

Retrofit of Ozone Contact Basins With Sidestream Venturi Gas Injection

James R Jackson¹, Srikanth S. Pathapati, PhD²

1. Mazzei Injector Co., LLC, 500 Rooster Drive, Bakersfield, CA, 93307, USA
2. Mazzei Injector Co., LLC, 500 Rooster Drive, Bakersfield, CA, 93307, USA

Abstract

The changing global economic climate has had a significant impact on the manner in which utilities operate their water and wastewater treatment facilities. Community job losses have reduced revenue, resulting in limited staffing as the most senior utility employees are enticed to retire early while the hiring of new employees is discouraged. Yet regulatory law continues to increase the burden of monitoring required to insure full compliance with the current and the anticipated future statutes which regulate the plants' water product quality. Utilities using ozone as part of their treatment process face additional complexity in plant operation and maintenance.

Utilities using ozone today as well as those adding ozone to their treatment process have responded to the need to operate with less revenue and staffing by modifying plant equipment and design. Outdated, high maintenance equipment is being replaced by more reliable equipment that provides a sustained level of performance without requiring difficult and time consuming maintenance procedures, thus saving utility man hours and reducing the cost of plant operation. In recent years, modifications made to many existing ozone utility designs as well as proposed new plants in construction have included the use of sidestream venturi injection (SVI) to replace or in preference to their existing ozone contacting system.

This paper reviews three Public Utility ozone treatment plants that operate at a combined water flow of 5,000 MLD at a peak ozone production capacity of 459 kg/h. Each utility has replaced their original contacting system design with SVI and a basin nozzle manifold (BNM) or have selected the SVI-BNM contacting system in preference to alternative contacting methods.

Key Words: Ozone, Ozonation, Fine Bubble Diffusion, Injection, Sidestream Venturi Injection, SVI, Basin Nozzle Manifold, BNM, Multi-phase Computational Fluid Dynamics, Computational Fluid Dynamics, Retrofit.

Case History 1: Expansion and Upgrade of WWTP Ozone Disinfection System

Background

The City of Springfield, Missouri's Southwest Wastewater Treatment Plant (SWWTP), recently renamed as the city's Southwest Clean Water Plant, has continuously used ozone for wastewater disinfection since 1978. The plant disinfects secondary wastewater at an average daily flow of 36 MGD and a peak monthly flow of 64 MGD.

The ozone system installed in 1978 utilized a 50 Ton cryogenic oxygen plant to feed plate ozone generators that discharged ozone gas into the head space of the plant's three contactors which operated at an average side water depth of 7 feet [1]. Head space ozone gas was mixed into the shallow water using three 30 HP turbine mixers at each contactor (Figure 1)[1,2]. Ozone off gas was not destroyed by an ozone destruct module, but instead was collected, re-compressed and sent to an activated sludge basin[1].

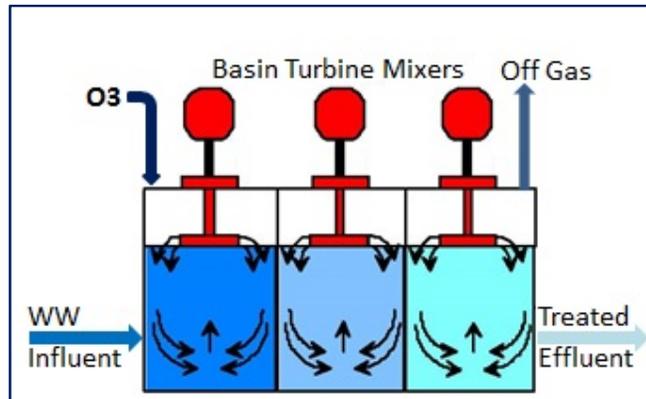


Figure 1. Ozone gas contacting system 1978

The plate ozone generators were replaced in 1988 with Emery ozone generators which produced a firm ozone output of 1,800 ppd at 3% wt. The replacement ozone generators allowed the plant to continue to meet its disinfection goals, but by 2008 the annual ozone maintenance costs began approaching \$ 100,000 for labor, materials and downtime[2]. The financial cost to maintain the ozone equipment and increasing scarcity of generator replacement parts motivated the utility to upgrade their ozone system.

