

Choosing the Right **Disinfection Technology** *for a Municipal Drinking Water Plant: Part 2*

Major Disinfection Processes for Drinking Water Treatment

Disinfection technologies readily available and in common use each have their strengths and weaknesses in treating municipal drinking water. In the face of ever-increasing regulations, the final decision on a disinfection process involves a judgement where the effectiveness of one method outweighs its limitations. The answer may be choosing a hybrid system, such as filtration followed by using a disinfectant downstream or pretreatment with a disinfectant.

An intimate knowledge of available disinfection processes is a prerequisite to selecting the most appropriate system. This knowledge must be combined with an equally intimate awareness of the water quality to be treated and all applicable regulations and rules at the WTP site. The permutations and combinations are many and the rules keep changing.

The following is a list of disinfection technologies and related treatment processes covered briefly in this section. Key selection factors for each are summarized in Table 1. These technologies include

- chlorine gas (bulk liquid),
- chlorine gas with on-site generation,
- hypochlorites (sodium and calcium) including on-site generation,
- chloramines ,
- chlorine dioxide (on-site generation),
- ultraviolet (UV),
- ozone (on-site generation), and
- filtration (conventional and "fine" in various degrees, including reverse osmosis).

There are other disinfectants/oxidants that have been used such as hydrogen peroxide, ozone/peroxide blends, potassium per-

manganate and iodine. However, their current level of use for disinfection in municipal drinking water systems is relatively minor.

Along with brief profiles of the listed disinfection processes, factors such as their relative effectiveness, formation of disinfection by-products (DBPs), operational complexity, safety risks and relative cost are summarized in Table 1.

This section also includes a summary table showing the results of a 1998 AWWA survey comparing current disinfection technologies use to what it was in 1989 (Table 2). The results show that chlorine gas (bulk liquid) still plays a dominant role in the plants surveyed.

Chlorine Gas (Bulk Liquid)

Chlorine gas is produced at chlor-alkali plants and shipped to water treatment plants (WTPs) as a liquid in pressurized bulk containers. These containers range in size from rail tank cars and road tank trucks down to 150-lb cylinders. For more than a century chlorine gas has been used successfully to disinfect drinking water, eliminating such diseases as typhoid fever and dysentery. When added to water, chlorine forms hypochlorous acid (HOCl), an active disinfectant.

The main capabilities of this disinfectant are that it

- Destroys a broad range of microorganisms, including bacteria, viruses and some protozoa,
- Controls many taste, color and odor problems in raw water by oxidation of the constituents that cause these problems, and
- With proper dosages, remains as chlorine residual in water distribution systems to protect against regrowth of algae or microorganisms. This residual can

serve as an indicator of water quality.

This broad range of capabilities is very cost-effective. However, during the 1960s, some concerns developed about this method. Briefly, these are the potential hazards it presents in transportation and storage; the possible creation of harmful DBPs (THMs and HAAs) and its weakness in inactivating *Cryptosporidium*.

These perceived limitations opened the door to alternative, albeit more expensive, disinfection processes using chlorine or other methods. Nonetheless, as evidenced by the AWWA survey, chlorine-based disinfection processes are still used in more than 90 percent of the U.S. drinking water plants that use a disinfectant.

Chlorine Gas (On-site Generation)

Over the past 20 years, a number of companies have attempted to introduce on-site generation of chlorine gas for disinfection. The methods typically have used electrolysis with membrane cells and brine (sodium chloride) as the source of chlorine. The objective of this approach is to provide chlorine gas at the plant for use on demand and thereby eliminate the aforementioned hazards of transportation and storage.

In the past, none of these attempts have been very successful. Problems include high capital costs as well as the costs for operation and maintenance. What amounts to having a small chemical plant on site was viewed as too complicated for most treatment plant operators. Further, the technology was less developed and bulk hypochlorites were relatively cheap.

