Comparison of Alternate Methods of Disinfection for Reclaim Effluents

Robert A. Elefritz, Jr.

Disinfection of wastewater effluents has become a prominent issue because of increased concerns over handling hazardous chemicals, as well as concern over what degree of disinfection is really necessary for some effluent applications. Disinfection also significantly affects water reclamation and reuse.

Chlorination has long been the technology of choice for wastewater disinfection and is commonly considered to be the cornerstone of modern sanitation. Given this strong measure of success, why should we even be concerned about alternative forms of disinfection?

There are three issues that prompt disinfection today. The first, obviously, is safety. Chlorine gas is a dangerous material to handle and use. It always has been, but only recently has the general population become attentive to the perceived dangers. To a great extent, this has been stimulated by the Clean Air Act provisions on storing and handling various hazardous materials.

For many years plant operating staffs have routinely dealt with chlorine gas with little public awareness. It is ironic that as long as the risk was thought to be limited to the operating staff, the chemical wasn't really perceived as a problem. Today, that situation has changed dramatically with the general public becoming much more aware of some of the basic risks in our society and reacting in an outspoken way about what it believes, rightly or wrongly, to be a threat to public health and safety.

For example, last year there was a very strong reaction in central Florida because the local school board had decided to locate a new elementary school near a regional wastewater treatment plant. There were already three schools nearby. When I heard the story, my first thought was that the parents were concerned about the potential health effects of activated sludge, aerosols, odors, etc. I was wrong. It turned out that the surrounding neighborhood had a strong fear of potential chlorine leaks from the plant's existing disinfection system. They feared being near the site themselves and absolutely refused to allow their children to be located even closer to the site.

Given our years of experience in the industry, many of us might feel that this is an unreasonable reaction on the public's part. Nonetheless, it is very common.

Restrictions on hazardous chemical handling are being imbedded in basic building codes. In many cases, the requirements are placed to protect emergency personnel who might have to respond to an accident at a plant. We also face federal requirements on risk assessment planning for many hazardous chemicals that are widespread in our society. That includes chlorine and sulfur dioxide commonly used in our industry for disinfection, as well as countless other potential hazards from every industry. We face an environment with increasing liability and expensive regulation as a reaction to the potential risks.

The second issue that comes to the forefront is the cost of a chemical that is perceived to be dangerous. Often there are intangible "costs" that are very hard to evaluate. Frankly, most of us have worked with chlorine for so long that we don't have any idea how much it really costs. There are a number of hidden components to that cost that might not be immediately obvious. We will explore some of those costs in detail.

In this article I will discuss the apparent costs of several alternative methods of disinfection, including basic chlorination. We will postulate a plant example to explore the potential disinfection costs of three different design flow rates at 5, 10, and 15 MGD. For each alternative, we will prepare capital and operating cost comparisons, and make generalized conclusions about the applicability of the various alternatives. We will compare the various examples so that we can see the impact of each alternative at each design flow.

Robert A. Elefritz, Jr., P.E., is a senior process engineer with McKim & Creed, P.A.

The final issue that has a great deal of influence on the disinfection process is the popularity today of water reclamation and reuse applications. Every state has its own rules to be met for disinfection, but just about everybody has stricter requirements for effluents to be applied in reuse projects. For example, both California and Florida have very strict requirements for disinfection performance in reuse situations. Later we will discuss a rule called Title 22 that relates to the use of UV for reuse effluents. In this case, California uses total coliforms as a criteria and requires no more that 2.2 TC/100 mls. Florida, on the other hand, has its own definition of "high-level" disinfection that impacts any water going to reuse or any surface water that entails public exposure. Florida's high level disinfection is based on fecal coliform and requires non-detectable samples for 75% of the monthly samples and a single month upset value of 25 colonies per 100 mls. North Carolina's requirements are set forth in NCAC 2C.0200 as 14 and 25 colonies per 100 mls. North Carolina also requires a chlorine residual in the final effluent, whereas the other states do not.

With the proliferation of water reclamation sites and reuse applications, we can expect most states to develop similar requirements. Those requirements have a decided impact on the cost and operation of any disinfection alternative. We have found in some cases that high level chlorination actually can't produce the necessary performance required. Thus we are forced to choose from other alternatives.

Specific Disinfection Alternatives

We will discuss several alternative methods of disinfection including gaseous chlorination; on-site generation of hypochlorite; commercial hypochlorite (bleach); and ultraviolet radiation. In each case, we will discuss the alternative in general terms to describe the operation and any critical design criteria. Then we will postulate three hypothetical treatment plants rated at 5, 10, and 15 MGD of average daily flow. We will develop both capital cost and operating cost estimates for an all new disinfection facilities for each alternative.

We will compare the various costs: capital, O&M, and present worth for the various alternatives at each flow. Present worth costs will be compared for each alternative on the basis of unit flow, as well as for each increment. Economy of scale will be evident in some of the alternative technologies, whereas it will not be possible in some others.

Chlorination

Since gaseous chlorination is the most widespread alternative, and since most readers will be experienced with the technology, we will not concentrate much on the basic details. We will concentrate primarily on economics for this alternative. The economics will be based on an all new system, not assuming any salvage or reuse from existing equipment, tankage, etc. Obviously, salvage of an existing system is a site specific issue and really cannot accurately be taken into account here.

The obvious costs in chlorination involve the equipment and control systems. We will work with ton cylinder based header systems. The actual chlorinator could be either a wall mount or a floor console style. The system will operate under vacuum with a water based feed system. The equipment will be include leak containment and gas scrubbers. For systems with free surface discharges, it will be assumed that de-chlorination will be required and a corresponding sulfur dioxide system will be included.

Contact tanks for chlorination vary in design from state to state. The systems estimated herein are based on a 15-minute detention time at maximum hour flow. In lieu of any other data, maximum hour flow is considered to be three times the average day flow. This is the current requirement in Florida and is generally more restrictive than found in some other states. For every alternative analyzed, we have estimated a relatively simple expansion cost for existing tankage.

Based on an expected maximum chlorine demand for nitrified effluents, we will size for a dosage of 10 mg/L for all flow ranges. At 5 MGD average day flow, with a peaking factor of 2.5, this would correspond to 1,050 pounds of gaseous chlorine per day. At 10 and 15 MGD, we would be expecting 2,090 and 3,150 pounds per day, respectivelyz. We will assume two types of facilities: those that discharge to surface waters and need de-chlorination and those that supply only effluent reuse systems and do not require de-chlorination.

The use of chlorine and sulfur dioxide at wastewater treatment plants has been impacted not only by the 1990 Clean Air Act amendments, but also by revisions to fire codes. Model fire codes in the United States include the Uniform Fire Code (UFC), the Building Officials and Code Administration (BOCA) , and the Standard Fire Prevention Code (SFPC). The UFC, published by the International Fire Code Institute in Whittier, California, is used predominantly in the western U.S. The BOCA is headquartered in the Midwest and the northeastern U.S. The SFPC, from Birmingham, Alabama, and published and enforced as part of the Southern Building Code Congress International, covers the south-central and southeastern U.S. Additionally, the National Fire Protection Association (NFPA), while not having a model code, does develop and publish technical documents and standards. NFPA standards are referenced as code documents by all three model codes and government groups.

In addition to the various fire codes to be complied with, the 1990 Clean Air Act established the need for Risk Management Plans (RMP) for communities using materials defined as hazardous substances. Since both chlorine and sulfur dioxide are considered as hazardous materials by both UFC and USEPA, communities using these chemicals are required to establish risk management plans to deal with potential catastrophic accidents involving the chemicals.

As you might expect, the enactment of these rules and codes have had a serious impact on the cost of chlorination. Table 1 summarizes a present worth of cost analysis for basic chlorination both with and without de-chlorination. We have included equipment costs for both chlorine and sulfur dioxide feed systems where appropriate. We have also included a building, designed for air handling with leak containment and catastrophic leak scrubbers, to house both chemicals. We have included standard cylinder handling equipment for both chemical and standard personnel safety equipment. Finally, we have sized and costed the chlorine contact tanks based on 15 minutes detention at maximum hour flow. For operating expenses, we have considered gaseous chlorine at $0.24 per pound, gaseous sulfur dioxide at $0.30 per pound, and labor (including fringes) at $35 per hour.