Design Considerations

The expansion and upgrade of the ozone system required a review of plant operations and a re-evaluation of the wastewater's ozone demand. Bench scale tests determined that the wastewater's ozone demand, to the 90th percent confidence, was 3.8 mg/l (Table 1)[1]. Additional testing showed that a firm applied dose of 5.2 mg/l was required at the plant's peak monthly flow of 64 MGD to both satisfy demand and ensure the plant met its disinfection goals[1].

Table 1. Ozone Demand

DATE	OZONE DEMAND mg/l
11/15/2006	3.02
11/16/2006	1.78
11/30/2006	3.36
12/01/2006	2.13
10/14/2008	3.19
10/15/2008	3.35
Average	2.8
Maximum	3.4
Standard Deviation	0.7
90 Percent Upper Confidence Limit*	3.8
*Calculated using tail area for t-Curve	

Early in the design stage, the decision was made to replace the high energy turbine mixers with a lower energy, more efficient sidestream ozone injection system which utilized sidestream Venturi

injectors (SVI) for primary ozone contacting, followed by basin nozzle manifolds (BNM) for secondary gas contacting into the basins' bulk wastewater flow[1]. However, retro-fitting the basins with an SVI-BNM ozone contacting system proved challenging due to their structural geometry.

Each contact basin contained three 34' x 34' cells that operated in series at an average side water depth of 7 feet. Under the existing ozone contacting design, ozone gas fed into the contactor head space was mixed into the wastewater flow using a 30 HP turbine mixer at each cell [2]. The combined 90 HP of mixing energy was sufficient to ensure complete contacting of ozone gas into the shallow wastewater flow.

The proposed SVI-BNM retrofit, in contrast, would apply all of the ozone at cell no. 1 using only 4.5% of the basin's peak monthly flow and 12 Brake HP of pump energy to mix ozone gas into solution using the subsurface jets of a basin nozzle manifold [3]. This jetting of ozone gas into the wastewater, though adequate for ozone transfer, would not provide sufficient mixing energy to completely contact all of the cell's water volume. Consequently, to ensure complete contacting of the wastewater with ozone, the wastewater inlets at the front of the contactors required structural modification.

Final Design and Operation

The final retrofit design included a structural modification of the basin inlets to allow the SVI-BNM retrofit to contact all of the basin's wastewater flow. The dual inlet gates at the front of each contactor are enclosed in a concrete structure that funnels entering wastewater into a narrow tunnel to allow confined space gas mixing (Figure 2) [4]. The BNM counter current nozzle jets that aggressively mixed and transferred ozone into the channeled wastewater flow are followed by static mixing elements that provide a final mixing of the bulk water flow prior to discharge into the larger downstream cells. To ensure even distribution of ozone into the bulk wastewater flow, Computational Fluid Dynamics (CFD) was used to direct the design and placement of the channels' basin nozzle manifolds and static mixing elements (Figure 3.).

Each BNM receives ozone gas from 1 or 2 duty SVI which are installed on top of the basin. The mixed flow of the injectors enters the nozzle manifold through a common, vertical 8" line (Figure 4). Ozone production is provided by a single ozone generator that produces 2,800 ppd of a 7% wt. ozone gas to treat the peak monthly flow of 64 MGD. A fully redundant generator allows the plant to disinfect during storm water flows up to 100 MGD.

