No Contactor? Remove Sulfide Using Side Stream Ozone Injection

Curtis Kunihiro, Quyen Tram Newell, and Nathan Hillard

The Toho Water Authority provides water and wastewater service to most of Osceola County. In the northwest portion of the county, the Southwest Water Treatment Plant (SWWTP) on Osceola-Polk Line Road was built to supplement water production from the existing Northwest Water Treatment Plant.

The SWWTP was designed by Jacobs Civil in 2002, and constructed by Wharton-Smith in 2003 as an 8.64 million-gallons-per-day (MGD) water treatment plant using conventional tray aeration for sulfide removal. Two offsite raw water wells were sited and designed east of the plant by the Toho Water Authority's geotechnical consultant.

In August 2003, the Florida Department of Environmental Protection (FDEP) adopted the guideline for control of copper corrosion and black water in 62-555.315(5), FAC. According to this guideline, raw water containing 0.3 milligrams per liter (mg/l) or less total sulfide could be treated with direct chlorination and conventional aeration could be used on raw water containing between 0.3 and 0.6 mg/l total sulfide, but forced draft aeration or equivalent treatment was needed for raw water containing between 0.6 mg/l and 3.0 mg/l total sulfide.

While the SWWTP and the raw water wells were under construction, the raw water was found to contain 1.4 to 1.6 mg/l total sulfide. Following completion of the plant, it remained idle until the raw water sulfide issue could be addressed.

A bench-scale testing program and a sulfide removal evaluation were performed in 2004 by Jacobs Civil's subconsultant, Malcolm Pirnie Inc. Bench-scale testing of hypochlorite on the raw water confirmed that turbidity would increase by five or more nephelometric turbidity units (NTUs) due to colloidal sulfur formation from the reaction of sulfide and chlorine. The FDEP rule does not allow an increase of more than two NTUs from raw water to finished water, so the SWWTP needed sulfide removal as part of its treatment before it could be placed into service.

The plant is not connected to a sewer or force main, and waste streams could not be handled in its septic system. The sulfide removal evaluation identified ozone injection for sulfide removal instead of forced draft aeration or packed tower aeration, because during periodic shutdowns the aeration processes would generate significant volumes of cleaning and flushing wastes that would have to be trucked offsite.

Ozone injection in water treatment has been used for disinfection, as well as oxidation of sulfide and other constituents in water. Contactor basins typically have been used for ozone dissolution in water using a fine bubble diffusion system.

In the past, ozone generators produced ozone concentrations on the order of 5 percent or less. Extended detention times were needed to dissolve ozone into water at these concentrations. The contactors are an effective way to dissolve ozone in the water and provide detention time, especially if ozone is being used as the primary disinfectant.

The ozone and dissolved oxygen (DO) remaining in the water after treatment have the potential for accelerated corrosion rates and cloudy water, so they are stripped from the water using various methods.[1] The Orlando Utilities Commission uses diffused air in the final contactor basin of its water treatment plants to strip ozone and DO from the water exiting ozone treatment.[2]

In recent years, ozone generators are capable of producing ozone concentrations on the order of 8 to 11 percent or more from oxygen gas without requiring excessive power. This higher concentration allows the use of venturi injectors to dissolve ozone effectively in water without the need for the diffusers and detention time provided by contactors. Furthermore, it was found that pressurized contact of ozone using venturi injectors provided more rapid, consistent oxidation of sulfide ion at lower applied ozone dosages than fine bubble diffusion.[3]

The use of gasification-degasification treatment™ combines pressurized venturi injection to dissolve ozone with degasification under pressure to remove undissolved ozone and oxygen that is entrained in the water following injection. This process is used in both side stream and full stream applications.[3] For the SWWTP, side stream injection was more attractive because it further reduced the DO concentration in the treated water.

During the spring of 2005, Malcolm Pirnie performed a pilot study on the raw water entering the SWWTP. The study determined that the ozone dosage was on the order of 3.3 pounds of ozone per pound of sulfide; that sulfide could be reduced to non-detectable levels; that ozone was not present in the treated water; and that DO concentration was on the order of 12 mg/l and could be lowered to 9 mg/l by contact with air, similar to conventional tray aeration.

The ozone for the pilot study was produced onsite by a small ozone generator using oxygen gas. The results of the pilot study were used to design the full-scale facility.

Curtis Kunihiro, P.E., BCEE, is a principal engineer with the Orlando office of AECOM Water. Quyen Tram Newell, P.E., is a senior engineer with the Toho Water Authority. Nathan Hillard, E.I., is a project manager with the construction firm Wharton-Smith Inc.