Table 1: Gaseous Chlorination

	5 MGD	10 MGD	15 MGD
CL2 Equipment	$150,000	$200,000	$250,000
Building	$400,000	$500,000	$600,000
SO2 Equipment	$150,000	$200,000	$250,000
Scrubbers	$250,000	$250,000	$250,000
General Safety Equip.	$150,000	$200,000	$250,000
Contact Tanks	$210,000	$330,000	$462,000
Subtotal	$1,310,000	$1,680,000	$2,062,000
* O&M $/Yr.	$49,200	$92,900	$147,600
** PW O&M	$379,920	$717,370	$1,139,770
Total PW, $	$1,689,920	$2,397,370	$3,201,770
Cost $/Gal PW			
With SO_2	$0.34	$0.24	$0.21
Without SO_2	$0.26	$0.19	$0.17

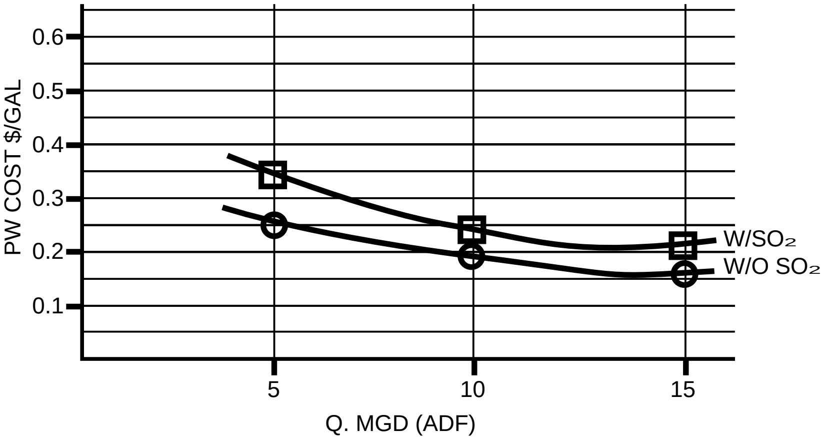
*CL_2 @ $0.24/Lb., SO_2 @ $.30/Lb., Labor @ $35/Hr.

Table 2: On-site Hypochlorite Generation

	5 MGD	10 MGD	15 MGD
General Equipment	$750,000	$875,000	$1,750,000
Contact Tanks	$100,000	$200,000	$300,000
SO2 Equipment	$150,000	$150,000	$150,000
Scrubbers	$150,000	$150,000	$150,000
Building & Misc.	$250,000	$500,000	$500,000
Subtotal	$1,400,000	$1,875,000	$2,850,000
* O&M $/Yr.	$145,000	$290,000	$2,850,000
** PW O&M	$1,119,690	$2,239,380	$3,461,000
Total PW, $	$2,519,690	$4,114,380	$6,311,000
Cost $/Gal PW			
With SO_2	$0.50	$0.41	$0.42
Without SO_2	$0.43	$0.37	$0.39

** PW @ 5% / 10 Years = 7.722

Figure 1. Gaseous Chlorination



For a new 5 MGD facility with dechlorination, we estimate the capital cost of disinfection to be $1,310,000. The annual operating cost at full design flow would be approximately $49,200 per year. The present worth has been calculated for a 10-year operating period at 5% interest to be $379,920 for O&M. The total present worth of the facility has been calculated to be approximately $1,689,920 in today's dollars. This corresponds to a total operating expense of $0.34 per gallon at full design capacity. If we back out the costs for dechlorination to estimate the expense for a reuse effluent containing a free chlorine residual, we find an expected operating cost of $0.26 per gallon, again at full design flow.

Table 2 summarizes similar costs for 10 and 15 MGD, respectively. Figure 1 shows the economy of scale that can be expected as the facility size increases. The ratio of total present worth to design flow in dollars per gallon appears to range from $0.17 up to $0.34 for the conditions stated.

In the real world, these costs are conservative. Rarely do we encounter facilities that we can't salvage something from the existing systems. However, they do make the point graphically that even good old chlorination is a significant cost today.

On-Site Hypochlorite Generation

One of the first alternatives that we turn to after chlorination is the potential use of hypochlorite. There are two approaches for using hypochlorite. It can either be generated on-site electrolytically, or it can be purchased in bulk solution. This section will discuss the on-site generation of a dilute solution of sodium hypochlorite that meets the hazardous material rules of use.

On-site generation of hypochlorite is a very straightforward process that has been around for nearly 100 years. It is largely an outgrowth of two industries: swimming pools and the salt production industry. It may well be a system largely unknown to your operating staffs, but it is a pretty simple process to learn.

Rock salt in bulk is dissolved into a concentrated brine solution, typically about 30% TDS concentration by weight. The solution is diluted with softened process water and passed across electrodes powered by a low voltage current. Figure 2 shows the basic process schematic and requirements. The result is a dilute 0.8% hypochlorite solution that is stored in a day tank and injected into the disinfection process by a simple liquid metering pump.

Except for the need of a larger capacity metering pump, the storage and injection steps for this process are nearly identical to those used with commercial bleach (12%) hypochlorite systems. In this case, 15 gallons of the 0.8% solution are equivalent to one pound of chlorine gas. A small amount of hydrogen gas is safely vented into the atmosphere. Typically, the system is one in a true batch mode, making enough solution in a short period of time to get through an entire operating day. In most cases, the feed water for dilution must be softened to protect the electrodes. This contributes a small amount of recharge brine to waste. Salt for the softener regeneration is typically drawn automatically from the bulk brine storage tank.

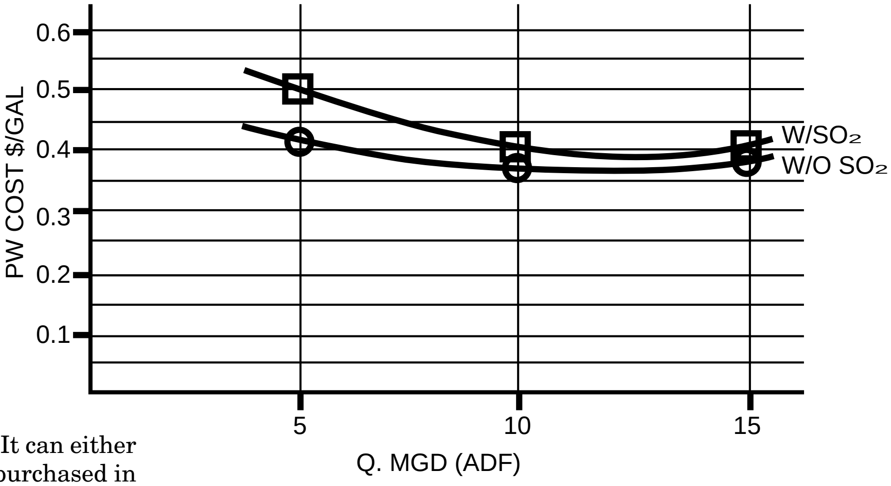
One major advantage of this approach is that no hazardous materials are ever handled via this system. Only raw materials (salt, water, and power) are handled and/or shipped for this process. The dilute solution produced is relatively harmless in the event of a spill. Finally, unlike commercial bleach products, the dilute solution of sodium hypochlorite is relatively stable and rarely degrades on storage. There is no known shelf life for the product material.

Reducing the operation to its basic components, 3.5 lbs of salt added to 15 gallons of softened water with 2.5 KwHrs of power make 15 gallons of 0.8% by weight solution. These 15 gallons are equivalent to one pound of gaseous chlorine. Typically, this product varies in cost from $0.19 to $0.25 per pound depending on the local cost of salt and power.

Normally, the system components consist of the following:

- 30 day salt/brine concentrator and storage tank
- water softener
- hypochlorite generator
- day tanks for the final product
- liquid metering pumps
- control system

Figure 2. On-Site Hypochlorite Generation



Functionally, the brine tank stores the salt and converts it to a 30% by weight brine solution. The tank is usually fully enclosed and there is no handling of the salt by the operators. The water softener is used to reduce calcium hardness scale on the electrodes of the generator cell. The generator is an electrolytic reactor that combines the brine solution with a low voltage current to produce the hypochlorite ion. The product storage is a day tank sized to handle enough product for a 24-hour period. Actually the product can be stored for several days if necessary, but sizing typically is based on a 24-hour operating period. Production is normally on a true batch mode of operation with the generator automated by a level signal in the product tank. Metering pumps deliver the liquid product to however many application points are required within the facility.

The operation and maintenance routine of the process usually includes quarterly acid backwashes to remove the hardness scale from the electrodes and the cell body. In some cases the actual cell is transparent so any scale buildup is visible from outside the unit. Generally, the backwash time ranges from one to two hours as long as the water has been adequately softened during normal operations. Monitoring of the generator system for scale will usually be done each week. Normally, there will be an annual tank inspection for the brine storage vessel. Finally, the water softener has to be regenerated frequently. Typically, the brine for the regeneration is automatically drawn from the bulk brine tank. Salt is delivered to the site in bags for small scale systems, or in special trucks for larger scale facilities.