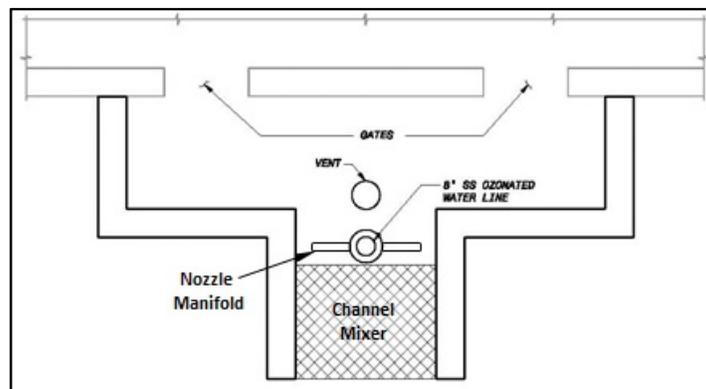


Figure 2. Basin inlet modification, plan view

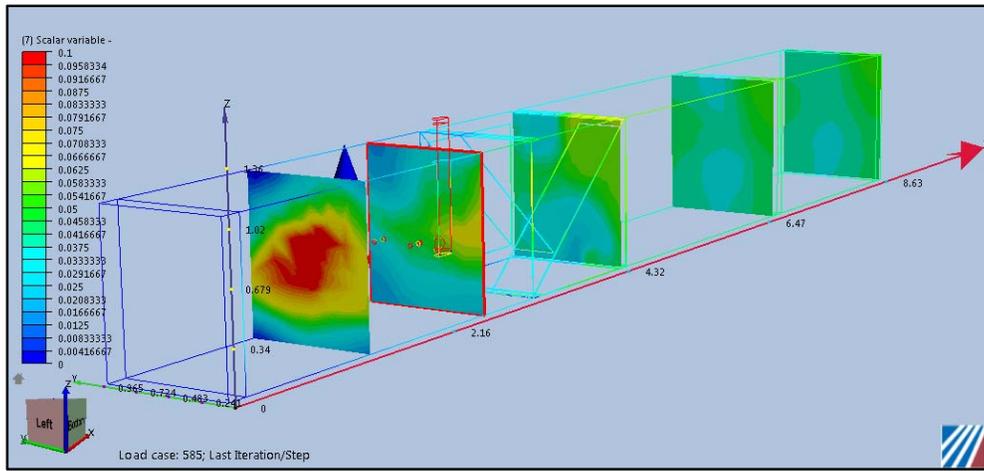


Figure 3. Cross sections of (O3) concentration in channel and its discharge plume.

Plant data comparing the energy cost of the SVI-BNM ozone dissolution system with the turbine mixing design showed the retrofit design reduced the energy cost of ozone contacting by an average of 69.2 % under all plant flow conditions (Table II)[1]. Performance data taken during a Mazzei site visit on April 16, 2014 showed an ozone transfer efficiency of 92.1% was achieved using an applied ozone dosage of 2.5 mg/l of 6 % wt. ozone.

Table II. SVI-BNM contacting energy savings

Plant Flow Condition	Ozone Production (PPD)	SVI-BNM Energy Use (kWh/lb.)	Turbine Energy Use (kWh/lb.)	SVI-BNM Energy Savings (kWh/d)
Average	750	1.19	6.44	3,937
Maximum	2,800	0.63	1.73	3,080
Storm Water	4,300	0.42	1.12	3,010



Figure 4. Contactor No. 3 ozone injectors

Case History 2: Largest Ozone Facility in N. America Installs SVI-BNM Contacting

Background

In October 2008, the North Texas Metropolitan Water District began working with Black and Veatch to add ozone to its four interconnected water treatment facilities which operate as the Wylie WTP. Sitting on 442 Acres, Wylie was designed to treat up to 770 MGD of raw water using coagulation, settling, multi-media filtration and chlorine disinfection. The decision to add ozone was prompted by both regulatory requirement and the desire to remediate taste and odor compounds [5].

Design Considerations

To minimize ozone dosage and the potential for bromate formation, the preliminary design called for ozone to be added after chemical coagulation and settling had removed a majority of the raw water solids, but prior to final polishing with multi-media filters. The design also called for conversion of the multi-media filters to bio-filters to remove assimilable organic carbon and provide additional removal of taste and odor compounds. However, the cost and time required to re-bed 100 filters made immediate conversion unrealistic. Consequently it was agreed that the conversion to bio-filtration would be phased in slowly as filter media replacement became necessary [5].

Early in the design phase the decision was made to utilize sidestream venturi injection (SVI) to help minimize the size and maintenance of the 11 ozone contact basins that would treat a future maximum flow of 890 MGD [6]. To ensure the SVI ozone effluent was well mixed into the raw water flow, basin inlet channels were constructed to allow confined space gas mixing of all incoming water with a single BNM (Figures 5 & 6).