Implementation Schedule

In August 2005, the Toho Water Authority authorized Jacobs Civil to design a full-scale side stream ozone injection system for the SWWTP. The project was implemented using the construction manager at risk (CMAR) project delivery method. The team included the Toho Water Authority; Wharton-Smith as the CMAR; the water authority's consultants for survey and geotechnical services; and Jacobs Civil and its subconsultants, Malcolm Pirnie, Structural Technologies, and EMA.

The challenge for this project was to have the sulfide removal system and the SWWTP producing water by June 1, 2006, to meet water supply commitments to Polk County and to increase system pressure west of the plant. The team designed and permitted the project within four months.

The CMAR embraced the side stream ozone injection technology, identified the long-lead items for early procurement, and assisted with value engineering of the project. Wharton-Smith and Jacobs prepared early procurement bid documents for the ozone generators and selected Fuji equipment through a competitive bidding process.

Photo 1 – Overall View of SWWTP

Early procurement of a rotary UPS, electrical gear, liquid oxygen storage, and vaporizers allowed the design to be tailored to the selected equipment, including provisions for ozone generators, liquid oxygen storage, vaporizers, cooling water, ozone injectors, injector booster pumps, ozone destruct units, etc. The team also worked together to reduce the size of the Ozone Building by postponing a phase of the building and achieving significant savings for Toho.

Following bidding, Wharton-Smith started construction in January 2006. In addition to its project management and supervisory responsibilities, the CMAR self-performed the mechanical equipment installation to meet the tight schedule.

With the mechanical equipment installation's value of 20 percent of the $2.49 million construction cost, workers spent 80 consecutive days of 10 hours or more on the job site to maintain the project schedule.[4] Construction duration from start to producing water was a record 4.5 months!

From the start of design to the production of water, the side stream ozone injection project took nine months. The SWWTP began producing water on June 1, 2006, and construction was completed a month later. The Wharton-Smith and this project won a 2007 Associated General Contractor of Greater Florida's "Horizon Award" for Municipal/Utility – New Construction Category and a 2007 Eagle Award for ABC Excellence in Construction.

System Description

The side stream ozone injection system is located near the front of the SWWTP site, as shown in Photo 1. The major structures, clockwise from the left foreground, are:

- Ozone Injection Pad
- Ozone Building (beige with white roof) housing the Ozone Generators and associated power distribution
- Liquid Oxygen/Gaseous Oxygen Pad
- 2-million-gallon Ground Storage Tank
- Operations Building (blue with white roof) housing high-service pumps, power distribution, and controls
- Chemical Building (short blue with white

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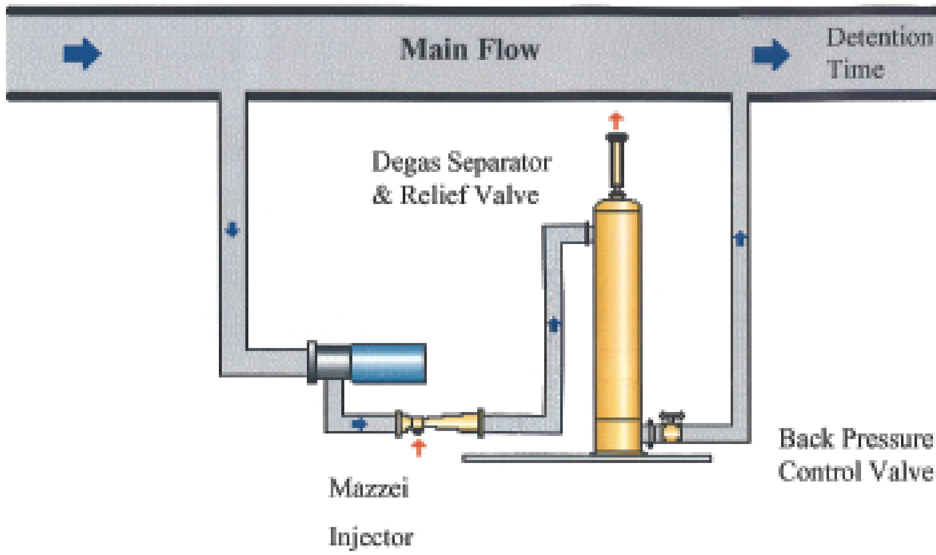
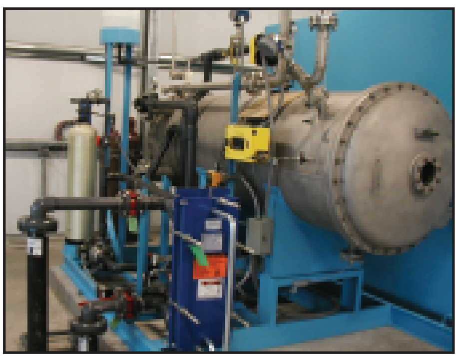