The on-site hypochlorite system is extremely simple to master. Even though your operating staff probably isn't experienced with this type of technology, it won't take them long to learn it. The advantages of the system are obvious. At no time will you handle, store, or transport free chlorine or any other hazardous chemical. The product hypochlorite concentration is well below the EPA hazardous material threshold. The small amount of hydrogen gas that forms at the one electrode is easily and safely vented to the atmosphere and at no time approaches the lower explosion limits in air. Electrical requirements are 480 volts, three phase power. The electrical draw is approximately equal to 20 amps per 100 pounds of product per day. Smaller systems of less than 50 pounds per day, typically used in collection and distribution systems, can normally operate on 110/220 volt power as well. Systems are available from 6 pound equivalent per day up to about 1200 pound equivalent on a skid mount. The largest systems currently in service, located in Palm Beach County, go up to 3600 pound chlorine equivalent per day.

The system is considered to be simpler and easier to operate than the traditional V-notch gaseous chlorinator system. Since the product never reaches the hazardous concentration limits, it is an inherently safe system and does not need the leak

Table 3: Commercial Bleach

	5 MGD	*10 MGD*	*15 MGD*
Equipment	$100,000	$200,000	$250,000
Equip. Contact Tank	$100,000	$200,000	$300,000
Building, HVAC	$150,000	$300,000	$450,000
Sulfur Dioxide Equip.	$150,000	$150,000	$150,000
Scrubbers	$150,000	$150,000	$150,000
Miscellaneous	$100,000	$150,000	$200,000
Subtotal	$750,000	$1,150,000	$1,500,000
* O&M $/Yr.	$140,000	$280,000	$420,000
** PW O&M	$1,081,080	$2,162,160	$3,243,240
Total PW, $	$1,831,080	$3,312,160	$4,743,240
Cost $/Gal PW			
With SO2	$0.366	$0.331	$0.316
Without SO2	$0.333	$0.301	$0.280

*Bleach at $0.65 per gallon
** PW @ 5% / 10 Years = 7.722

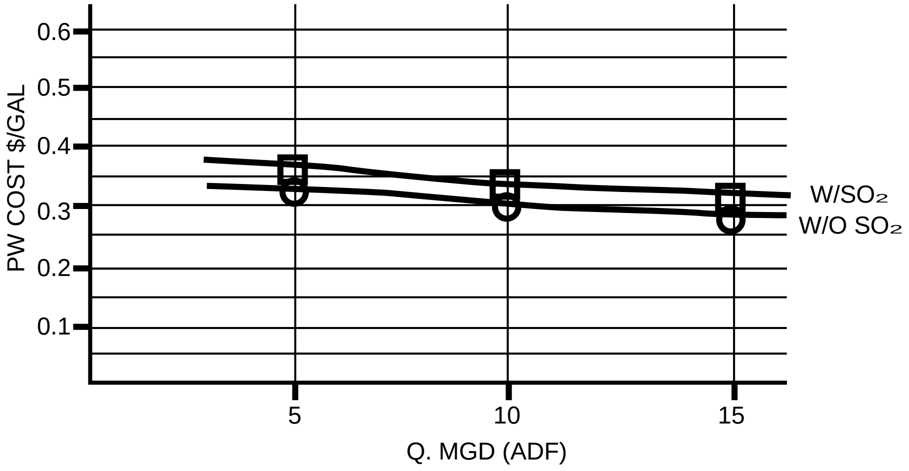
containment and scrubbing equipment often associated with chlorine. Note, however, the relatively high power demands of this alternative and the fact that it requires substantially more standby power than is required for simple chlorination.

For wastewater effluent disinfection, this alternative, like traditional chlorine, would need the ability to de-chlorinate some effluents. If de-chlorination is required, a traditional sulfur dioxide system works fine, but that also often requires leak containment and scrubbing equipment. One way to avoid any leak containment and scrubbers totally, is to de-chlorinate with an alternative reducing solution like sodium bi-sulfite. Finally, chlorine contact tank sizing for this alternative would be the same as for traditional chlorination. An interesting question for the Consultant in this alternative, state by state, is just what is really required to rate this alternative category 1 reliable? To date there do not seem to have been any firm requirements established anywhere to resolve this question. In some cases extra storage is acceptable, or a standby contract for commercial bleach is acceptable. With the worst case scenario, a spare cell may be required.

As with the gaseous chlorine example, we have estimated sample costs for a 5, 10, and 15 MGD average day flow facility with a 2.5 peaking factor. Table 3 summarizes these costs for the various plant capacities. For example, the 5 MGD size range would have an estimated capital cost of $1,400,000 which would be reasonably competitive with gaseous chlorine. We have estimated annual operations and maintenance costs at $145,000 per year. This is substantially more expensive than traditional chlorine. Operating and maintenance costs are the primary difference between the two alternatives.

Cost calculations have been completed for this alternative in the same manner as for the traditional chlorine system. Again, we have estimated a present worth of operating expenses based on 5% interest for a 10 year operating period. The present worth of O&M is estimated to be $1,018,480. The total present worth of the alternative at 5 MGD would be $2,418,480. If we compare the total present worth of cost to the design flow, we find a ratio cost of $0.48 per gallon of flow with de-chlorination and $0.34 per gallon without de-chlorination. Figure 3 summarizes these cost calculations in a typical design curve that again suggests the potential economy of scale that might be realized as the system size increases.

Figure 3. Commercial Bleach



The conclusion is that on-site generation systems cost more than traditional gaseous chlorination. On the other hand, the systems are becoming very popular in the southern and western portions of the country, particularly in small drinking water systems. For remote sites that cannot be easily visited, or for small sites located in domestic housing areas, the extra cost can often be written off against the advantage of not having to visit as often, or not having to live with the hazard of chemicals stored in close proximity to the local population.

Commercial Sodium Hypochlorite

For this alternative, commercial sodium hypochlorite, at about 12% by weight, is produced off-site and then delivered in bulk. It is stored and metered into the treatment system just like the on-site alternative we have just discussed. The only real differences involve smaller metering pumps and tanks, since the bulk material is significantly more concentrated.

Another difference that becomes readily apparent is that commercial bleach at the higher concentration is not inherently chemically stable. It does degrade in storage and has a very definite shelf life at the plant. The stability of commercial bleach is impacted by heat, light, pH, and the presence of heavy metal cations. Deterioration rates increase with rises in temperature and increases in solution concentration.

The presence of heavy metal cations such as iron, copper, or nickel enhances the deterioration of the solution. The rate of deterioration is a decreasing function as the solution's strength goes down. In Florida, generally, the half life of the commercial bleach solution is approximately 15 to 30 days, depending on the time of the year. The most stable solutions are those of low hypochlorite concentration (<10%), with a relatively high pH (>11%), and low concentrations of the various metals (<0.5mg/L), stored in the dark at a temperature of about 70 degrees F. In a hot climate, it may be advantageous to store the solution in an air conditioned building to slow down the rate of degradation.

The storage of sodium hypochlorite is not a fire hazard in any concentration, but the higher the concentration of hypochlorite the higher the potential "out-gassing" of chlorine from the solution in the event of a leak. The system generally consists of storage tanks and metering pumps. Power requirements are minimal, unless one air conditions the storage areas. The entire system is relatively low maintenance and takes little if any training to implement. A final advantage of this approach is that the Clean Air Act does not require a Risk Management Plan (RMP) for systems using this alternative.

However, rhe alternative has some serious disadvantages.

