

A Side Story: Design Considerations of a Sidestream Ozone Injection System

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Tampa Bay Water supplies water to Hillsborough, Pasco, and Pinellas counties, and the cities of New Port Richey, St. Petersburg, and Tampa. The South Central Hillsborough Regional Wellfield is owned and operated by Tampa Bay Water and supplies raw water to the Hillsborough County Lithia Water Treatment Plant (WTP). The County removes the hydrogen sulfide from the raw water supply via cascade aeration at the WTP. Tampa Bay Water currently meets its contractual obligation for hydrogen sulfide through a credit for the County's existing treatment process. However, the existing hydrogen sulfide removal equipment at the WTP has reached the end of its useful life and requires replacement.

Tampa Bay Water and the County entered into a Memorandum of Understanding in October 2004 to replace the existing hydrogen sulfide treatment process. The proposed Lithia Hydrogen Sulfide Removal Facility (HSRF) will be owned and operated by Tampa Bay Water, and treated water will be provided to the County for final treatment/disinfection at the WTP. The proposed location of the HSRF, outlined in red in Figure 1, is adjacent to the existing WTP.

Water Sources

Raw water to the HSRF will be supplied from the South Central Wellfield, which is comprised of 17 existing wells of varying water quality. The water blend changes through daily well operational sequencing to meet production needs. Hydrogen sulfide (H_2S) concentrations in the raw water historically range from 1.0 to 4.12 milligrams per liter (mg/L), with a 90th percentile maximum concentration of 2.60 mg/L.

Ozone was chosen as the treatment process for H_2S oxidation. Pilot testing of an ozone system in a previous project performed by Black and Veatch determined that the optimum ozone to H_2S dosage ratio is 3.1:1.

The permitted flows in the water use permit (WUP) are measured in million gallons per day (mgd), with 24.1 mgd (average day), 33.0 mgd (peak month), and 44.6 mgd (maximum day). The actual flow rates can vary from a minimum of 3.5 mgd up to a maxi-

mum 45 mgd. Based on the historical data and permit limits, the proposed treatment system will be based on a minimum flow of 7.5 mgd and a maximum of 45 mgd, with an average of approximately 24 mgd.

Sidestream Ozone Injection

A typical sidestream ozone injection system diverts a portion of the raw water to the sidestream ozone injection pumps, where the pressure is increased upstream of an ozone injector. The ozone injector is shaped like a venturi with an ozone gas connection at the throat. The shape of the venturi creates a pressure drop at the throat, inducing suction on the ozone gas connection and helping the ozone gas and water flow to mix together to create a concentrated ozone solution. The ozone saturated water is then blended with the balance of the raw water flow at a pipeline mixer (pipeline flash reactor) where H_2S is oxidized in the total flow stream. After ozonation, the treated water typically enters an ozone dissipation chamber or piping, which allows for the carryover ozone residual to decay in a corrosion resistant pipeline to prevent corrosion of the downstream piping. A process flow diagram for the sidestream

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ozone injection system at the HSRF is shown in Figure 2.

Sidestream Ozone Injection System Design Considerations

There are many intricacies related to the design of a sidestream ozone injection system. One of the more difficult process design elements of this type of ozone system is coordinating the gaseous ozone flow with the sidestream water flow. Balancing the venturi-shaped ozone injector and its gas eduction capabilities with the liquid flow through the sidestream pumps is complex and required coordination among multiple parties involved in the design. The design of the process components listed below was more closely examined:

- ◆ Ozone Injector

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Figure 1: Location Map

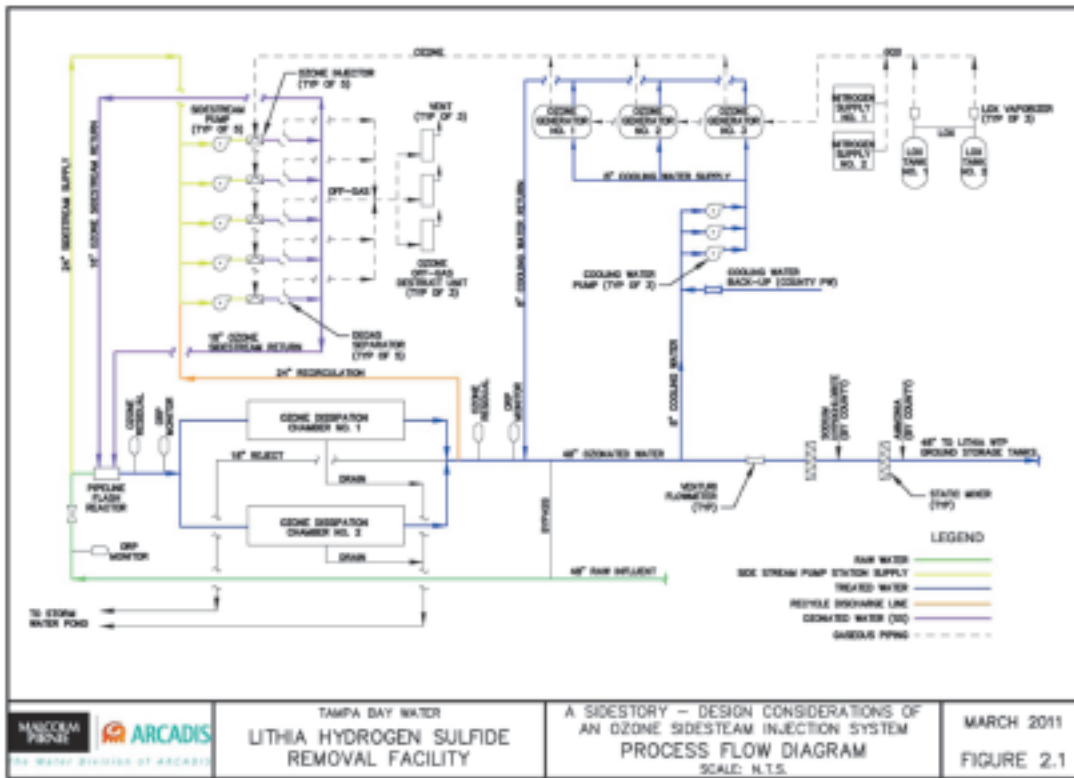


Figure 2: Process Flow Diagram

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- ◆ Sidestream Pump Design
- ◆ Protection of Ozone Gas Lines
- ◆ Sidestream System Equipment and Materials

Ozone Injector Design Requirements

The sidestream system size is based on the design flow, required ozone dose, and the concentration (percent wt ozone) of the ozone gas being generated. The following factors control the mass transfer of ozone into solution at the sidestream injector:

- ◆ Ozone gas concentration (6 to 12 percent wt)
- ◆ G/L Ratio: ratio of gas (total of ozone and oxygen) volume to the liquid (sidestream water) volume
- ◆ Injector outlet pressure

The higher the ozone gas concentration (percent wt ozone), for any given ozone dosage, the lower the volume of the gas feed stream. At a fixed injector flow, the lowering of the gas feed stream reduces the gas to liquid (G/L) ratio, increasing the mass transfer of ozone into the solution since a smaller volume of gas is being driven into the liquid. Using a smaller volume of gas has the additional benefit of reducing the amount of sidestream water flow volume required to adequately transfer ozone into solution. For example, a smaller sidestream will be required for a 12 percent wt ozone gas feed than a 10 percent wt ozone gas feed; thus, it was selected to provide for optimum transfer efficiency. The ozone

generators were designed to produce ozone at 12 percent weight during average operating conditions (24 mgd and 4.65 mg/L ozone dose) and 10 percent weight at maximum operating conditions (45 mgd and 8 mg/L ozone dose). Table 1 provides the design parameters for the sidestream ozone injection system.

