolite) that absorbs nitrogen under pressure and allows oxygen to pass through. Under normal atmospheric pressure, the zeolite releases the nitrogen back into the atmosphere. A vacuum pump is used to depressurize the zeolite and increase the regeneration efficiency.

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VPSA systems may be leased or purchased. A leased system would require a 15-year commitment to the equipment and a recurring monthly expenditure for the lease. A purchased system would require a large capital expenditure and the Authority would be responsible for operating and maintaining the equipment. Note that VPSA systems are generally not cost effective when they are operated at less than full capacity.

Evaluation of Alternatives: For evaluation purposes, it was assumed a demand of 15 tons per day would be required. Four alternatives were evaluated: lease VPSA equipment, purchase VPSA equipment, lease LOX equipment, or purchase LOX equipment. Again, anticipated life cycle costs were used to compare alternatives. The lowest life cycle costs were for purchasing VPSA equipment for generating gas oxygen on site ($3.8 million over 20 years). The second lowest costs were for leasing LOX tanks and vaporizers and purchasing LOX ($4.5 million over 20 years). Even though it did not have the lowest life cycle costs, leasing LOX equipment and purchasing bulk oxygen was selected for the three reasons listed below.

1. Leasing equipment has the lowest capital costs.
2. The industrial gas supplier that leased the equipment is responsible for safety and maintenance of their equipment.
3. The break even point for purchasing VPSA equipment occurred at approximately 15 years, which would require a long-term economic investment and commitment to this technology.

DETAILED DESIGN

Following selection of technology for oxygen injection and for oxygen supply, detailed design was initiated.

Equipment

The initial design consisted of two 12-foot diameter by 20-foot tall downflow bubble contactors. Because the final DO of the system is dependent upon the pressure inside the contactor, an evaluation was made between installing the cones below grade or installation at grade. A below grade installation required higher capital costs for construction of the vault, but would have lower operating costs because the pressure in the contactor would be generated by static head. An at-grade installation would have lower capital costs (since there would be no need for a vault) but would require higher head pumps to generate the needed pressure.

The economic evaluation showed that placing the contactors in a 30-foot deep reinforced concrete vault would have life cycle costs approximately $2 million less than placing the contactors at grade, although the initial capital construction costs would be slightly higher.

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Mechanical Design

Once the equipment and site were selected, liquid process design essentially involved a pumped sidestream. A system curve was generated and a pump was specified. Stainless steel and epoxy coated ductile iron process piping were both used due to corrosion concerns with the highly oxygenated wastewater. A solids handling centrifugal wastewater pump was specified to transfer screened wastewater between the existing force main and the contactors. Two independent sidestreams were designed, one for each of the pump station force mains.

Gas oxygen process design was slightly more complicated, primarily due to safety concerns with pure oxygen. Typical atmospheric concentration of oxygen ranges from 19.5% to 23.5% on a volume basis, and are usually around 21%. When the concentration exceeds 23.5%, it becomes an "oxygen enriched atmosphere" (OEA). Although very high atmospheric concentrations of oxygen have the possibility of causing health effects, the primary design concern involved oxygen-fueled fires.

In an OEA, materials that normally are not flammable can ignite and/or support combustion. To address this concern, a "failure modes and effects analysis" and a "system level hazard analysis" was performed on the system. Concerns raised by these analyses were addressed during design. The final design included using 316-stainless steel piping for gas oxygen service and a combination of more exotic metals for severe duty components.

CONCLUSION

Performing a bench scale laboratory study resulted in projected savings of $4.7 million for initial construction costs and $183,000 in yearly operational costs. The study determined the reaction rate in the wastewater stream for sulfide, which allowed optimization of design.

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