Table 4: Low Pressure UV Non-Title 22

	5 MGD	10 MGD	15 MGD
General Equipment	$540,000	$1,041,300	$1,124,900
Contact Tanks	$50,000	$75,000	$125,000
Miscellaneous	$150,000	$200,000	$250,000
Subtotal	$740,000	$1,316,300	$1,499,900
* O&M $/Yr.	$35,900	$61,800	$96,600
** PW O&M	$277,220	$477,220	$745,950
Total PW, $	$1,017,220	$1,793,520	$2,245,850
Cost $/Gal PW	$0.203	$0.179	$0.150

* PW @ 5% / 10 Years = 7.722

Table 5: Low Pressure UV Title 22

	5 MGD	10 MGD	15 MGD
General Equipment	$2,261,300	$4,625,000	$6,530,000
Contact Tanks	$100,000	$150,000	$200,000
Miscellaneous	$250,000	$300,000	$350,000
Subtotal	$2,611,300	$5,075,000	$7,080,000
* O&M $/Yr.	$133,400	$266,800	$339,800
** PW O&M	$1,030,115	$2,059,700	$2,623,936
Total PW, $	$3,641,415	$7,134,700	$9,703,936
Cost $/Gal PW	$0.728	$0.713	$0.647

** PW @ 5% / 10 Years = 7.722

Table 6: Medium Pressure UV Non-title 22

	5 MGD	10 MGD	15 MGD
General Equipment	$532,000	$900,000	$1,100,300
Contact Tanks	$50,000	$100,000	$150,000
Miscellaneous	$100,000	$150,000	$200,000
Subtotal	$682,000	$1,150,000	$1,450,300
* O&M $/Yr.	$40,600	$79,900	$130,000
** PW O&M	$313,500	$617,000	$1,003,860
Total PW, $	$995,500	$1,767,000	$2,454,160
Cost $/Gal PW	$0.200	$0.177	$0.164

** PW @ 5% / 10 Years = 7.722

Table 7: Medium Pressure UV Title 22

	5 MGD	10 MGD	15 MGD
General Equipment	$1,875,000	$3,187,500	$4,250,000
Contact Tanks	$100,000	$150,000	$200,000
Miscellaneous	$150,000	$200,000	$250,000
Subtotal	$2,125,000	$3,537,500	$4,700,000
* O&M $/Yr.	$89,400	$177,400	$268,400
** PW O&M	$690,350	$1,369,900	$2,072,600
Total PW, $	$2,815,350	$4,907,400	$6,772,600
Cost $/Gal PW	$0.563	$0.491	$0.452

** PW @ 5% / 10 Years = 7.722

The degradation of the bleach solution is a constant worry and means that limited amounts can be stored on site. This requires very reliable contract relations and shipping to insure chemical replenishment as soon as needed. Product handling can be a messy business and it is strongly recommended that handling and storage areas be designed for frequent and easy wash down and cleaning. Treatment plant personnel are often exposed to bleach solution during handling, so inevitably clothing and skin are in contact with the solution. Skin needs to be cleaned and flushed promptly. Face protection and eye guards are a necessity. Usually respirators are not an immediate requirement, but they should be kept available. Lastly, since the solution has a relatively high pH, any leaks or contacts with acidic materials have the possibility of strong acid/base chemical reactions.

We have estimated costs for this alternative using the same procedures as the previous alternatives. We have assumed that the available chlorine content in the commercial bleach solution is about 12% by weight, which is approximately 1 gallon of bleach equivalent to one pound of gaseous chlorine. Assuming a 15 day supply stored on hand, we have estimated on the basis of 5,000 and 10,000 gallon storage tanks. System capital cost is a little less than for either of the previous alternatives. Table 3 summarizes the present worth of both capital and operating costs. Note for this approach operating cost vastly outweighs the initial capital cost.

O&M costs for this alternative are dominated by the cost of the chemical itself. Average bleach solution costs across the state of Florida run about $0.60 to $0.65 per gallon of solution. Price contract guarantees rarely extend for more than a single year at a time. Commercial bleach is delivered to the site by tanker truck, much like many of the chemicals typically used in treatment facilities.

Ultraviolet Radiation

Ultraviolet radiation disinfects wastewater by altering the genetic DNA material in cells so that bacteria, viruses, and other microorganisms cannot reproduce. In UV disinfection, the UV light is produced by lamps that operate in the germicidal energy range. As filtered effluent flows past the UV lamps, the suspended solids and microorganisms are exposed to a lethal dose of UV energy. The UV dose is measured as the product of the UV light intensity and the exposure time within the UV lamp array. Transmittance is defined as the percentage of UV light actually absorbed by the microorganisms. As the UV light passes through the wastewater medium, any suspended solids or tannic color absorb the energy and decrease the amount of light that actually reaches the microorganism. A typical effluent transmittance ranges from 65 to 75 percent. As the transmittance value goes down, more and more energy is required to achieve a kill, thus driving up the cost of the system.

It is generally accepted that the germicidal nature of UV light stems from the disruption of microorganisms' DNA strands by radiation wavelengths between about 220 and 300 nanometers (nm) wavelength. With most biological organisms, this effect is maximized at about 260 nm. The various UV system suppliers all have specific claims as to UV efficiency from their lamps and systems. It is accurate to say that for low pressure lamps, about 85% of the total UV output is centered around the germicidal wavelength of 253.7 nm. This makes the low pressure lamp monochromatic in its output. Medium pressure lamps, on the other hand, produce a wider band of energy with several different peaks that span the range of 220 to 300 nm, with the largest peak just over 254 nm.

UV disinfection has been used routinely in many states, but my own state of Florida has been slow to adopt it. The prevalence of reuse water in Florida and the potential of regrowth has been a dominant issue for many years. It has now been conclusively proved that properly irradiated water will not exhibit regrowth and the state does accept UV disinfection for a variety of purposes, although it doesn't officially appear in the rules yet. UV disinfection can be permited for effluents going directly to surface water, to indirect restricted access reuse systems, or with great care, to unrestricted public reuse systems. This has been a great debate in Florida for many years since the state reuse regulations do not require a chlorine residual in reuse water.

For public reuse systems, Florida does not yet have its own guidelines and rules in effect to define how the technology can be used. Florida currently requires us to rely on a California document called the Title 22 Guidelines to establish your design needs for UV. Title 22 is a document and rule in California established by a committee convened by the National Water Research Institute and the California Department of Health Services. The objective of the committee was to establish design and operational guidelines to comply with the California Wastewater Reclamation Criteria, Title 22, Chapter 3 of the California Code of Regulations. The document was developed to prove the equivalency of UV disinfection to conventional chlorine disinfection as used in wastewater reclamation plants.

Equivalency of UV disinfection to a conventional process used in wastewater reclamation and reuse must be demonstrated by the following criteria:

1. Filtered effluent turbidity equal to or less than 2 NTU, met with the same statistical frequency required for chlorine disinfection.
2. Total coliform count equal to or less than 2.2 colonies per 100 ml sample, met with the same frequency as required for chlorine disinfection. Florida requires fecal rather than total coliform. Florida high level disinfection requires 0 colonies per 100 mls sample for 75% of monthly samples with a one time high of 25 allowed in any given month. Florida high level disinfection corresponds to Title 22, whereas basic level disinfection is reserved for non-reuse or recreational discharges.
3. Virus inactivation efficiency equivalent to that achieved with chlorine disinfection(4-logs of inactivation — 99.99% reduction — based on polio virus).

Title 22 only comes into play for those systems that involve direct public reuse. It establishes some minimum standards for design purposes. Most states that use the rule interpret those guidelines as guidelines, not as absolutes. The minimum Title 22 standards are very restrictive and can be very costly in terms of capital and operating costs. Because of the cost inherent with Title 22, the policy guidelines also provide for the ability to run a pilot plant for sufficient time to prove UV equivalency at something less that the conditions imposed by Title 22. Typically, the conditions that are most often considered for modification are the dosage and transmittance values.

In strict compliance with Title 22, a UV disinfection system for the most restrictive reuse applications should be designed to deliver, under the worst operating conditions, a minimum UV design dose of 140 mWs per square centimeter at the maximum flow. The minimum required design dose must be based on the following conditions:

1. Design UV lamp output at 70% of new lamp output.
2. Transmittance through the quartz sleeve to be 70%.
3. Minimum allowable wastewater transmittance is 55%. If continuous transmittance data has been collected for a minimum period of six months, including wet weather periods, a higher transmittance may be allowed. Typical transmittance values run from 60 to 70% and are affected by tannic acids and any other organics that may absorb energy.
4. The UV dose calculation should normally be based on the point source simulation method.
5. The UV dose is to be achieved with a minimum of three UV banks in series with one or more additional banks for standby redundancy.