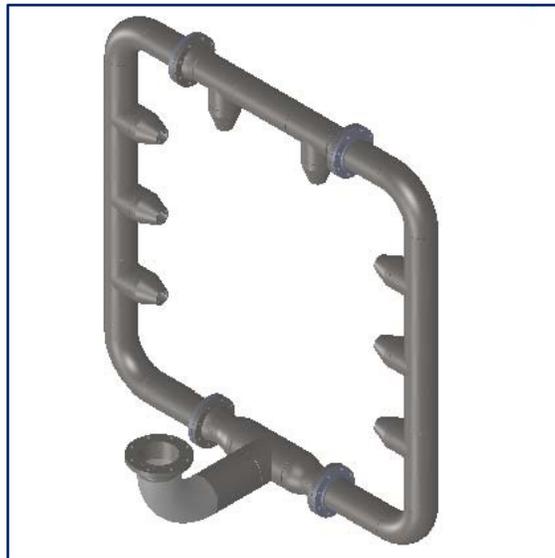


Figure 5. Wylie Basin Nozzle Manifold

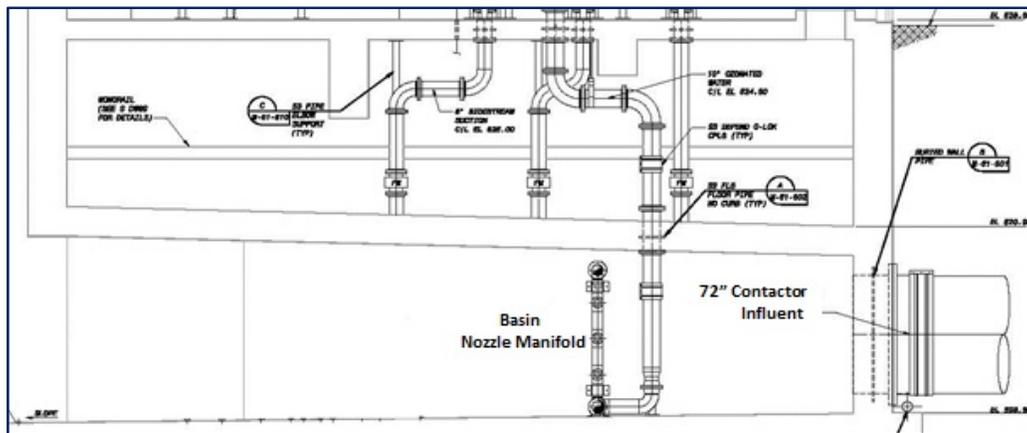


Figure 6. Wylie contactor 1 - 1

To provide turn down, each BNM was designed to operate using either a single or dual SVI with the number of duty injectors sequenced with ozone feed requirements [6]. During a final review of the SVI – BNM process piping, members of the design team became concerned that the long horizontal pipe runs, required to connect the remote Venturi injectors with nozzle manifolds, combined with the lower pipeline velocity of a single SVI flow would cause extreme stratification of the injectors’ 2-phase effluent and result in pockets of gas slug feeding into the BNM. If gas slug feeding occurred, the BNM would provide poor gas mixing and low ozone transfer by burping large gas bubbles into the basin water flow, similar in behavior to a fine bubble diffusion grid operating with leaking gaskets. [7].

To test the validity of their concern, Mazzei ran a multi-phase CFD analysis on Wylie contactor 4-1, which had longest horizontal pipe run from SVI to BNM and therefore was potentially most likely to experience low ozone transfer from phase separation and slug gas feed into its BNM. Mazzei proposed two possible piping modifications and set up the analysis to examine phase separation on three different piping configurations (Figure 7) [7].

The CFD analysis verified significant phase separation occurred by the end of a 11.3 m horizontal pipe run. This phase separation continued through the 10” LR elbow for both the “As is” and “Modification 1” conditions (Figure 8) [7]. On “Modification 2”, the single branch flow through an 8” tee remixed the stratified flow producing a homogenous mixture at the tee outlet. The analysis also showed significant mixing by the vertical pipe drop in all three test conditions produced a mostly homogenous mixture at the BNM inlet for the “As is” condition that was similar to end of pipe mixture produced by “Modification 2”[7].

Final Design and Operation

The mixing provided by the vertical pipe drop resolved Mazzei’s concern of low ozone transfer from slug gas feed which allow the SVI-BMI installation to proceed per the “As is” piping design. Each of the 11 contact basins was provided a single BNM with 2 duty and 1 stand-by SVI. The final SVI design operated at an energy cost of 0.99 kW/ kg of applied ozone at the peak ozone design dosage of 3.5 mg/l. A site visit made on October 2, 2014 showed the average ozone transfer efficiency for plants 2, 3 & 4 (Plant 1 was not in operation at the time of the visit), was > 95% (Figure 9) with exception of plant 2, which showed an ozone transfer efficiency of < 92%.