Figure 1 – Side Stream Injection Schematic (adapted from figure in ref. 3)

Photo 2 – LOX/GOX Pad
Photo 3 – Ozone Generator



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roof) housing hypochlorite and fluoride storage and feed systems

Liquid oxygen (LOX) is received and stored at the site in a 9,000-gallon vertical insulated tank. Two vaporizers, each rated at 12,750 standard cubic feet per hour (scfh) at 8-24 hours, produce gaseous oxygen (GOX) that flows under pressure through stainless steel pipe to the Ozone Building.

The LOX tank and vaporizers are shown in Photo 2. There is space on the LOX/GOX pad for a second LOX tank and a third vaporizer to provide capacity at buildout.

In the Ozone Building, GOX is filtered and a small amount of dry air is added to the GOX to help keep the ozone generator internals clean. Two ozone generators, each rated at 400 pounds per day ozone at 9 percent in oxygen, create ozone from the GOX. An ozone generator is shown in Photo 3.

Ozone is created in the stainless steel reactor vessel in the middle of the skid. The skid also has power and controls, closed loop cooling water treatment and recirculation, heat exchanger, and ozone concentration meter.

The ozone generator and Ozone Building are equipped with safety features to shut down the system in case of malfunction or leak of ozone or oxygen because ozone and oxygen are oxidants, and ozone is toxic.

Raw water enters the site from two offsite wells, each rated for a minimum of 3,000 gallons per minute (gpm) flow rate. The raw water is split into three streams, two side streams and a bypass stream. Each side stream has an injection booster pump rated up to 1,800 gpm, a Mazzei® venturi injector rated up to 36 standard cubic feet per minute (scfm), and a degas separator, as shown in Figure 1.

The side stream inlet pipes and bypass pipe are painted blue in Photo 4. The output from the ozone generators is sent to the venturi injectors, where it is injected into the side stream raw water.

Piping that carries ozone or ozonated water is stainless steel in Photo 4 with the direction of flow from left to right. The degas separators are the vertical stainless steel vessels with gas release valves on top. From the degas separators, ozonated side stream water combines with the bypass raw water.

In Photo 5, ozonated side stream manifold flows toward the viewer, and the combined water then flows to the left, turns, goes through a static mixer, and flows away from the viewer.

Photo 4 – Ozone Injection Pad

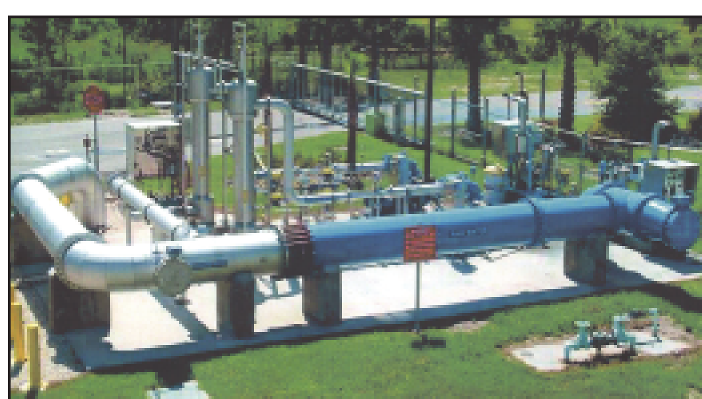

Photo 5 – Ozone Injection Pad

Photo 6 – Ozone Destruct

Photo 7 – Ground Storage Tank

There are two ozone destruct units to handle undissolved ozone and oxygen gas captured by the degas separators, and a carbon canister to handle gas from the air release valve downstream of the reaction zone. These units, shown in Photo 6, are located south of the Ozone Injection Pad.

The combined water is devoid of ozone and has a total sulfide concentration less than 0.2 mg/l as it enters the ductile iron water line that takes water to the hypochlorite injection point for primary disinfection, and then to a 2-million-gallon ground storage tank (GST), shown in Photo 7. The water remains under pressure from the raw water wells through ozone treatment to the conventional aerator on top of the GST, so the only additional pumping is the injection booster pumps at 75 horsepower each.