Figure 4. Low Pressure UV

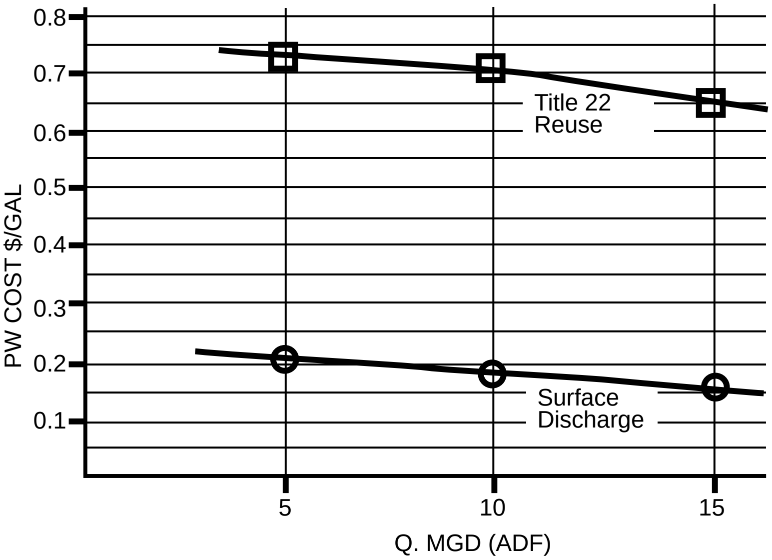
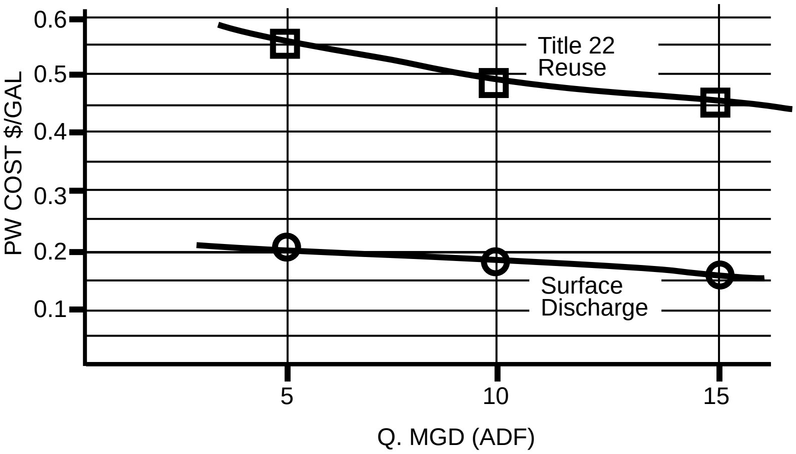


Figure 5. Medium Pressure UV



When you start looking at UV equipment you will find numerous manufacturers divided between two camps - the low pressure lamp and the medium pressure lamp. There are several manufacturers in each category. Lamp applications can range from low pressure to medium pressure based on the vapor pressure of mercury within the lamp. They can also range from low intensity to high intensity, also based primarily on pressure and on the operating temperature of the lamp. Obviously, the highest operating power equates with the highest operating intensity, and the highest lamp temperature. The best energy efficiency falls to a compromise class in between low and high intensity that attempts to optimize UV power intensity with the energy lost to thermal energy. This low pressure/high intensity system is the newest product on the market.

When one compares typical low pressure lamps with medium pressure lamps, it quickly becomes apparent that the higher the intensity applied, the fewer lamps required. For basic level disinfection, this trade-off is not very significant monetarily, but as one looks at high level disinfection systems for reuse applications, the cost of lamps quickly becomes very significant. For example, for a 10 MGD reuse plant operating with a 2.5 peaking factor, a Title 22 reuse design would require approximately 600 medium pressure lamps arranged in four separate banks of one channel. The same design would require approximately 10,000 low pressure lamps again arranged in four individual banks, but in multiple channels. The new low pressure/high intensity lamp would require approximately 2,000 lamps, arranged in four banks, probably in two channels. We find in various field applications that a single medium pressure lamp is the equivalent of about 15 low pressure lamps and about 3 of the compromise low pressure/high intensity lamps.

Decisions over which lamp or system to use are extremely complex, taking into account up-front capital cost, as well as operating power, lamp replacement, operating labor, chemicals for cleaning, and so on. For example replacement cost of a low pressure lamp is about $50, whereas replacement of a medium pressure lamp is about $250, but the system has thousands more low pressure lamps to replace. From the standpoint of power efficiency, the compromise low pressure/high intensity lamp has a lower operating temperature and greater energy efficiency than the medium pressure lamp. It rarely is a crystal clear decision as to which system to apply at any given site, but we normally prefer firms with extensive field experience. For reuse systems in Florida we also usually require the firm to be certified for Title 22 work in California before we will consider them for bidding purposes.

One of the most significant issues to decide with regard to UV disinfection is the question of down time due to power outages or power blips in the distribution network. Can the facility tolerate the UV system being off line or is it allowed any period off line? The answer in Florida and California usually is no. Given the amount of power disruptions in the Florida grid, this means we have to look for ways to either divert or store effluent during an outage, or in the case of large systems we have to look at uninterrupted power systems (UPS) in addition to standby generators to insure that the UV lamps, electronic ballasts, and controls are always available regardless of the status of the commercial power grid.

Finally, UV systems can come with a wide variety of contact options, either open channel or closed pipe. Most typically, we consider retrofitting existing open channel chlorine contact tanks to handle UV equipment. This works very well in the large Title 22 type reuse systems. For smaller facilities and non-Title 22 we also have the ability to enclose the reactors in piping, avoiding the need of an open contact tank entirely.

Similar to our other examples, we have estimated the sample costs for the 5, 10, and 15 MGD treatment plant examples. This time we have estimated cost for both low pressure and medium pressure systems for both a surface discharge and a public reuse application.

For a low pressure system with a surface water discharge, we estimate that the system equipment costs would range from $750,000 to $1,500,000. O&M cost would consist of power, replacement lamps, and labor. We have estimated them to total $36,000 to $97,000 per year. For this low pressure example, the total present worth of cost would range from $990,000 to $2,200,000, or from $0.20 to $0.25 per gallon of capacity.

A medium pressure system with the same characteristics, i.e. non-Title 22, would range from $680,000 to $1,500,000. O&M cost would be $41,000 to $130,000 per year. For this medium pressure example, the total present worth of cost would be $970,000 to $2,400,000, or from $0.16 to $0.20 per gallon of capacity.

The highest capital cost systems will always be the Title 22 reuse applications for unrestricted public access. The required redundancies and safety factors increase the cost figures significantly. Estimated low pressure cost for this alternative range from $2,600,000 to $7,100,000. O&M costs would be higher as well, reflecting the higher applied dosages, ranging from $134,000 to $340,000 per year. For this low pressure application, we would expect total present worth of costs ranging from $3,600,000 to $9,500,000, or from $0.63 to $0.70 per gallon of capacity.

Finally, we have done the same estimation for a medium pressure example, Title 22 again for unrestricted public access reuse. The initial capital costs would range from $1,900,000 to $4,300,000. O&M costs are estimated to be $89,400 to $269,000 per year. For this medium pressure application, the total present worth of costs are estimated to range from $2,800,000 to $6,600,000, or from $0.44 to $0.55 per gallon of capacity.

Conclusions

Disinfection is expensive, whether it is simple chlorination or a more sophisticated alternative. For straight surface water discharge, unless there are extremely high disinfection requirements, ultraviolet disinfection is competitive in cost with chlorination, without even considering the safety aspects of handling the chemicals. Alternatives like commercial bleach and on-site hypochlorite generators have significantly higher unit costs than simple chlorination and are often applied for situations where safety or risk has a special concern. Finally for effluent reuse applications, high level chlorination is the least expensive disinfectant, but in many cases it cannot give the extremely high level kill required for reuse in some states. In such cases, high intensity UV is usually the alternative of choice, despite the higher costs. ■

Glossary of Common Terms Used in this Publication

AWT	advanced water treatment
AWWT	advanced wastewater treatment
AWWA	American Water Works Association
BOD	5-day biochemical oxygen demand
BOD$_x$	BOD test based on other than 5 days
CBOD	5-day carbonaeous BOD
COD	chemical oxygen demand
CWA	Clean Water Act
DEP	Florida Dept. of Environmental Protection
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FAC	Florida Administrative Code
fps	feet per second
FSAWWA	Florida Section of AWWA
FWEA	Florida Water Environment Association
FWPCOA	Fla. Water & Pollution Control Operators Assoc.
GIS	Geographic Information System
gpcd	gallons per capita per day
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
MGD	million gallons per day
mg/L	milligrams per liter
MLSS	mixed liquer suspended solids
MLTSS	mixed liquer total suspended solids
NPDES	Nat. Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
ORP	oxidation reduction potential
POTW	public-owned treatment works
ppm	parts per million
ppb	parts per billion
psi	pounds per square inch
PVC	polyvinyl chloride
RO	reverse osmosis
SCADA	supervisory control and data acquisition
SJRWMD	St. Johns River Water Mangement District
SFWMD	South Florida Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
USGS	United States Geological Survey
WEF	Water Environment Federation
WRF	water reclamation facility
WTP	water treatment plant
WWTP	wastewater treatment plant

Side Stream Ozone Addition and Dissolved Oxygen Control

Steven A. Yeats

The utilization of ozone has gained popular acceptance in the United States over the last 50 years as a reliable, effective water treatment technique. Advancements in ozone generation technologies have led to the production of higher weight ozone gas streams from "pure" gaseous oxygen. The higher weight ozone streams are then dissolved in raw or partially-treated water. One result of the use of pure oxygen-fed ozone generators and high weight ozone gas streams is supersaturated dissolved oxygen concentrations (15 to 25 mg/L or higher) in the finished water. Dissolved oxygen concentration levels in this range may promote accelerated corrosion of water treatment and conveyance systems. A unique approach was undertaken at the Valdosta Water Treatment Plant in Valdosta, Georgia, to minimize finished water dissolved oxygen concentration levels resulting from the use of high weight ozone gas.