When Mazzei inquired about the low ozone transfer of plant 2, Wylie operators explained that accidental over feeding of Ferric Chloride had resulted in carryover of coagulant solids into the ozone contact basin, fouling the strainers on the SVI pumps as well as the dissolved ozone sensors. The 0 mg/l dissolved ozone reading from fouled ozone sensors had subsequently caused a prolong overfeeding of ozone, while fouling of the SVI pumps cause low water flow across the gas injectors, increasing injector gas liquid mixing ratios and reducing the discharge velocity of the BNM gas mixing nozzles. Since Mazzei's visit, the plant has scheduled a change out of the pumps strainers to a larger mesh and has made repairs to their chemical feed system to avoid future upsets from coagulate carry over.

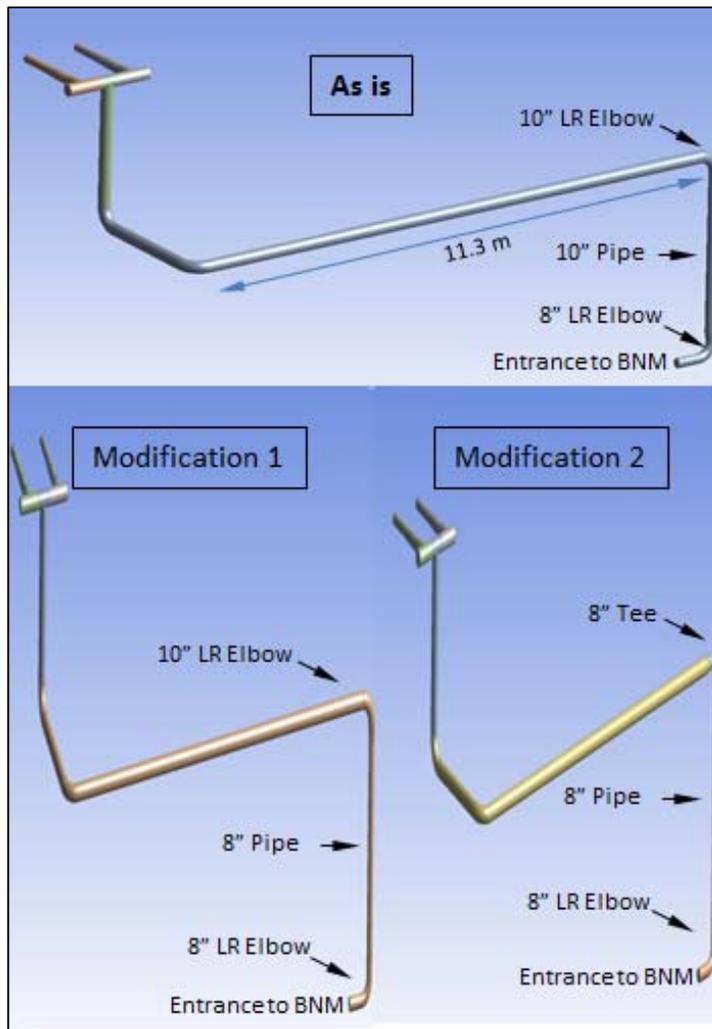


Figure 7. Contactor 4-1 SVI-BNM piping options

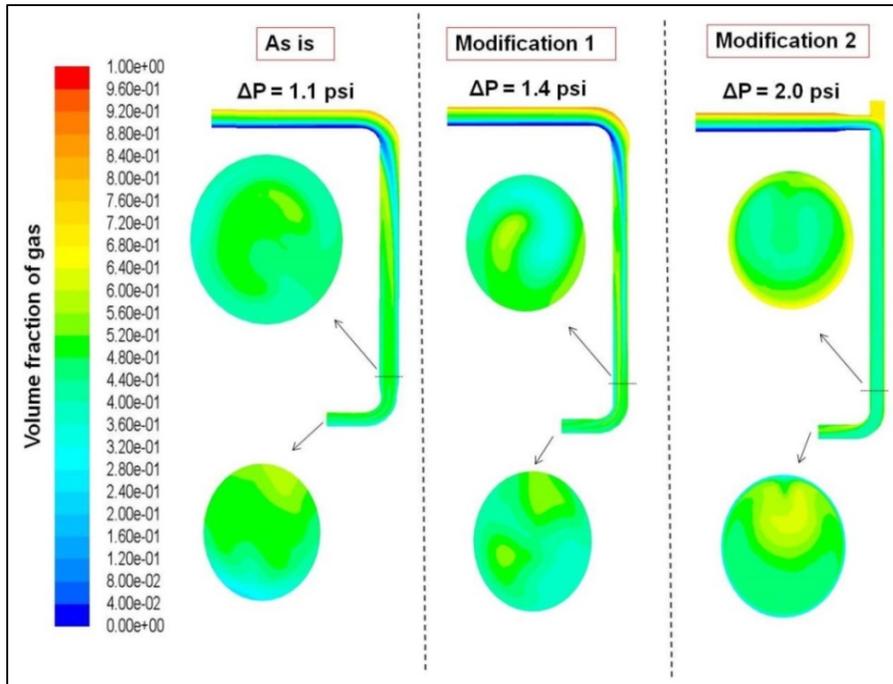


Figure 8. CFD analysis contactor 4-1 SVI-BNM piping options

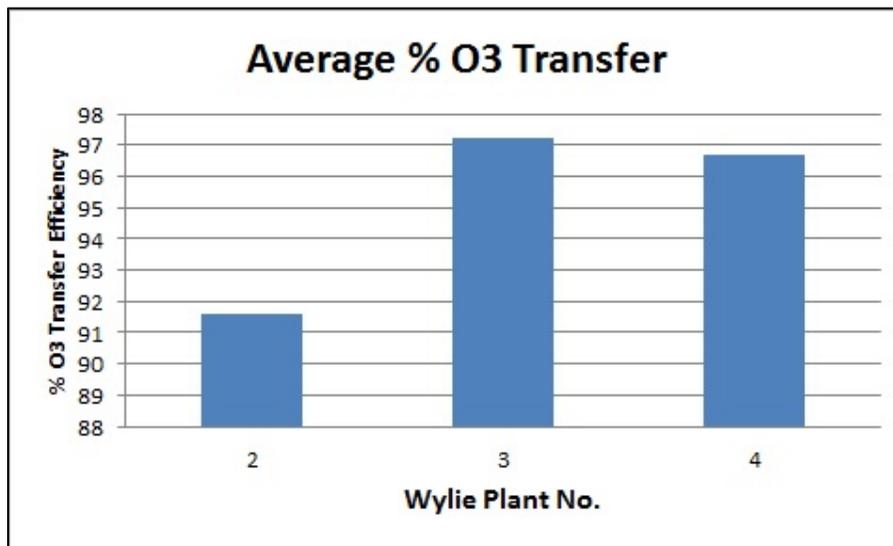


Figure 10. Wylie Ozone Transfer Efficiency by Plant

Case History 3: City of Montreal Upgrade of the Atwater and Des Bailleurs WTPs

Background

In 2001 a water quality audit revealed that two of the largest drinking water plants in the City of Montreal were out of compliance with Quebec's latest water quality rules. In response to the audit, the city upgraded the 1,400 MLD Atwater and the 1,280 MLD Charles J Des Bailleurs (Des Bailleurs) water plants to comply with the water quality rules and meet the water quality goals shown in Table III below [8].

