Evaluation of Mixing, Mass Transfer, Operation and Maintenance, Energy, and Material Requirements for Hydrogen Sulfide Oxidation at the Orlando Utilities Commission Water Treatment Plants

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Ozonation is an efficient and fast method for odor control and removal of hydrogen sulfide (H_2S) from well water. The Orlando Utilities Commission (OUC) is the second largest municipal utility in Florida and 14th largest in the United States. Starting in the late 1990s, the OUC installed air-fed and liquid oxygen (LOX)-fed ozonation systems using fine bubble diffusers (FBD) for gas dissolution, followed by over-and-under contacting basins for mixing, disinfection, and completing oxidation reactions and blending at eight water treatment plants for mitigation of H_2S from well water.

The OUC continually takes advantage of technological changes, such as advances in ozone generation and dissolution to improve its treatment processes. It has also been upgrading older ozonation systems with newer oxygen-fed ozone generators, coupled with sidestream venturi injection and pipeline contacting designed with advanced modeling techniques.

This article presents data from retrofit projects at the OUC Southwest Water Treatment Plant (WTP), Conway WTP, and Pine Hills WTP, which involved replacement of FBD with sidestream venturi injection ozone dissolution technologies. The two technologies are compared based on mixing and mass transfer efficiency, operation and maintenance (O&M), specific energy, materials, and required physical footprint per unit mass of ozone transferred. With respect to mixing efficiency, a statistical analysis was performed to compare the coefficient of variation of ozone residual for both technologies and the impacts on control schemes for H_2S oxidation.

Background

The OUC draws water from the Lower Floridan aquifer from a system of 31 deep wells that contain varying amounts of naturally occurring H_2S. The H_2S is oxidized rapidly with ozone to form sulfate, which eliminates H_2S-related taste and odor and reduces the amount of chlorine required for residual disinfection.

In 1997, OUC installed an air-fed ozone system using FBD and over-under contacting for the reduction of H_2S. Eventually, all OUC WTPs implemented ozone for treatment of sulfide-containing wells (Rakness, 2011).

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Almost a decade ago, OUC began the process of upgrading all water treatment facilities from FBD to sidestream injection (SSI) and from air-fed ozone generators to LOX-fed ozone generators.

Each plant has a minimum of two ozone contactor basins. Currently, the three plants (Southwest, Conway, and Pine Hills) have been retrofitted from FBD to SSI, which are the two main methods of ozone dissolution.

The ideal ozone contacting system would have homogenous gas-liquid mixing in the dissolution zone, followed by near plug flow in the contacting/reaction zone. Ozone contacting for municipal water treatment is conducted in baffled basins, either vertical (over-under) or horizontal (side to side).

The design of FBD systems is similar to aerated bubble columns, with guidelines for maximum gas loading rate, floor area coverage, contact time, and water column depth. Separate dissolution chambers and

Table 1. Summary of Previous and Current Designs

Plant	Method of Ozone Dissolution	Design Capacity, mgd	No. of Contactors	Ozone Generators				Side water depth, ft
				Qty.	Ozone production (ppd)	Type	Feed Gas	
Conway	FBD (Schulz, et.al., 1999)	26.75	2	3	1000	Medium-Frequency	LOX	20
	SSI upgrade 2021							
Southwest	FBD (Schulz, et.al., 1999)	30	2	4	1000	Medium Frequency	Air	24.5
	SSI upgrade 2014	40	3	3	1260	Medium	LOX	

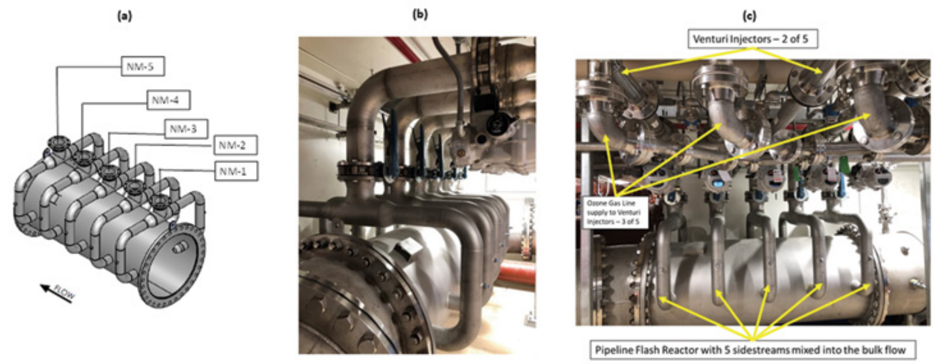

Figure 1. (a) Mazzei pipeline flash reactor, (b) Conway Water Treatment Plant ozone sidestream injection into bulk flow, and (c) Conway Water Treatment Plant pipeline flash reactor, venturi injectors, and ozone gas lines.