This year, a new design of on-site generation of chlorine, tradenamed the ElectroChlor process, was introduced in the U.K. (See Ref. 4.) It produces chlorine

gas on demand by the electrolysis of hydrochloric acid in an electrochemical cell. Automatic controls permit variation in the rate of chlorine gas produced to suit the needs of the water treatment plant.

The world's first large-scale use of this new process is at the Frankley plant of Severn Trent Water, Ltd., where two 500-kg (one-half ton)-per-day units are being readied for commissioning. The compa-

ny's decision to replace existing bulk liquid chlorine for disinfection was based on the desire to avoid the potential hazards of a chlorine gas leak. Severn Trent Water is reported to have plans for converting to

Table 1: Application Guide for Key Disinfection Processes

Disinfection Process	Disinfection Effectiveness			By-Product Formation			Multi-Function		Safety Risk	Complexity	Cost' \$K gal
	Bact/Virus	Cysts	Residual	Organic	Brominated	Inorganic	Oxidation	Other			
Chlorine Gas ²	Very Good	Fair	Good	High	High	No	Good	MF ³	High	Low	0.006
Chlorine Gas On-Site Gen. ⁴	Very Good	Fair	Good	High	High	No	Good	MF	Low	High	0.024
Hypochlorite (Sodium & Calcium)	Very Good	Fair	Good	High	High (Bromate)	High	Good	MF	Medium	Low	0.009
Sodium Hypochlorite (On-site Gen.)	Very Good	Fair	Good	High	High (Bromate)	Medium	Good	MF	Low	Medium	0.012
Chloramines	Fair	Very Poor	Excellent	Medium	No	No	Poor		Low	Medium	0.009
Chlorine Dioxide	Very Good	Very Good	Fair	Low	No	High	Good	MF	Low	High	0.08
Ozone	Excellent	Excellent	No	Low	High (Bromate)	Medium	Very Good	MF	Low	High	0.13
Ultraviolet (UV)	Good	(Under Study)	No	No	No	No	H ₂ O ₂ /O ₃		Low	Low	0.06
Filtration											
Conventional	Poor	2 log ⁵	No	No	No	No	No	Filter ⁷	None	Medium	0.50
Microfiltration	Fair	>2 log ⁶	No	No	No	No	No	Filter ⁷	None	L/M	0.57
Ultrafiltration	Good	>2 log	No	No	No	No	No	Filter ⁷	None	L/M	0.65
Nanofiltration/Reverse Osmosis	Very Good	>2 log	No	No	No	No	No	Filter ⁷ softener organic reduction	None	Medium	0.8

1. Costs dependent on installation size.

2. Chlorine Gas (Bulk Liquid).

3. MF = Micro Flocculant.

4. ElectroChlor Process ("ElectroChlor" is a copyrighted trademark of Severn Trent Plc).

5. Signifies amount of reduction in log terms (Example: 2 log means a 10,000 size reduced to 100 size).

6. No EPA guidance. Assumed better than conventional.

7. See text regarding range of particulate sizes filtered.

Under the heading *Disinfection Effectiveness*, this table summarizes, very qualitatively, the effectiveness of the selected processes with regard to bacteria and viruses, cysts such as *Giardia* and residual that remains for the distribution system to combat regrowth of bacteria.

Under the heading *By-Product Formation*, the table indicates possibilities of harmful disinfection by-products (DBPs) rating these for raw water that contains organic matter, bromides that can form bromates, and inorganics (the latter possibly producing an unwanted DBP such as chlorites).

Under the heading *Multi-Function*, the various disinfection processes are rated as

to their ability to be good oxidants, where applicable. Obviously, filtration processes do not apply, but are rated by the second function of filtration, based on degree of fineness.

Under the heading *Safety Risk*, note that the risks do not apply to the non-chemical methods such as UV and filtration. This is a selection factor that needs to be kept in mind with regard to the specific regulations at the plant site.

The heading *Complexity* is used to broadly classify the various disinfection processes from an operational viewpoint. Descriptions of the methods themselves address this issue as appropriate.