The Atwater modification would require the installation of pre-filter ozone, coagulant and post filter UV to improve disinfection and remediate taste and odor compounds. Des Bailleurs, already using air fed ozone, would convert to oxygen fed ozone and add a pre-filter coagulant, post ozone UV and sodium hypochlorite generators to further improve disinfection [8].

Table III. Water Quality Goals

Water Quality Target	Charles J. Des Bailleurs WTP Water Quality Goal	Atwater WTP Water Quality Goal
Cryptosporidium	3 log removal	3 log removal
Giardia	3 log removal	4 log removal
Virus	4 log removal	5 log removal

Design Considerations

Both drinking water facilities were located in heavily populated areas. Consequently plant modifications had to be accomplished within their existing infrastructure footprint. This was especially true for the Atwater WTP. Commissioned in 1918, the facility is surrounded by shops and residential homes and has insufficient space to allow the construction of a building to house new ozone contact basins. Therefore, it was proposed that an existing filter gallery would be converted into four ozone contact basins using sidestream Venturi injection (SVI) with basin nozzle manifolds (BNM) for ozone contacting [8].

However, Atwater's 1918 construction left no room for the installation of SVI skids near the converted filter gallery. Instead, the ozone injectors were wall mounted with the injectors pumps remotely located in another part of the building (Figure 10).

The addition of horizontal baffles converted the filter gallery into four serpentine contact basins. At each inlet a vertical BNM was designed to provide full flow contacting of the raw water as it passed through each contactor's inlet gate (Figures 11 & 12).