contact chambers are required and the number of chambers depends on the size of the applied dose and type of application. The FBD is known to be generally less energy-intensive due to its passive mixing imparted by ozone bubbles rising through the water column. The FBD has also been shown to have higher O&M costs due to plant shutdowns and confined space entry for maintenance and replacement of the diffuser gaskets and diffusers (Snider, 2020; Smith et al., 2017).

With SSI dissolution systems, a sidestream is pulled from the bulk flow and ozone gas is injected via venturi injectors. The ozonated sidestream is then remixed into the bulk flow with jet nozzles, downflow tubes, or static mixers, or a combination thereof. The process of rapid ozone dissolution starts in the venturi injector and pressurized sidestream piping, continuing in the main pipeline or over-under contactor. The mixing zone can have a smaller footprint when compared to diffusers, especially at high applied doses. This approach avoids confined space entry into the contactor and typically requires less maintenance, but needs careful design to maximize the active mixing and minimize sidestream pump energy use.

The SSI can be applied both to pipeline contactors and traditional contact basins; pipeline contacting offers better control and near plug-flow conditions. The sidestream systems, pipeline, and traditional contact basins provide the flexibility of turndown as flow rates and doses change. The engineering solution to this has been to utilize tracer studies (when available) to identify and reduce dispersion in contactors. The solution can add significant increases to overall costs due to structural modifications. These modifications can include adding more baffles and/or inlet flow energy dissipation methods; however, engineers often do not have access to tracer studies and actual flow rates may vary from tracer runs.

The volumetric efficiency of the contactor can have a direct impact on ozone generation costs, due to poor mixing efficiency. In recent years, computational fluid dynamic (CFD) modeling has been successfully applied to improve contactor design for reducing short-circuiting and improving basin hydraulics.

Due to the passive mixing of FBD basins, they require deeper water columns (20 to 25 ft) to increase static pressure over the diffusers, thereby minimizing the size of bubbles released from the diffusers and improving ozone gas transfer into water. The two-stage, active mixing imparted with venturis and nozzles, however, creates a constant shearing of bubbles, resulting in improved transfer due to the rapid renewal of the gas-liquid interface; therefore, the higher mixing energy of SSI systems can be used to decrease the contact basin water column depth (typically less than 16 ft).

Previous Work

This article builds on a peer-reviewed paper by Schulz and Bellamy (2000) on the role of mixing in ozone systems. Key results from that study include SSI-based ozone contactors that were shown to:

- Improve mixing, with velocity gradient values ranging from 600 to 900 per second, three to eight times higher than FBD.
- Improve mixing, indicated by coefficients of variation ranging from 5 to 10 percent, compared to 20 to 45 percent with FBD systems.
- Control ozone dosage, which is not instantaneous with FBD, and control changes need to account for this built-in detention time requirement.
- Optimize design of the pipeline contactor, which is critical for achieving homogenous mixing.

The objective of this study is to compare the performance of FBD and SSI systems for H_2S oxidation with ozone with respect to the following performance metrics:

- Mass transfer efficiency
- Total specific energy (mass transferred per unit energy consumed)
- Total pumping energy
- Mixing efficiency
- O&M differences

Methodology

Description of Facilities

Southwest Water Treatment Plant

The Southwest WTP includes three parallel ozone contactor trains and has a design capacity of 40 mil gal per day (mgd). In early 2010, the ozone system was upgraded with new ozone generation equipment and the existing FBD dissolution system was replaced with a new SSI system. The ozone improvements project was completed in late 2014 and early 2015.

The design replaced four air-fed generators with three 1,260 pounds per day (ppd) oxygen-fed generators to deliver an applied ozone dosage of 7.4 to 9.84 mg/l at ozone gas concentrations of 8 to 12 percent wt. The contact basins at Southwest had 1,656 diffusion stones that were replaced by five, small venturi gas injectors. The injectors discharge into a common pipeline flash reactor (PFR) located directly upstream of the ozone contact basins. This design modification allowed the existing dissolution chambers in the contactor to now function as reaction chambers. The design team used multiple small injectors to provide turn down that would allow the plant to minimize pump energy costs by reducing the number of ozone injectors required at low to average ozone production rates.