The injector's working outlet pressure af-

fects the transfer of ozone into the solution: the higher the injector outlet pressure, the higher the rate of ozone mass transfer into the sidestream flow. This is due to the greater ozone gas solubility at the higher pressure, which results in higher mass transfer of ozone into the solution. In other words, increasing the injector outlet pressure allows more gas to be compressed per unit volume of water and, therefore, increases the mass transfer efficiency per unit volume of water. To optimize the transfer of ozone into the solution through the sidestream system, an injector outlet pressure with 40 pounds per square inch (psi) was selected. The design team decided to use a hydraulic pressure sustaining valve (PSV) for this application to maintain a constant pressure immediately downstream of the ozone injector. This type

Sidestream Pump Design

Horizontal split case pumps were selected to boost the pressure of the sidestream flow

Table 1 - Sidestream Ozone Injection System Operating Criteria

Parameter	Min.	Avg.	Max.
WTP Flow (MGD)	7.5	24	45
Main Flow Stream O ₃ Dose (mg/L) ⁽¹⁾	3.1	4.7	8.0
Sidestream O ₃ Dose (mg/L)	7.3	17.4	28.1
Ozone Conc. (% wt)	12	12	10
No. of Sidestream Trains/Pumps Operating ⁽¹⁾	1	2	4
Design Capacity per Pump (MGD) ⁽¹⁾	3.1		
Pump TDH at Design Capacity (ft)	157		
Pump Motor (HP)	125		
Percent of Flow used for Sidestream (%) ⁽¹⁾	44	27	30
Injector (Sidestream) Ozone Mass Transfer Eff. (%) ⁽¹⁾	99	95	95
Min. Injector Inlet Pressure (psi)	73		
Max. Injector Inlet Pressure (psi)	84		
Min. Injector Outlet Pressure (psi)	40		

(1) Values shown represent conditions at minimum, average, and maximum plant flow scenarios.

upstream of the ozone injector. Pump size was determined based on requirements for appropriate ozone transfer at the injector, while balancing the required pump horsepower. The layout of the sidestream pump system is shown in Figure 3. The goal for the sidestream pumps was to keep pump horsepower to a minimum and reduce operating costs. Various combinations of flows and injector inlet and outlet pressures were evaluated. The main concern with modeling the sidestream system was the hydraulic response of the ozone injector. Since this equipment not only has liquid flowing through it, but also has ozone gas being injected, there is not a single minor loss coefficient that can be used for the injector. The other issue is that the suction pressure on the sidestream pumps ranges from 5.43 psi to 20.21 psi due to the plant flow and surface water level of downstream ground storage tanks. These issues were coupled with