The Upside of Ozone – A Powerful and Effective Water Treatment Tool

Ozone has been widely used to treat potable water throughout Europe for more than 90 years. It was first used in 1906 for taste and odor treatment in Nice, France. The first use of ozone for potable water treatment in the United States is reported(1) to have occurred in 1940 at Whiting, Indiana.

The name "ozone" is derived from the Greek word "Ozein" meaning "to smell."(1) A symmetrical triatomic form (O_3) of oxygen that is unstable and highly reactive, it is an effective disinfectant and a powerful oxidizing agent. Ozone gas displays a blue color and a characteristic pungent odor.

Ozone is formed from oxygen in the presence of a high voltage electrical discharge. The characteristic sharp electrical odor after a lightning storm is an example of this natural phenomenon. It is also a component of air pollution or smog, with ground level ozone concentrations carefully monitored by local and federal environmental authorities. High ground level ozone concentrations are considered detrimental to human health.

On the other hand, a layer of ozone in the earth's upper atmosphere serves a useful purpose by blocking harmful ultraviolet light. Consequently, the absence of sufficient ozone in the upper atmosphere, known as the "hole" in the ozone layer, is also considered detrimental to human health.

In water treatment, the application of ozone is always for the benefit of human health or for aesthetic (taste, odor, or color) purposes. When applied correctly, the use of ozone can result in a dramatic improvement in the quality of the finished water product.

Because of its extremely high oxidation potential, ozone can be used to oxidize and remove trace amounts of potentially toxic, carcinogenic, and mutagenic compounds in water. Under certain circumstances, ozone must be used as a pre-treatment prior to chlorine disinfection, if the raw water supply contains compounds that will form trihalomethanes when oxidized by chlorine. Furthermore, surface waters and groundwater supplies that are subject to cryptosporidium and giardia contamination are best treated with ozone to safeguard the public from these potentially fatal human pathogens.

Ozone can achieve a greater than three-log inactivation of bacteria with a 0.1 to 0.2-mg/L ozone residual and a five-minute contact time. Three-log inactivation of viruses can be achieved with a 0.4-mg/L ozone residual and four-minute minimum contact time. In the United States, 0.4-mg/L minimum ozone residual and 10-minute contact time are frequently used for design.(1)

Steven Yeats, P.E., is a water/wastewater process engineer with Jones, Edmunds & Associates, Inc., Gainesville.

Since ozone is unstable, it must be generated on-site near the point of use, a process that requires substantial amounts of oxygen and electricity. Currently, ozone is generated most cost-effectively using a concentrated oxygen feed gas stream that may be produced by on-site oxygen/air separation systems (e.g., cryogenic, pressure swing adsorption, vacuum swing adsorption) or from vaporization of stored liquid oxygen (LOX)(2). Oxygen-fed ozone generation systems typically in use today produce from 6 to 15% weight ozone gas streams containing 80 to 90% oxygen and 5% impurities (argon, nitrogen, and other trace gases).

The generated ozone gas stream is typically transferred into water by either passing the pressurized gas stream through a ceramic diffusion stone grid located at the bottom of a concrete ozone contactor basin, or by utilizing special cavitating venturi injectors, a method similar to that used for chlorine injection. These special cavitating injectors are used to aspirate and mix ozone gas into small water streams that are discharged directly into the bottom of the concrete basins using pipe or special mixing nozzles. Most ozone contacting basins are designed to operate in a plug flow mode and have water depths ranging from 18 to 25 feet.

When the generated ozone/oxygen gas stream is fed into the contact basin with a diffuser stone and stainless-steel diffuser type grids, ozone transfer may range from 80 to 95%, depending on the contactor design and the age and condition of the diffusers. If ozone is mixed into the contact basin with cavitation venturi style gas injectors, ozone transfer efficiencies may range as high as 99%.(3)

A relatively new method of ozone contacting, the GDT process, utilizes a special cavitating injector for ozone mixing and additionally provides pressurized mixing and detention time to rapidly transfer ozone into solution. The distinct advantage of this method over atmospheric ozone injection and fine bubble diffuser systems is the ability to achieve a high ozone transfer efficiency regardless of the design of the primary ozone contacting basin. How this advantage is achieved may be explained in part by Henry's Law, which states that the weight of any gas that dissolves in a given volume of liquid at constant temperature is directly proportional to the pressure the gas exerts above the liquid. This means the solubility or dissolution of ozone and oxygen gases will increase in direct proportion to the increase in the mixing pressure utilized by the gas injection process.

The Downside of Ozone – Corrosion

As part of the planning for the new 150 MGD River Mountains Water Treatment Facility, the Southern Nevada Water Authority conducted a study to review dissolved oxygen concentration profiles for six large U.S. water treatment facilities employing oxygen-fed ozone generators.(4) The authority, aware of the potential for accelerated corrosion of the water distribution system resulting from high dissolved oxygen concentrations associated with ozone treatment and oxygen-fed ozone generators, had some concerns about the effect oxygen generated ozone would have on their distribution system.

The six water treatment plants studied ranged in capacity from 15 to 600 MGD. All of the plants applied ozone to surface waters with initial raw water oxygen concentrations ranging from 5.8 to 10.1 mg/L. The applied ozone dosages ranged from 1.5 to 3.0 mg/L. Analysis of the finished water at these water treatment facilities revealed that dissolved oxygen concentrations ranged from 15 to greater than 20 mg/L. The study noted that none of the six water treatment facilities or associated water treatment systems has had significant corrosion problems attributed to the high dissolved oxygen concentrations. The study noted, however, that most of the facilities reviewed were only one to five years old and that the long-term effects of accelerated corrosion driven by excessive oxygen levels may not yet be recognized. The study also did not address the effects on industrial water users who may have been experiencing corrosion problems as a direct result of the high dissolved oxygen content levels in the potable water supplied to them.

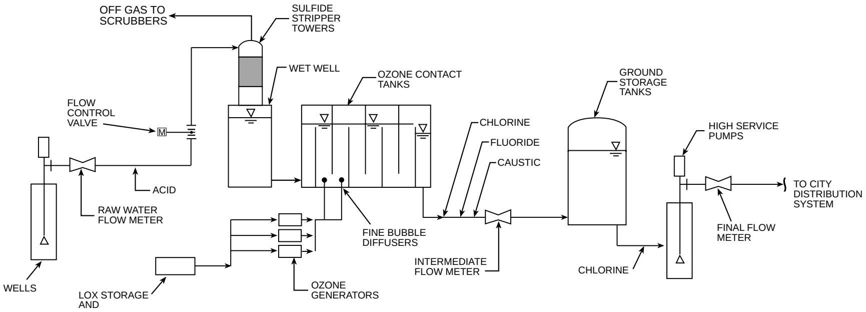


Figure 1. Valdosta Water Treatment Plant Flow Schematic.

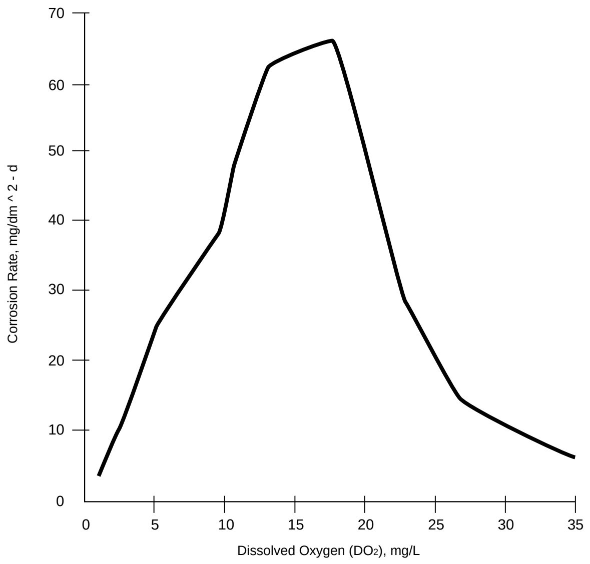


Figure 2. Influence of DO2 Concentration on Corrosion of Mild Steel in Slowly Moving Distilled Water, 48-Hour Test, 25°C.