Details of the SSI-PFR design for the Southwest plant are available elsewhere (Pathapati et al., 2016) and are not reproduced here.

Conway Water Treatment Plant

The upgraded Conway WTP includes two parallel contactor trains and has a design capacity of 26.75 mgd, with a maximum

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consumptive use permit (CUP) allocation of 30.9 mgd. The redesigned ozone dissolution system uses sidestream ozonated water, which is mixed with bulk water in the pipeline via one PFR, as shown in Figures 1A, 1B, and 1C. The PFR consists of five nozzle manifolds (NM), each connected to one venturi injector (five injectors total) and each equipped with two discharge nozzles (10 nozzles total). The NM on the PFR are labeled as NM-1, NM-2, NM-3, NM-4, and NM-5, with NM-1 located the furthest upstream and NM-5 located furthest downstream. A Westfall Static Mixer (model 2800) is included in the SSI system. A summary of previous and upgraded designs is provided in Table 1.

Conway Water Treatment Plant Design With Computational Fluid Dynamic

The CFD modeling was used to design the ozone dissolution and mixing system with the pipeline contactor. The geometry and the mesh are shown in Figure 2.

The geometry was meshed with approximately 5.7 mil locally refined hybrid cells. All piping was assumed to be constructed of Schedule 40 stainless steel. For all cases, the primary phase is the untreated water entering through the main pipeline and the secondary phase is the sidestream gas; the water temperature is assumed to be 20°C.

Input data for CFD modeling is listed in Table 2. All analyses are steady-state and steady-flow. Flow rates other than those specified and start-up/ramp-up conditions are not part of the scope of this study. In addition, any effects of undefined upstream plumbing and hydraulics, as well as the presence of gas slugs, pulsating flows, etc., are not modeled here. The vent branch downstream of the air dam is assumed to be closed in the model, and CFD modeling was performed with ANSYS Fluent (v19.2).

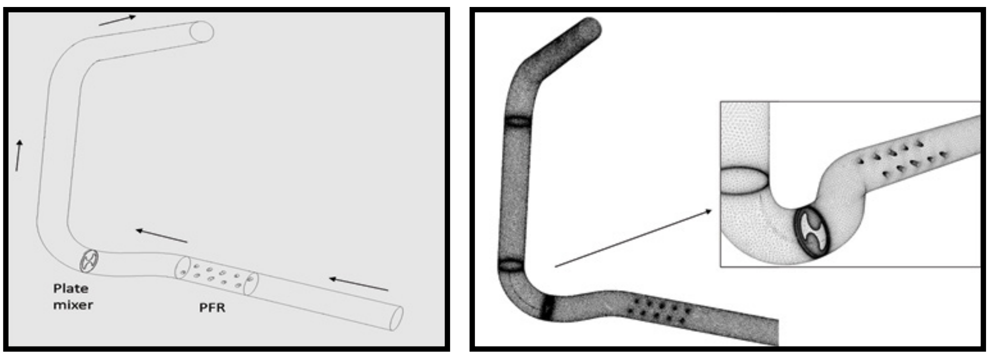

Figure 2. Pipeline flash reactor geometry and mesh for computational fluid dynamic model at Conway Water Treatment Plant.

Table 2. Inputs to Computational Fluid Dynamic Model for Sidestream Injection Pipeline Contactor Design

Case	1	2	3	4	5
Plant Flow (mgd)	6.0	13.0	20.0	27.0	30.9
Pipeline Diameter (in.)	36	36	36	36	36
Pipeline Pressure (ft w.c)	18.6	20.0	22.4	25.9	28.7
Applied Ozone Dose (mg/l)	12.0	12.0	12.0	12.0	12.0
Ozone Concentration (% wt)	10%	10%	10%	10%	10%
Per-Injector Ozone Injection Volume (scfm)	48.7	52.8	54.2	54.9	50.2
Number of Sidestream Venturi Injectors	1	2	3	4	5
Nozzle Manifolds in Operation	NM-1	NM-1, NM-2	NM-1, NM-2, NM-3	NM-1, NM-2, NM-3, NM-4	NM-1, NM-2, NM-3, NM-4, NM-5

Mixing Energy Calculations

The following equations were utilized for mixing energy calculations:

Hydraulic HP =
head (ft) x flow rate (gal per min [gpm]) x (specific gravity)/3956 (1)

Brake HP =
Hydraulic HP/pump efficiency (2)

Power input for diffusers = P =
35.28 Q in [(h+ 33.9)/33.9] (3)

Where "h" is the depth of the gas diffuser below the water surface (ft)

Power input for SSI =
Injector inlet pressure (ft of water) x flow rate (gpm)/3956 (4)

$$\text{Velocity gradient, } G = \sqrt{\frac{P}{\mu V}} \quad (5)$$

Where "P" is power dissipated in ft-lb/s, 'μ' is the viscosity of the water in Ib-s/ft^2, and "V" is the volume in ft^3 of the mixing reactor.