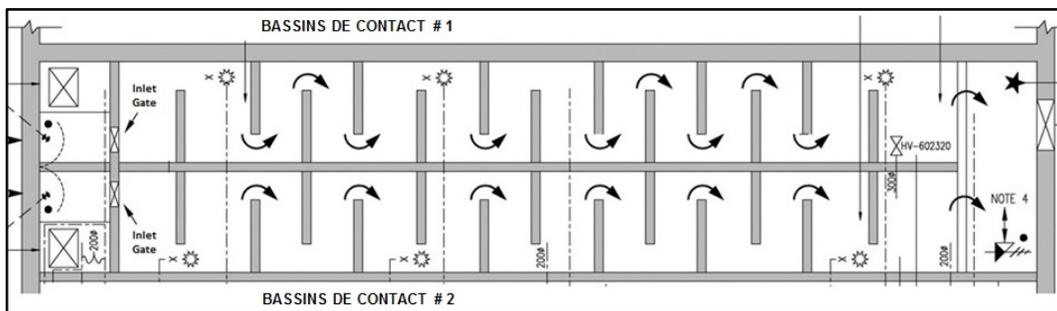


Figure 11. Atwater contactors 1 & 2.

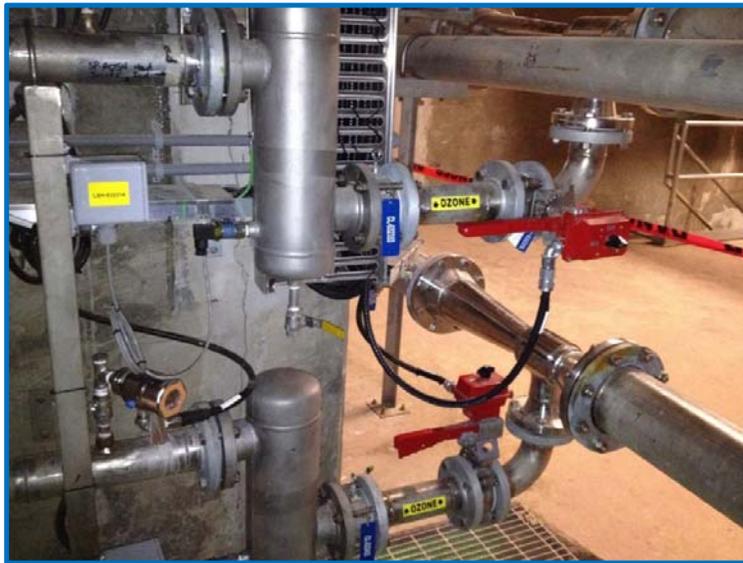


Figure 129. Atwater wall mounted injectors.

Des Bailleurs' conversion from air to oxygen fed ozone required modification of the existing fine bubble diffusion (FBD) contactors. Each contactor's 500 l/s air fed ozone gas stream would become a variable 10 – 57 l/s gas stream once the conversion to oxygen fed ozone was completed. It was evident that a modification of the FBD grid would allow the plant to continue to operate with diffusers at full gas flow. However the almost 6:1 ozone turn down to a 10 l/s gas stream at the minimum plant flow and dosage would make it difficult to completely contact the raw water flow using gas diffusion. The ozone turn down requirement as well as the expected bi-annual FBD maintenance motivated the design team to remove the gas diffusers and retrofit Des Bailleurs' FBD basins with SVI-BNM ozone contacting systems.

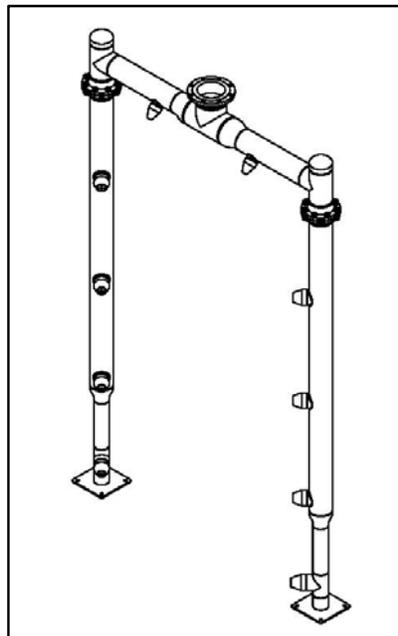


Figure 12. Inlet gate BNM.

The retrofit of the Des Baillets' existing ozone contactors with the SVI-BNM gas injection contacting systems was easily accomplished. The room housing the basins' ozone destructs sat directly on top of the contactors and had plenty of open space to floor mount the SVI systems directly above each contactor's BNM (Figure 13). To ensure full flow ozone contacting a tee type BNM was oriented to jet a high velocity plume, counter current to the entering raw water flow (Figures 14 & 15).