In contrast to the six facilities studied by the Southern Nevada Water Authority, the city of Valdosta has witnessed extreme corrosion of ferrous metal piping at the water treatment plant, in the water distribution system, and within residential, commercial, and industrial distribution and plumbing systems. In 1992 Valdosta commissioned one of the first ozone water treatment plants in the southeastern U.S. — a 15-MGD state-of-the-art facility that treats groundwater under the direct influence of surface waters with ozone for primary disinfection and taste and odor control. Treatment consists of hydrogen sulfide stripping, ozone disinfection, pH adjustment, and final chlorination. A simplified schematic of the Valdosta WTP is shown in Figure 1. Oxygen-fed ozone generators produce 6 to 7% weight ozone gases from vaporized LOX. Since startup, finished water dissolved oxygen concentrations of 22 to 26 mg/L have been consistently measured in the distribution system. Bi-metallic phosphates corrosion inhibitors are continuously fed in an attempt to control frequent red water corrosion problems.

Metals corrode when the metal is immersed and releases an electron into water. Once the electron is released, a molecule separates from the metal surface and enters the water as an ion. The release of electrons and metallic ions continues as long as an electron acceptor is present. Thus, immersed metals (electron donors) are corroded as they release electrons to dissolved oxygen molecules, a strong electron acceptor. The metal acts as an anodic half-cell and dissolved oxygen acts as the cathodic half-cell of a corrosion cell. Since oxygen is generally the strongest electron acceptor in natural or treated waters, researchers often measure and correlate rates of metallic corrosion to the decrease in dissolved oxygen content of the water studied. Ferrous metals (iron and steel), copper and copper alloys, and brass alloys containing lead, are subject to corrosion in the presence of dissolved oxygen.

An explanation for the extreme ferrous metals corrosion problems experienced in Valdosta is shown in Figure 2, which represents the measured corrosion rate of mild steel in distilled water.(4)(5) Mild steel corrodes at extremely high rates in dissolved oxygen concentrations above a few parts per million, reaches a peak corrosion rate, and then passivates to a lower corrosion rate as the dissolved oxygen concentration continues to increase. In summary, ferrous metals corrode very slowly in the absence of dissolved oxygen and at normal temperatures. However, increased dissolved oxygen concentrations rapidly increases the rate of corrosion.

Pitting of copper surfaces also occurs in the presence of dissolved oxygen in water. Similar to ferrous metals, the rate of pitting and general corrosion increases with an increase in dissolved oxygen content.

Treat the Disease, Not the Symptom

Clearly, limiting the dissolved oxygen concentrations in a water treatment facility's finished water is an important goal, regardless of the method(s) used to treat the raw water. Since the application of ozone directly impacts a water system's dissolved oxygen levels, a well-designed ozone treatment system can minimize the impact on finished water corrosion potential. The on-going cost to repair or replace pipe and equipment that has undergone excessive corrosion or has generated complaints from water customers about interrupted service or red water stains and damage can quickly turn into a public relations nightmare. Consequently, those considering the use of ozone should address the need to control and minimize finished water dissolved oxygen concentrations to mitigate potential corrosion impacts to public and private water systems.

Various methods are currently in use to reduce high dissolved oxygen concentrations exiting ozone water treatment systems. Such methods include packed tower deaeration columns or air-stripping with fine bubble diffused aeration systems, which require energy intensive equipment and only achieve an oxygen reduction to saturation or near-saturation levels (9- to 12-mg/L dissolved oxygen) in the finished water. These add-on methods are addressing the high dissolved oxygen concentrations after the fact.

A unique approach to controlling dissolved oxygen concentrations in the finished water was investigated by Jones, Edmunds & Associates, Inc., for the city of Valdosta in 1998. A pilot demonstration project was conducted to investigate a side stream ozone addition (SSOA) process configuration followed by the rapid removal of undissolved gas bubbles to control dissolved oxygen concentrations. The SSOA process configuration is shown in Figure 3. The side stream pilot unit consisted of a pilot ozone contacting skid supplied by GDT Water Process Corporation. This skid utilized the patented GDT process, which provides a rapid mass transfer of gas into solution immediately followed by the rapid removal of undissolved gas bubbles.

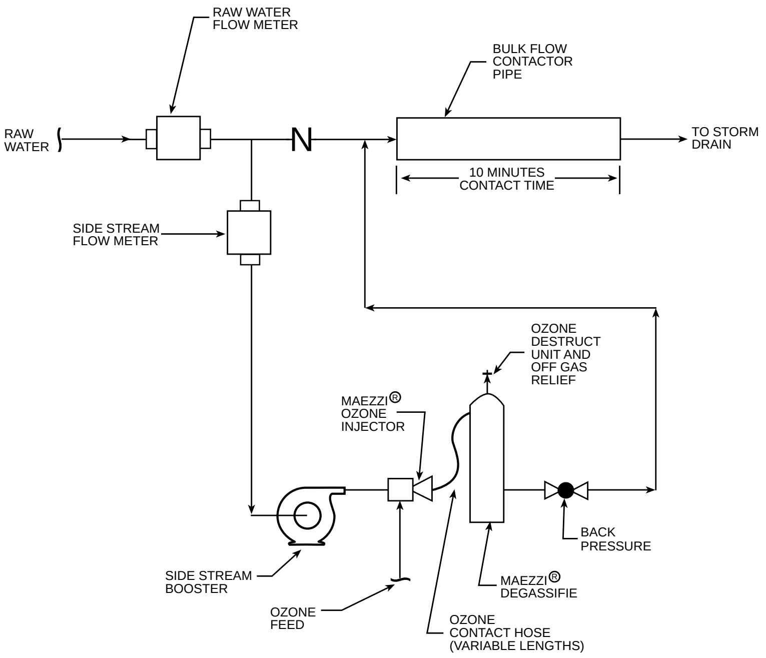


Figure 3. Valdosta Water Treatment Plant Side Stream Ozone Addition and Dissolved Oxygen Control Pilot Demonstration Test Flow Schematic.

The use of the GDT pilot skid to transfer ozone gas into a small side stream allowed for the study of gas saturation at various contacting pressures and detention times. Detention times were varied through the use of different detention pipeline volumes placed between the outlet of the Maezzi injector and the degas separator. Gas-water mixing pressures were controlled utilizing a simple outlet valve to control the mixing pressure downstream of the injector.

The control of the primary process variables of mixing pressure and gas-liquid contact time, in addition to controlling ozone dosages and ozone gas concentrations, provided sufficient flexibility to examine the SSOA system operating parameters that would be required to effectively minimize the plant's finished waters DO_2 levels.

The operating parameters used for the Valdosta demonstration project included ozone feed gases ranging in concentrations from 6 to 12% weight, gas-liquid mixing pressures from 10 to 35 psig, and hydraulic detention times ranging from 4 to 38 seconds. Gas to liquid ratios were varied from 0.03 to 0.54.(6)

By adjusting contact (mixing) pressure, contact time, and gas-to-liquid ratios, the desired concentrations of dissolved ozone and dissolved oxygen were produced in the side stream. This highly concentrated stream was then blended with the bulk raw water flow to achieve disinfection and the complete oxidation of hydrogen sulfide.

Table 1. Raw and Finished Water Qualifier.

Constituent	*Raw Water Fed to SSOA System*	*Finished Water at Exit from Bulk Flow Contactor*
Turbidity (NTU)	<0.01-0.05	<0.01
Color (PCu)	8-14	<1.0
pH	7.9-8.04	7.6
Total Sulfide (mg/L)	1.54-1.69	<0.001
Fe++ (mg/L)	0.02-0.04	<0.01-0.02
Mn++ (mg/L)	0.03	0.01-0.02

Process monitoring instrumentation included an In-USA model H1-X high concentration ozone feed gas analyzer and ATI dissolved ozone and oxygen analyzers for determination of applied and dissolved ozone dosages and the resultant dissolved gas concentrations. Dissolved oxygen and dissolved ozone instrument readings were confirmed or corrected by using the modified azide Winkler method for dissolved oxygen, and the colorimetric indigo trisulfonate and amperometric titration methods for ozone.

The goals of the SSOA system pilot demonstration project were as follows:
1. Maximize transfer of ozone gas and minimize the transfer of accompanying oxygen gas to the side stream flow.
2. Achieve near complete oxidation of inorganics, disinfection, and color removal while limiting dissolved oxygen concentration exiting the main stream contactor basin to 5.0 mg/L or less.