Power/Volume =
total energy input in HP/(volume in gal) (6)

Operation and Maintenance Considerations

Automation and Overfeed

The goal of achieving target mass transfer efficiency is important, as well as maintaining the stability of ozone residual. The coefficient of variation (COV) of dissolved ozone residual downstream of the ozone dissolution process can be used to evaluate the stability of the ozone residual. As plants move toward automation, where the applied ozone dose is adjusted based on measured residual readings, stable ozone residuals are required to provide this level of automation. Tighter control of the ozone dose in response to plant flow or water quality changes will meet treatment performance targets (i.e., complete sulfide oxidation) at the least cost.

The COV, also known as concentration variance, is expressed as follows:

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Table 3. Comparison of Fine Bubble Diffuser System to Sidestream Injection for Ozone Contacting at Mannheim Water Treatment Plant, Kitchener, Ont. (Snider, 2020; Smith et al., 2017).

O&M Component	Annual O&M costs		25-Year O&M costs	
	FBD	SSI	FBD	SSI
Diffuser Decalcification (every other year)	$5,500	N/A	$137,500	N/A
Diffuser Inspection and Minor Repairs (every other year)	$3,800	N/A	$95,000	N/A
Diffuser Replacement Cost (two diffusers per year)	$800	N/A	$20,000	N/A
Gasket Replacement Cost (64 every two years)	$3,200	N/A	$80,000	N/A
Electricity for Pumping	N/A	$ 5,000	N/A	$ 125,000
Pump Maintenance	N/A	$ 500	N/A	$ 12,500
Inspect SSI Equipment (weekly)	N/A	$ 600	N/A	$ 15,000
Inspect Contactor Nozzles (once every two years)	N/A	$ 1,500	N/A	$ 37,500
Total Annual Cost	**$13,300**	**$ 7,600**	**$ 332,500**	**$ 190,000**
Total Facility Downtime for Maintenance	**7**	**2**	**175**	**50**

Table 4. Summary of Computational Fluid Dynamic Results for Conway Ozone Pipeline Contactor Design

Case	1	2	3	4	5
Plant Flow (mgd)	6.0	13.0	20.0	27.0	30.9
Total Ozone Injection Volume (scfm)	48.7	105.6	162.5	219.4	251.0
Uniformity Index at Ozone Sampling Location	>0.95	>0.95	>0.95	>0.95	>0.95
Coefficient of Variation of Ozone Residual	<0.05	<0.05	<0.05	<0.05	<0.05

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$$CoV = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\frac{(C_i - C_{mean})}{C_{mean}}} \quad (7)$$

Where "C_i" is the single-point measurement of instantaneous concentration, "C_{mean}" is the time-averaged mean dissolved ozone concentration and "N" is the number of samples.

For ensuring satisfactory mixing in ozone contactors, Schulz and Bellamy (2000) recommended a COV target of 5 percent or lower to achieve homogenous mixing and lower than 10 percent for closed-loop monitoring and control of real-time data, such as online residual measurements.

A high dissolved ozone residual COV can result in overproduction of ozone, thus resulting in significant material costs.

Maintenance

The FBD systems require plant shutdown and confined space entry for regular diffuser and gasket replacements. A recent comparison of SSI and FBD systems for ozone contacting for a 14-mgd plant in Kitchener, Ont., is shown in Table 3.

Results and Discussion

Evaluation of Mixing With Computational Fluid Dynamic for Conway Water Treatment Plant

Mazzei Injector Co. performed multiphase CFD analysis for the Conway plant. In order to quantitatively define the extent of mixing, a uniformity index (UI) is used to evaluate results of the CFD model.