The conventional aerator is used to lower DO prior to the water entering the GST. High service pumps send water from the GST into the potable water distribution system.

Performance

Data obtained from the SWWTP in May 2007 is provided in Table 1. This data was used to calculate the values in Table 2 for ozone feed rate in pounds per hour (lbs/hr), power-to-ozone ratio in kilowatt-hours per pound of ozone (kwh/lb), total ozone feed in pounds per day (lbs/d), total estimated power in kilowatt-hours per day (kwh/d), ozone dosage in milligrams per liter (mg/l), and dosage ratio in lbs of ozone per lb of sulfide.

Table 2 shows a power-to-ozone ratio ranging from 4.5 to 4.7 kwh/lb of ozone, which is what was predicted by Fuji, and a dosage of ranging from 2.78 to 2.95 lbs of ozone per lb of sulfide. The ozone dosage is slightly lower than the 3.33 lbs/lb predicted by the pilot testing program, which implies that the full-scale system is more efficient than the pilot plant setup.

The LOX deliveries to the SWWTP around the period of reported data are provided in Table 3. Using the 12,795-gallons total of four LOX shipments from 3/30/2007 to 6/29/2007 and 103 days from 3/19/2007 to 6/29/2007, the average oxygen consumption is approximately 124 gallons per day (gpd). Based on a LOX density of 1.14 grams per cubic centimeter (g/cc) and 9 percent ozone concentration, the oxygen consumption of 124 gpd results in 1,180 lbs/d of oxygen used and 106 lbs/d of ozone theoretically produced.

The ozone generation calculated in column (11) of Table 2 shows feed rates comparable to this theoretical average production of 106 lbs/d. Thus, the 9 percent ozone concentration indicated by the instruments appears to be valid.

The power consumption for the SWWTP was 122,200 kwh from 3/23/2007 to 4/20/2007. The calculated average power consumption over these 29 days is 4,214 kwh/d. This power consumption arises from injection booster pumps at 75 Hp each; high service pumps at 250 Hp each; and loads from building exhaust and cooling, lighting, controls, metering pumps, sample pumps, etc.

The approximate water production is 3.9

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Table 1 – Reported Data

Date	(1) Raw Water Flow, MGD	(2) Total Sulfide In, mg/l*	(3) Total Sulfide Out, mg/l*	(4) = (3)-(1) Total Sulfide Removed, mg/l	(5) Ozone Feed Rate, lbs/d*	(6) Ozone Power Rate, kw*	(7) Well 1 Run Time, hours	(8) Well 2 Run Time, hours
5/03/2007	3.2	1.2	0.05	1.15	275	54	6.9	8.0
5/04/2007	4.7	1.1	0.03	1.07	140	26	5.4	16.0
5/05/2007	3.7	1.2	0.03	1.17	275	54	7.1	10.5
5/07/2007	4.0	0.9+	0.01	0.89+	291	55	8.7	10.2

* Instantaneous reading
+ Total Sulfide In appears to be an outlier; if (2) was 1.2, then (4) would be 1.19 and (14) would be 2.89

Table 2 – Calculated Values

Date	(9) = (5)/ 24 hrs/d Ozone Feed Rate, lbs/hr*	(10) = (6)/(9) Power-to-Ozone Ratio, kwh/lb	(11) = 275*(7)/24 hrs/d + 140*[(8)-(7)]/24 hrs/d {or 291*(7)/24 hrs/d + 148*[(8)-(7)]/24 hrs/d for 5/07/2007} Total Ozone Feed, lbs/d	(12) = (10)*(11) Total Power, kwh/d	(13) = (11)/ [(1)*8.34] Calculated Ozone Dosage, mg/l	(14) = (13)/(4) Calculated Dosage Ratio, lbs Ozone/ lbs Sulfide
5/03/2007	11.46	4.71	85.5	403	3.20	2.78
5/04/2007	5.83	4.46	124	553	3.16	2.95
5/05/2007	11.46	4.71	101	476	3.28	2.80
5/07/2007	12.12	4.54	115	522	3.44	3.86+

*Instantaneous reading
+Total Sulfide In appears to be an outlier; if (2) was 1.2 mg/l, then (4) would be 1.19 and (14) would be 2.89

Table 3 – LOX Deliveries

Date	3/18/2007	3/30/2007	4/04/2007	5/17/2007	6/29/2007
LOX, gallons	3,150	1,563	2,900	4,300	4,032

Ozone Generators set at 9 percent ozone concentration in GOX exiting the ozone generator(s).