Under *Cost*, the listed processes are given a rating in terms of \$K/gal. To get a dollar/gallon cost figure, multiply the given number by 1,000. For example, the given figure of 0.006 for chlorine gas (bulk liquid) would signify a cost of \$6/gal. and is seen to be the lowest for all the methods covered. At the other extreme, Nanofiltration at .80 is seen to be quite expensive—some \$800 per gallon.

The cost figures given are quite general and serve primarily to show relative comparisons. Any such figures are subject to change, and perhaps rapidly so, since manufacturers have on-going value engineering/cost reduction efforts on new and existing offerings.

the new process at several of its other plants now using bulk liquid chlorine.

In the United States, Severn Trent Services, Inc., is investigating the potential market for the ElectroChlor process. The somewhat higher cost inherent in the process needs to be weighed against removal of the potential hazards cited for use of bulk liquid chlorine. It also has the same limitations that come from using only chlorine gas as a disinfectant/oxidant.

Hypochlorites

Both sodium hypochlorite, (NaOCl) and calcium hypochlorite (CaOCl₂) offer an excellent alternative approach to disinfection. The active ingredient in both compounds is the hypochlorite ion OCl⁻, which hydrolyzes to form hypochlorous acid (HOCl).

Sodium hypochlorite (bulk liquid), often called liquid bleach, is considered to be the second cheapest disinfectant after bulk liquid chlorine gas. Commercially available as a 12.5 percent solution, it offers most of the advantages of chlorine gas—as a disinfectant, oxidizing agent and residual disinfectant, yet it does not have transportation or storage hazards to the extent present with chlorine gas. The supplier should be consulted as to specific hazards it may introduce if not properly handled.

Bulk sodium hypochlorite presents two problems. First, it tends to decompose in storage depending on the storage temperature, its age, concentration and contaminants it may contain. A much larger issue is the possible presence of bromates; this EPA-regulated DBP can come from bromide impurities that may be in the sodium chloride from which sodium hypochlorite is made.

On-site generation of sodium hypochlorite is an option, using the electrolysis of a dilute brine solution in a low voltage cell. This produces a 0.8 percent solution of sodium hypochlorite that is stored in a holding tank and fed into the process by a metering pump. Compared to the 12.5 percent chemical solution, this weaker alternative is not subject to decomposition. However, it can produce bromates if bromide impurities exist in the salt brine.

Equipment to produce sodium hypochlorite on site has a high initial capital cost and requires periodic replacement of electrodes as well as de-scaling of the cell. Its generation on site may be cheaper

Table 2: 1998 AWWA Survey
Percent of U.S. Municipal Drinking Water Treatment Systems Using Different Disinfectants

Disinfection Process	Large Systems ¹		Small Systems ²
	1998	(1989)	
Chlorine Gas (Bulk Liquid)	84	87	82
Chlorine Gas (On-site Generation)	0	0	0
Sodium Hypochlorite (Bulk Liquid)	18	7	15
Sodium Hypochlorite (On-site Generation)	2	0	2
Calcium Hypochlorite (Powder)	1	1	9
Chlorine Dioxide	8	5	6
Ozone	6	Small	0
Ultraviolet	Small	0	0

1. "Large Systems" serve greater than 10,000 consumers.
2. "Small Systems" serve 10,000 or fewer consumers.

than bulk methods depending on brine and power costs. In spite of its relatively high cost, many municipalities are using this method of on-site generation.

Installations are usually found in the southern half of the United States where higher ambient temperatures would cause decomposition of bulk commercial hypochlorite. Systems are in use with capacities ranging from grams per hour to thousands of pounds per day.

Calcium hypochlorite is normally delivered to WTPs in powder or granular form and mixed with water for application. It often is supplied in tablets, briquettes or other solid forms that are used in erosion type feeders. In smaller quantities, it is about twice as expensive as sodium hypochlorite. Nonetheless, it is preferred, primarily in smaller water treatment plants, because it is more stable and produces far less inorganic DBPs. In smaller amounts, it also is easier to handle and store.