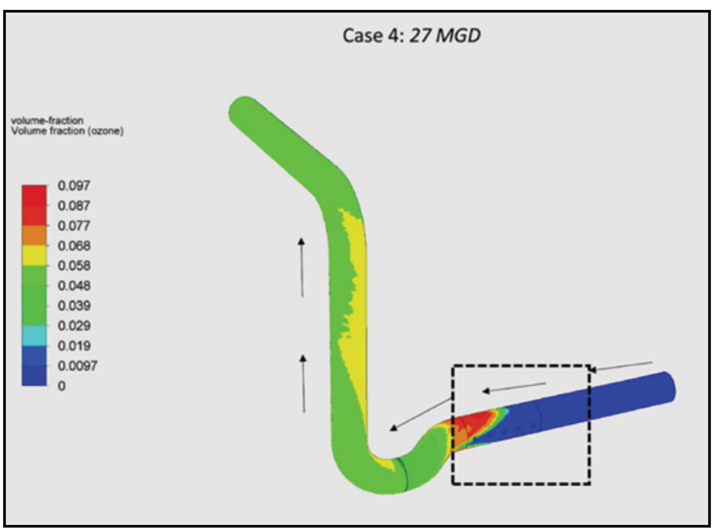

Figure 3. Contours of volume fraction of gas across representative cross sectional planes, Case 4, isometric view, and global scale.

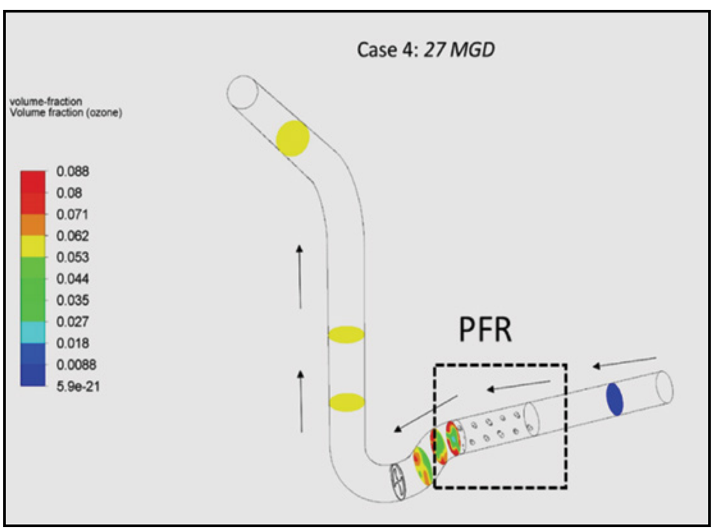

Figure 4. Contours of volume fraction of gas across representative cross sectional planes, Case 4, isometric view, and local scale.

Table 5. Conway Water Treatment Plant Ozone Injection Performance Test Data

No. of wells	Number of Injectors	Plant Flow (mgd)	Ozone Gas % wt	Total sidestream flow (gpm)	Ozone lbs/day	Applied Ozone Dose (mg/L)	Off-Gas Ozone Conc (AIT-No. 1) ppmv	Off-Gas Ozone Conc (AIT-No.2) ppmv	Ozone Gas Flow, scfm	Transferred Ozone Dose	Ozone Residual Concentration (mg/l)	Gas to Liquid Ratio	Mass Transfer Efficiency (Calc AIT No. 1)	Mass Transfer Efficiency (Calc AIT No. 2)	Test Point Weighting Factor	Weighted MTE, AIT No. 1	Weighted MTE, AIT No. 2
all 5	3	26.1	10.05	2030	1620	7.44	1200	1100	144.0	7.31	0.09	53.1%	98.3%	98.4%	22%	21.62%	21.65%
1,2,3,4	3	21	10.07	2035	1350	7.70	3280	3090	120.0	7.34	0.08	44.1%	95.3%	95.6%	45%	42.88%	43.00%
1,2,3	2	13.4	9.90	1366	894	8.00	990	850	79	7.88	0.06	43.3%	98.6%	98.8%	22%	21.68%	21.73%
4	1	8.3	10.02	680	603	8.71	1520	1260	52	8.52	0.08	57.2%	97.8%	98.2%	11%	10.76%	10.80%
WEIGHTED MTE																96.9%	97.2%

The UI is defined as the normalized root mean square (RMS) of the difference between the local gas fraction and the spatial mean of the gas fraction integrated over the area of a representative cross sectional plane. A UI of 1 indicates complete homogeneity of mixing. The area-weighted UI of the gas phase is calculated using the following equation:

$$UI = 1 - \frac{\sum_{i=1}^{n}\left[\left(\left|\phi_i - \overline{\phi_a}\right|\right)A_i\right]}{2\left|\phi_a\right|\sum_{i=1}^{n} A_i} \tag{8}$$

Where i is the facet index of a cross sectional plane with facets (mesh elements), $\overline{\phi}_a$ is the average value of the gas phase volume fraction over the outlet boundary, given as follows:

$$\overline{\phi_a} = \frac{\sum_{i=1}^{n} \phi_i A_i}{\sum_{i=1}^{n} A_i} \tag{9}$$

Overall results indicate a high level of uniformity of mixing and dispersion (UI>0.95) of sidestream gas with bulk flow at the sampling planes, as shown in Table 4.