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MGD (equivalent flow of 2,708 gpm), and the ozone generators run for approximately 11 hrs/d. The ozone generator power was estimated based on assumed 11 hours per day operation, with 7.5 hours at 54 kw and 3.5 hours at 26 kw.

The ozone generator power falls within the calculated range previously estimated to range from 400 to 550 kwh/d. The average April 2007 power consumption of 4,214 kwh/d less 2,704 kwh/d for high-service pumping, 616 kwh/d for the ozone injector booster pump, and 496 kwh/d for ozone generation results in approximately 398 kwh/d calculated for miscellaneous power loads.

Features

The gasification-degasification treatment™ system uses high efficiency Mazzei® injectors to dissolve ozone gas in the raw water side stream. The high-intensity mixing allows a short detention time to dissolve ozone while limiting the dissolution of DO.

The ozone dosage for the total raw water flow is low enough that the side stream represents about 50 percent of the total raw water flow. The remaining 50 percent of the raw water bypasses the booster pump and injector for power savings.

Side stream injection of ozone has a short detention time because the side stream travels through a short length of pipe before entering the degas separator. The absence of a contact vessel limits the dissolution of oxygen in the side stream for lower DO concentration in the side stream. Sulfide is oxidized in the side stream prior to mixing with the bypass flow.

The volume of entrained undissolved oxygen and ozone exiting the degas separator is smaller than the volume of undissolved oxygen and ozone that exits contactors, so the ozone destruct units that treat this gas stream are smaller for the gasification-degasification treatmentTM system than those for contactors. Thus, the construction cost and operating cost for ozone destruct units used for this system are lower than those for contactors, which have higher ozone and oxygen flows exiting the contactors.

A static mixer downstream from where the ozonated side stream mixes with bypass flow provides intimate contact of ozone from the side stream with sulfide from the bypass flow. With good mixing of the ozonated side stream and the bypass flow, the dissolved ozone and oxygen in the side stream oxidize the sulfide in the bypass flow, the ozone is fully used with no residual, and the DO is diluted by 50 percent.

Use ozone for sulfide removal and use chlorination for primary disinfection to minimize detention time for ozone oxidation. Maintain sulfide residual leaving the ozone treatment process. If ozone is not used as the primary disinfectant, there is no need to maintain an ozone residual.

The complete oxidation of sulfide to sulfate occurs in three seconds, whereas the half-life of ozone is approximately 18 to 20 minutes.3 At the buildout flow rate of 12,000 to 14,000 gpm, the detention time in the 24 feet of 30-inch pipe downstream from the static mixer is more than six seconds.

The short detention time results in lower construction cost because there are no contactors, reaction tank, or long, large-diameter reaction pipe. Also, the operating cost is lower than that for contactors, which pump the full flow into contactors or tanks, use blowers for diffusing ozone, and use separate air blowers for stripping ozone in the last basin.

The conventional tray aeration at the top of the GST serves to lower DO in the water entering the GST by stripping out DO into the air. The lower DO concentration results in lower corrosion potential in the finished water.

Conclusions

The side stream ozone injection system is a viable method for removing sulfide in potable water treatment. Our experience showed that it can be implemented more quickly and for less cost than ozone contactors using fine bubble diffusion.

Operating data confirms the design criteria used for side stream ozone injection. The results show that the ozone dosage, ozone concentration, and energy consumption remain within design parameters.

Acknowledgements

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References

[1] Jackson, James R., Overbeck, Paul K., and Overby, John M. (1999). Dissolved Oxygen Control by Pressurized Side Stream Ozone Contacting and Degassing. Presented at International Ozone Association, World Congress, 1999 Annual Conference, August 24, 1999. Paper courtesy of Mazzei Injector Corporation.

[2] Personal communication with Orlando Utility Commission staff, 2005.

[3] Jackson, James R. and Overbeck, Paul K. (1997). Ozone Pipe-line Gasification-Degasification Treatment (GDTTM) Performance in Potable Water Treatment Plants. Presented at International Ozone Association, Pan American Group, 1997 Annual Conference, August 26, 1997. Paper courtesy of Mazzei Injector Corporation.

[4] Wharton-Smith, Inc. (2007). Entry package for 2007 Eagle Award for ABC Excellence in Construction, May 30, 2007.