Figure 13. Des Baillets sidestream Mazzei injectors.

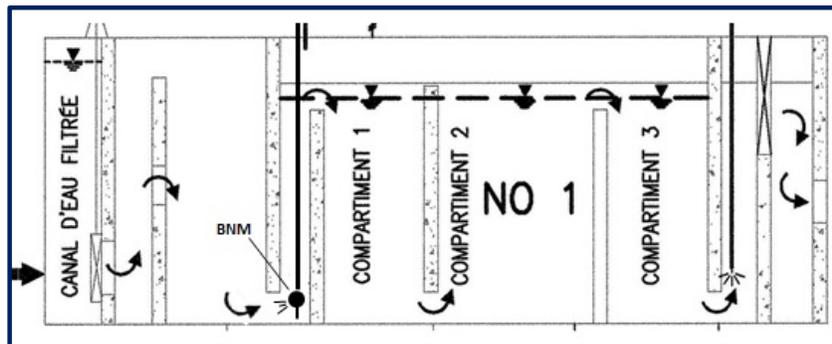


Figure 14. Des Baillets Contactor No. 1

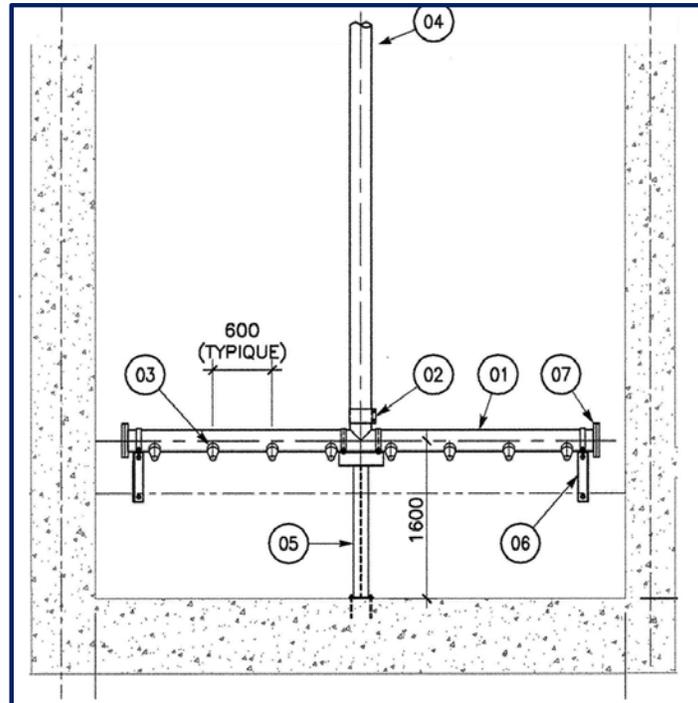


Figure 15. Basin nozzle manifold installation drawing.

Final Design and Operation

The final Atwater design called for an applied dosage of 1.9 – 2.53 mg/l at an ozone transfer efficiency of 95 % using 10% wt. ozone to remediate taste and odor compounds and meet the disinfection goals. The Des Baillets design called for an applied ozone dosage 1.05 – 3.2 mg/l and also set the requirement for an ozone transfer efficiency of 95% , using 10% wt. ozone to remediate taste and odor compounds and optimize downstream UV transmittance.

At the writing of this paper both facilities have installed all equipment and are in the process of commissioning their ozone systems. The SVI-BNM system was provided with an ozone transfer warranty of 98% and 97% respectively for the Atwater and Des Baillets WTPS, however, the final performance of the ozone system is yet to be recorded.

Summary

The retrofit of ozone contact basins with sidestream Venturi injectors and drop in basin nozzle manifolds (SVI-BNM) is an energy efficient upgrade that will provide a sustained ozone transfer efficiency ≥ 92 % in shallow contactors like the Springfield Southwest Clean Water Plant. In the construction of new contact basins, the use of SVI-BNM can minimize the contactor civil work by allowing for the use of a lower side water depths. In traditional deep water Fine Bubble Diffusion (FBD) basins, such as the Des Baillets WTP, the SVI-BNM retrofit allows easy installation and promises a sustained ozone efficiency ≥ 97 % while eliminating the labor and down time associated with the maintenance of an FBD basin.

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