Figure 3 and Figure 4 depict contours of volume fraction of gas across representative cut planes for Case 4. Model results show rapid mixing and dispersion of ozone gas in the pipeline downstream of the pipeline contactor.

Performance Testing

Orlando Utilities Commission Conway:

Ozone transfer efficiency was analyzed for design flows of 8.3, 13.4, 21, and 26.1 mgd and results are summarized in Table 5. Figure 3 and Figure 4 depict the pipeline contactor with five NM, one for each of the five wells. Well water is pumped through the venturi injector, and then directed thorough the nozzles into the pipeline contactor. The plant process was allowed to stabilize for approximately 30 minutes at the design flow before data was collected.

The performance test demonstrated the SSI ozone dissolution system's ability to meet the specified ozone transfer efficiency of 96 percent. Results from AIT Analyzer No.1 and No. 2 showed the test point weight, 96.9 and 97.2 percent, respectively, for the Case 4 design flows, shown in Table 5.

Mixing Energy

The mixing energy provided by FBD and SSI dissolution systems is significantly different. Table 6 shows a comparison of these technologies for the Southwest and Conway plants. The velocity gradients (G) for the FBD systems range from 108 to 232 sec^-1, whereas the SSI system range from 4800 to 7000 sec^-1. This demonstrates the significant increase in mixing energy when the Southwest and Conway plants upgraded from FBD to SSI.

This greater mixing energy also explains the lower COV measured with the SSI system when compared to the FBD system. The total reactor volume required for the ozone dissolution process is much larger if FBD is used, due to the upper limit of the amount of gas that can be effectively added per sq ft of the tank area. This effectively leads to an upper limit to the maximum-applied ozone dose that can be transferred per contactor chamber; higher doses and/or lower instantaneous demand will result in much higher capital costs.

Discussion

Comparison of Fine Bubble Diffusers and Sidestream Injection Systems

As the OUC plants upgrade from FBD systems to SSI systems, O&M personnel have noted several advantages.

Summary of Observations for Fine Bubble Diffusers

- The FBD requires an operator to closely monitor and adjust ozone dosages at each plant. Depending on the well or combination of wells supplying the plant during operation, the operator has to adjust the ozone dosage, allow time for change to take place, monitor ozone residual in the water, and evaluate whether to increase or decrease ozone dosage.
- The oxygen reduction potential (ORP) monitoring had been implemented at the FBD plants many years ago, but was discontinued due to wide-ranging readings from the instruments. The instability of the readings was due to the same phenomena that produces wide-ranging readings in the ozone residual: incomplete mixing.

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- The ORP monitoring assists the operator in evaluating the level of H_2S oxidation that is occurring, which is not an issue when the plant is operating in the proper ozone residual set point. This parameter becomes critical when ozone is being underfed and the ozone residual is zero. For these conditions, the ORP can provide an indication as to the level that ozone is being underfed, which eliminates the guess work in determining a recovery ozone dosage and allowing the plant to move back into proper dosages in a minimum amount of time.
- The FBD systems can see a large variation in the amount of ozone dose required. Because the ozone residual varies widely, operations must feed a greater amount of ozone to ensure that low ozone residual periods still provide sufficient oxidation of H_2S. This means that when the ozone residuals increase, the plant is in an overfeed situation.
- Because ozone dissolution occurs in the ozone dissolution basin, ozone residual sampling must be taken from the contact chamber downstream of the dissolution chamber. This added contact time requirement delays time between control actions. In addition, it makes the plant control actions subject to the current plant flows, because at high plant flows, the response times will be shorter, while at low flows, the response times will be lengthened.
- The FBD operation requires monitoring of the ozone off-gas to determine when the diffuser stones require inspection for possible replacement.