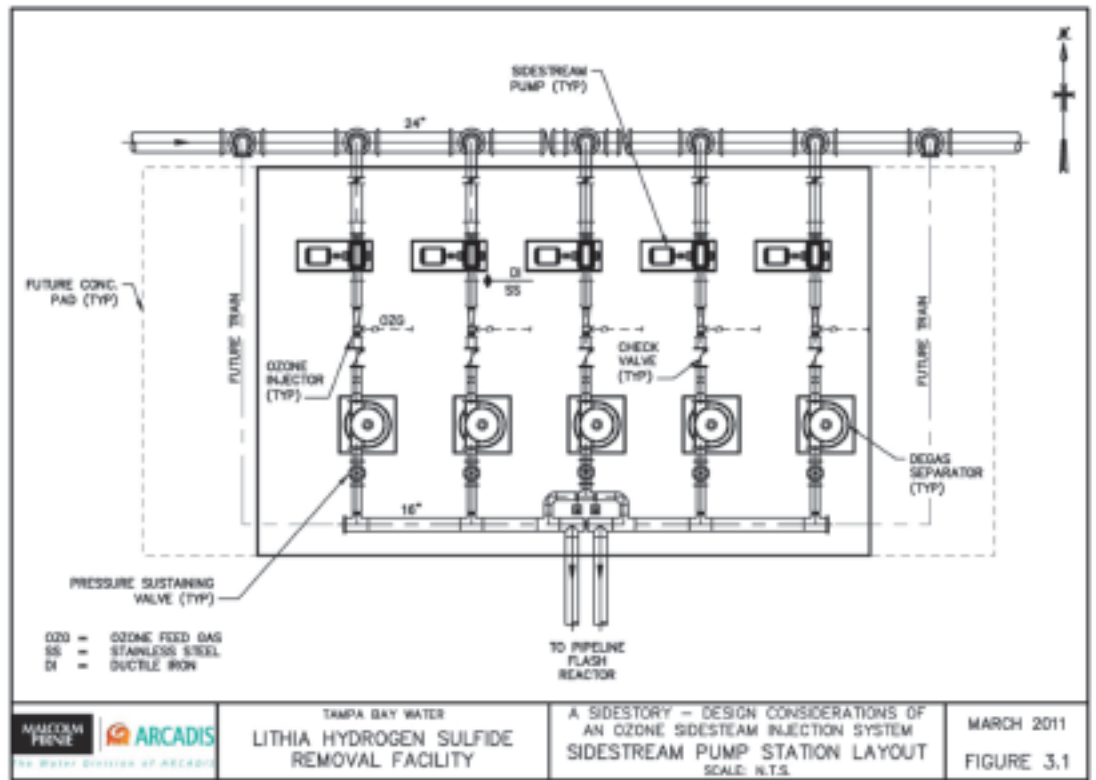


Figure 3: Sidestream Pump Layout

a minimum (7.5 mgd flow, 8.0 mg/L ozone dose) and maximum design condition (45

mgd, 8.0 mg/L ozone dose) to develop two systems. *Continued on page 24*

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tem curves, which are shown in Figure 4. The vertical lines in Figure 4 show the design flows as determined from the ozone injector points on the two system curves. The selected pump had to accommodate these two points as closely as possible to meet the range of conditions for the different operating scenarios.

Figure 4 also shows the high suction pressure system curve making a turn to a more severe slope at about 2300 to 2400 gallons per minute (gpm). This indicates where the PSV will theoretically be fully open, and downstream pressure on the ozone injector will be dictated by the head losses between the ozone injector and the pipeline flash reactor. This was another item that the design team had to balance, to make sure that, for typical operation, the PSV would be operating within its range and be able to provide a consistent 40 psi pressure downstream of the ozone injector.

Protection of Ozone Gas Lines

The potential for water to backflow from the sidestream piping into the ozone gas line is a significant concern due to the damage that water can cause the ozone generators. This can be troublesome for a sidestream injection system due to the pressure that the water is under at the ozone gas injector. Several methods were used to mitigate this concern:

- ◆ A bypass ozone gas line with isolation valves
- ◆ A multiple valve (automated valves and

check valves) arrangement to prevent water backflow

- ◆ A liquid sensing system on the gas line

The bypass ozone gas line is helpful for any situation in which the main ozone gas line fails, allowing the ozone system to continue to operate by turning a few valves. On each ozone gas branch line, prior to connection to the ozone injector, there are three valves: a check valve, a solenoid valve, and an automatic spring-loaded release isolation valve. The check valve should prevent any water from back-flowing into the ozone gas line, which is of particular concern immediately following sidestream pump shutdown. Pressures will be the highest in this situation until equilibrium is reached within the system. If the check valve fails and some liquid begins to flow into the ozone gas line, the liquid sensing mechanism will trigger the solenoid valve to close; failure of the solenoid valve will trigger the spring loaded isolation valve to shut. The multi-valve system and controls may seem somewhat complex, but they were designed to protect the main components of the HSRF: the ozone generators and gas delivery system.