The pilot demonstration project was conducted over a three-month period during which thirty-eight primary process variables combinations and 122 trial runs were performed. The raw water fed to the demonstration unit had a measured dissolved ozone demand of 5.5 mg/L. The plant operating staff normally maintains a 0.6 to 0.7-mg/L dissolved oxygen ozone residual exiting the existing ozone contactor basin, therefore a highly concentrated side stream was needed with sufficient dissolved ozone to satisfy a 6.2-mg/L dissolved ozone requirement. Raw and finished water qualities are presented in Table 1.

The results shown in Figure 4 illustrate the wide range of finished water DO_2 levels provided by using two distinctly different operating parameters for the SSOA system. The data indicate the use of a higher concentration of ozone gas, at a

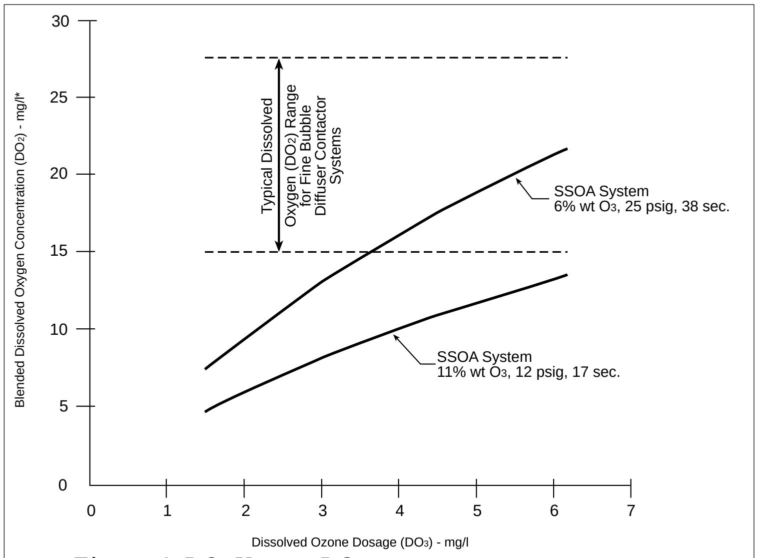


Figure 4. DO_2 Versus DO_3.

shorter contact time and lower mixing pressure, significantly reduces the oxygen content in the finished water.

The Valdosta SSOA system pilot demonstration did not achieve the goal of producing a finished water dissolved oxygen concentration of 5 mg/L or less with the use of 6% weight ozone from the plant's existing ozone generation system. However, the results indicate that dissolved oxygen exiting the existing fine bubble diffuser ozone contactor basin can be lowered from the existing 22- to 26-mg/L range to a range of 13- to 14-mg/L for a 6- to 6.2-mg/L raw water ozone demand if a SSOA system and a higher weight ozone generation system were implemented. Further reductions in dissolved oxygen concentrations could be achieved by lowering the ozone demand of the raw water and the use of an even higher weight percent ozone feed gas (15%).

Summary

The Valdosta SSOA pilot demonstration project provided the following results:

1. It was indicated that dissolved oxygen concentrations can be reduced to levels below saturation (8.5 mg/L) by the use of the SSOA process configuration and high weight ozone feed gas (≥11% weight ozone gas) when dissolved ozone dosages are 3 mg/L or less.
2. The 6% weight ozone feed gas and the SSOA process configuration did not achieve the desired low dissolved oxygen concentration level (£5 mg/L) for the complete oxidation of the raw water hydrogen sulfide (1.54-1.69 mg/L) and raw water disinfection (0.7 mg/L dissolved ozone residual). The dissolved ozone dosage required to achieve complete oxidation and disinfection was measured to be 6.2 mg/L.
3. The 11% weight ozone feed gas and the SSOA process configuration reduced the dissolved oxygen levels to 13 to 14 mg/L for disinfection and complete oxidation of the raw water hydrogen sulfide.

The Valdosta SSOA system and dissolved oxygen control pilot demonstration project has shown the SSOA system to be a viable process configuration to reduce dissolved oxygen concentration levels in finished waters exiting pure oxygen-fed generated ozone treatment processes. The SSOA process configuration offers great flexibility in selecting ozone transfer contact times, mixing pressures, and gas to liquid ratios. This configuration along with high weight ozone feed gases allows the production of a high concentration process side stream. This high concentration process stream can be blended with the bulk water flow to satisfy ozone treatment demands and minimize dissolved oxygen concentrations in the blended flow.

Use of higher weight ozone feed gas in the 15% weight range will reduce dissolved oxygen levels further. For raw waters containing hydrogen sulfide, for example, a pretreatment step could be implemented ahead of the ozone treatment step to reduce the dissolved ozone requirement to 3 mg/L or less. The hydrogen sulfide pretreatment step must be a process that removes the sulfides without the introduction of significant amounts of dissolved oxygen.

One such hydrogen sulfide removal process is a system developed and designed by Jones, Edmunds & Associates, Inc. for Hillsborough County.(7) A system was developed to remove 1.5 mg/L of hydrogen sulfide from the raw water treated at the Lithia Water Treatment and Pumping Facility. Hydrogen sulfide is provided by an automatically controlled side stream aeration oxidation system to achieve near complete removal of hydrogen sulfide while limiting the resulting dissolved oxygen concentration to 1 mg/L or less. This facility has been operated successfully for more than ten years.

The biological oxidation of sulfides by sulfide-oxidizing bacteria during air stripping was recently investigated at the Murphree Water Treatment Plant in Gainesville, Florida.(8) Raw water containing 2 to 3 mg/L hydrogen sulfide was observed to be reduced to <0.1 mg/L with low levels of diffused aeration promoting hydrogen sulfide gas stripping, and biological growth and bio-oxidation of the remaining sulfides.

More research and pilot demonstration work needs to be conducted to improve the performance of the SSOA process configuration to minimize dissolved oxygen concentration levels. Public and private utilities in Florida and in the United States will continue to use ozone for potable water treatment. Minimization of resultant dissolved oxygen concentration levels will be increasingly important to reduce the potential corrosive effects of the finished water's exposure to water treatment, transmission, distribution, and plumbing systems.

Acknowledgements:

Technical assistance was provided by Cliff Hall, P.E., of Jones, Edmunds & Associates, Inc.; Jim Jackson, GDT, Inc., Phoenix, Arizona; and Keith Martin, Laboratory Manager, Valdosta Water Treatment Plant, Valdosta, Georgia.

References:

(1) George Clifford White, *The Handbook of Chlorination*, 1986 Edition, Van Nostrand Reinhold Company, Inc.
(2) James R. Jackson, Paul K. Overbeck, John M. Overby, "GDT Water Process Corporation, Dissolved Oxygen Control by Pressurized Side Stream Ozone Contacting and Degassing," paper presented at the International Ozone Association World Congress 1999 Annual Conference, Dearborn, Michigan, August 1999.
(3) L. Joseph Bollyky, Ph.D., Bollyky Associates, Inc., Stamford, Connecticut, Angleo Maezzi, R. Michael Meyer, Maezzi Injector Corporation, Bakersfield, California, "Mass Transfer of High Concentration Ozone with High Efficiency Injectors and Degassing Separators," paper presented at the International Ozone Association Pan American Group, Cambridge, Mass., November 13, 1995.
(4) Michael Laranang, Senior Engineer, Montgomery Watson, Las Vegas, et al., "Assessing the Impacts of Oxygen-Based Ozonation on Water Supply Facilities."
(5) James M. Montgomery, Consulting Engineers, Inc., *Water Treatment Principles and Design*, 1985 Edition, John Wiley & Sons.
(6) Steve Yeats, P.E., Jones, Edmunds & Associates, Inc., Gainesville, Florida, "Valdosta Water Treatment Plant Side Stream Ozone Addition System with Dissolved Oxygen Control Pilot Demonstration Data Summary Report," March 30, 1999.
(7) Robert Edmunds, Harold Aikeu, and Michael McWeeny, "New Water Supply Facilities for South-Central Hillsborough County," *Florida Water Resources Journal*, April 1990.
(8) M.J. Dell'Orco, U.S. Army, Aurora, Colorado, Paul A. Chadik, Ph.D., Black Hall, University of Florida, et al., "Sulfide-oxidizing bacteria: their role during air stripping," *Journal AWWA*, October 1998, Volume 90, Issue 10.
(9) Discussions with Dr. Ed Singley, special consultant to Jones, Edmunds & Associates, Inc., concerning dissolved oxygen and the mechanisms of corrosion.