Table 6. Comparison of Mixing Energy Requirements

Parameter	OUC- Conway FBD (Schulz 2000)	OUC- Conway SSI-PFR	OUC- Southwest FBD (Schulz 2000)	OUC- Southwest SSI-PFR
Plant Flow (mgd)	10-15.5	6-31	12	10-45
Applied Dose (mg/l)	8	10-12	8	7.4-9.8
G, Velocity Gradient, sec^-1 in Dissolution Zone	108 - 131	6000-7000	232	4800-5300
Coefficient of Variation Of Dissolved Ozone Residual	45-46%	<5-7%	21-25%	<5-7%

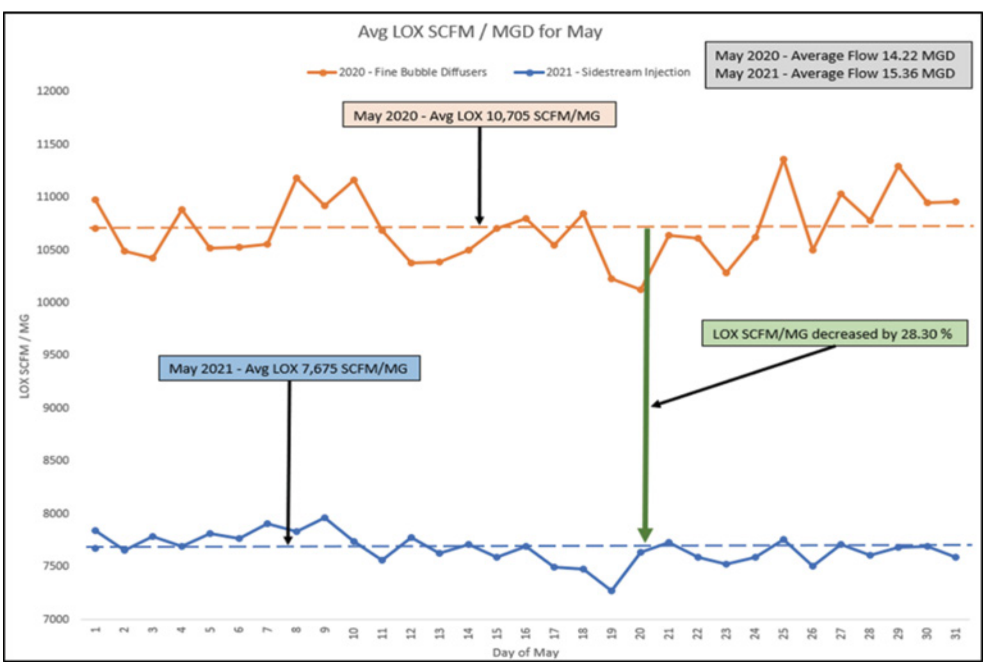

Figure 5. Comparison of 30-day liquid oxygen consumption (May 2020 with fine bubble diffusers compared to May 2021 with sidestream injection) for per mil gal of treated water for Conway Water Treatment Plant before and after upgrade to sidestream injection from fine bubble diffusers.

- The procedure for inspection of diffuser stones includes:
  - Confined space procedure (lockout/tagout)
  - Contactor valved out of service
  - Contactor drains overnight
  - Air or oxygen depending on what is available at the plant for bubble testing
  - Requires four technicians for two days to test and conduct inspection for a total of 64 labor hours per contact basin
  - Additional labor hours and material costs are added if diffuser stones require replacement or repair

Summary of Observations for Sidestream Injection

- The SSI ozone dosage control is made through the programmable logic controller (PLC). The stability of the ozone residual has allowed the utility to establish an ozone dosage requirement for each well. The PLC accounts for the wells that are operational and then determines the appropriate ozone dosage for that well combination. Once that ozone dosage is set, the PLC monitors the ozone residual and makes adjustments to the ozone dosage.
- The increased stability of the ozone residual has allowed the utility to bring back ORP monitoring to provide additional insight on complete oxidation of H_2S.
- Because ozone dissolution occurs in the PFR that is feeding the ozone contact chamber, ozone residual sampling is taken from the pipeline feeding the ozone contactor. This significantly reduces the delay in response times experienced with FBD systems; in fact, the response times to ozone dosage changes are essentially instantaneous. In addition, as the flow increases or decreases in the plant the corresponding change in response time is only incrementally affected.
- Upon conversion to SSI, resulting in a dramatically improved consistency in ozone residual due to the improved COV, the OUC was able to generate data that defined the ozone demand (due to H_2S) from each well. With this gained knowledge on each well, OUC was able to program the PLC to predict the required ozone dosage based on a weighted analysis of the specific wells that are on. This analysis incorporates the flow from each well as a percent of the total flow and the well's corresponding ozone demand; therefore, while data

sets are collected a year apart, the consistency of the wells ozone demand/ H_2S concentration allow this comparison. Ozone production and dosage have decreased at each plant that has been converted from FBD to SSI.