Sidestream System Equipment and Material

Both ozone gas and dissolved ozone are corrosive due to ozone's oxidation capabilities. In addition, the ozone system at the HSRF uses a high purity liquid oxygen feed for the ozone generators, allowing for increased percent weights of ozone gas in the feed to the side-

stream injection system. The potential for corrosion required all ozone gas feed piping in the sidestream area and all piping carrying liquid with an ozone concentration to be 316 stainless steel (316 SS). The 316 SS material provides adequate strength for the pressurized liquid, while also providing a high level of corrosion resistance to prevent ozone from damaging the interior of the piping.

All piping, equipment, and valves immediately downstream of the sidestream pumps to the pipeline flash reactor are now 316 SS. Although the 316 SS piping increases the capital cost of the project, it will prevent a more rapid deterioration of the process piping, which would contribute to higher maintenance costs in the future.

Conclusion

The design of the HSRF sidestream ozone injection system encountered several challenging engineering issues and required the design team to work across disciplines and with outside personnel to make sure they were appropriately addressed. A sample of the challenges encountered during design included:

- ◆ Balancing sidestream pump design and ozone generator design to provide effective ozone injection into the sidestream flow
- ◆ Specific hydraulic issues related to the sidestream system
- ◆ Potential for back feeding water through the ozone gas lines and into the ozone generators
- ◆ Materials of construction for sidestream system piping and equipment

When a design team becomes involved with a sidestream ozone injection system, it should have good communication with all engineering staff and maintain good relationships with the ozone generator and sidestream system suppliers. Communication is important for this type of design due to the amount of proprietary equipment and limited number of suppliers in the market. During any discussions, it is important to make sure that design parameters, changes, and expectations are coordinated and communicated clearly. Designs should not be approached with the assumption that all connections and affected systems will be addressed by the supplier. It is important that the design engineer performs a thorough investigation to make sure that the system meets the requirements of the overall project design, and most importantly, the client's expectations. ◊

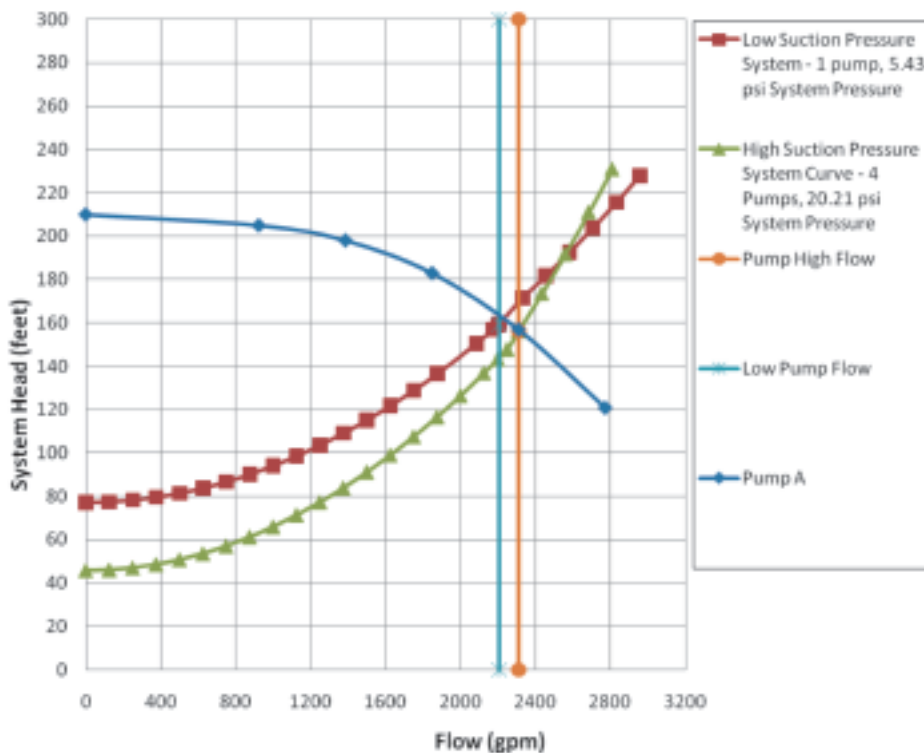


Figure 4: Sidestream Pump Design

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