Reliable monitoring and instantaneous dissolution of ozone in the pipeline with SSI systems and PFR permits mean much more precise, and economical, management of ozone in the upgraded installation, permitting a significant reduction in ozone production, as shown in Figure 5 and Figure 6. Further analysis is part of the continuing study of this installation.

Table 7 shows a comparison for ozone production for treating water from the same wells at similar flow rates. Results indicate that a well-designed SSI system can have a significant impact on reducing material costs.

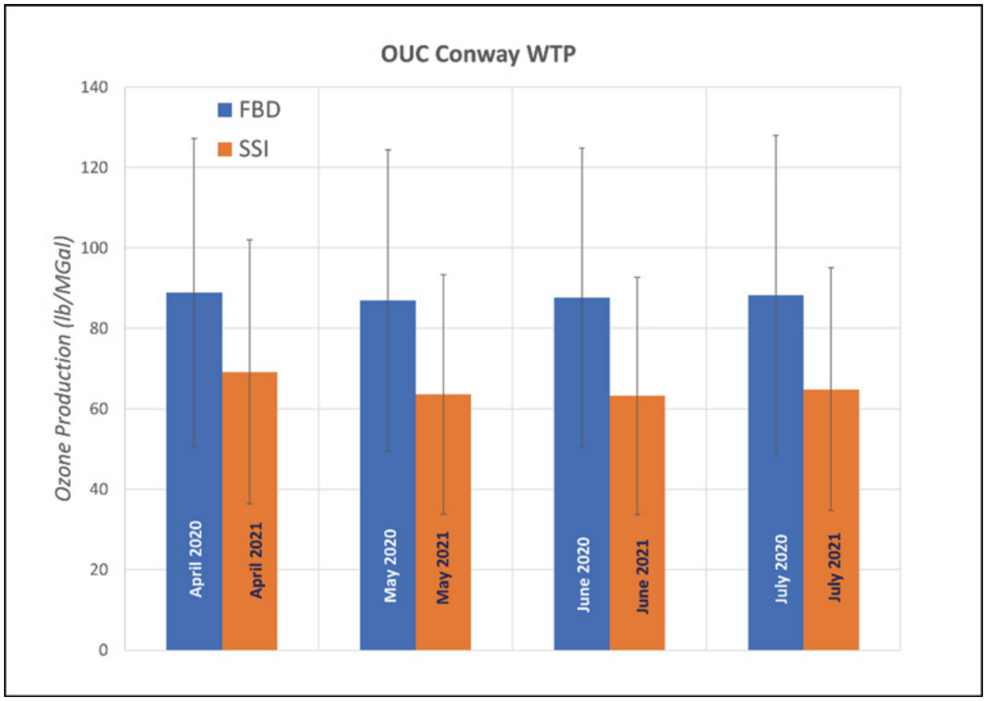

Figure 6. Comparison of monthly ozone production per mil gal of treated water for Conway Water Treatment Plant before and after upgrade to sidestream injection from fine bubble diffusers.

Table 7. Comparison of Mixing Energy Requirements

Date of Data Collection	25-Aug-20		5-Aug-21	
Ozone Dissolution Technology	FBD		SSI	
Wells in Operation	3&4		3&4	
Well 3 Avg Flow (mgd)	4.3		4.2	
Well 4 Avg Flow (mgd)	8.7		8.7	
Total Flow (mgd)	13.0		12.9	
Avg Pounds of Ozone Production/Day	1195		835	
Reduction in Ozone Production With SSI	**30.1%**			
Avg Ozone Dosage, Calculated (mg/L)	10.5		7.6	
Data Start and End Points	Start	End	Start	End
Time	8:29	14:28	0:00	6:00
Duration of Run (hrs:min:sec)	5:59:00		6:00:00	
Number of Data Points	359		360	

Conclusions

The OUC upgraded its ozone facilities from fine bubble diffusion to SSI with pipeline contacting at three locations: Southwest WTP, Conway WTP, and Pine Hills WTP. Upgrades resulted in the following:

- Improved operational control, resulting in tighter ozone dose control and potential for material savings.
- Tighter ozone residual control resulting in improvement to automated dosing systems.
- Significantly reduced maintenance and improved safety due to no-confined-entry requirements.
- Odor control and ozone residual targets continue to be successfully met.

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