This chemical requires special storage care to avoid contact with organic materials. These two substances can generate enough heat and oxygen to start a fire. Further, calcium hypochlorite mixed with water is an exothermic reaction. To prevent excessive heat, the dry chemical should always be added to the correct amount of water, rather than water added to the chemical.

Chloramines (Ammonia-Chlorine Process)

This process involves the addition of ammonia and chlorine compounds separately to a water treatment system. The two

ingredients (usually, anhydrous ammonia and hypochlorous acid) react to form chloramines. The ingredients also can be ammonium salts and liquid hypochlorites. This treatment procedure also is called chloramination or the chloramine process.

Compared to chlorine, chloramines produce fewer DBPs and do not combine with organics in the water to form trihaloamines (THMs). Chloramines can exist in mono-, di- or trichloramine forms. The proportions of these forms depend on chemical (pH) and physical properties of the water source and the ratio of chlorine to ammonia. In the chloramination process, ratios between 3 to 1 and 4 to 1 (chlorine to ammonia) limit the chloramine formation to monochloramine. This is a more desirable form that contributes little or no taste and odor that is attributable to di- and trichloramines.

In his chapter on chlorination of potable water, White devotes some 15 pages to various aspects of chloramination, emphasizing the importance of introducing the chlorine first and providing rapid mixing at the point of application. The ammonia-chlorine process is considered a secondary disinfectant, to be used in conjunction with another disinfectant technology.

Chlorine Dioxide

Chlorine dioxide (ClO₂) is usually produced on site by mixing chlorine gas with sodium chlorite (NaClO₂). In use since the 1940s, it is recognized as an efficient oxidizer and a broad-spectrum, fast-acting biocide. Today it is used by more than 1,000 water utilities in both the United States and

Europe but is relatively costly. In North America, it is used primarily for pretreatment of surface waters that have odor and taste problems or are high in manganese content. It also is used where only short contact time is available.

One desirable characteristic of chlorine dioxide is its selectivity as an oxidizing agent. For example, in dosages used in drinking water, it does not react with naturally occurring organic matter in the water to produce trihalomethanes (THMs) and haloacetic acids (HAAs) as chlorine does. It also does not react with bromides to form bromates, as ozone does.

Chlorine dioxide is unaffected by pH and hence offers better control of *Giardia* and *Cryptosporidium*. The chemical also has a long track record in removing iron and manganese. It is superior to chlorine in this regard, particularly where the iron and manganese exist in complex chemical compounds.

On the other hand, chlorine dioxide can produce undesirable by-products like chlorites (ClO_2^-) and chlorates (ClO_3^-). The MCL mandated for chlorite is one part per million. Since 80 percent of the chlorine dioxide is converted to chlorite, this rule limits the maximum practical dosage with this chemical to 1.25 ppm.

Finally, chlorine dioxide cannot be transported as a compressed gas; it has to be generated on site. Its use and generation requires skilled operators, further laboratory analyses and additional chemical storage—all factors in a higher operating cost. However, the development of newer generating equipment is improving the chemical handling aspects and minimizing needed operator skills.

Ozone

Ozone (O_3) is a very strong oxidizing agent as well as a broad range biocide. It is very unstable and must be generated on-site. One method is to pass dry air or oxygen through a high-voltage electrical discharge. It is the most expensive of the chemical disinfectants and, as a result, alternative versions of the generation process are being explored in an attempt to improve both its economy and reliability.

The chemical is excellent for

- Inactivating all pathogenic organisms – bacteria, viruses as well as the protozoa, *Giardia* and even *Cryptosporidium*,

- Eliminating bad taste, odor and color of water by oxidizing the offending organic and inorganic constituents,
- Converting iron and manganese to insoluble hydroxide sludges for easy removal, and
- Reducing THM formation.

A major drawback of using ozone is it converts bromides in the raw water to the undesirable bromates. High cost and operational complexity of its production are also significant limitations to its use.

Ultraviolet (UV)

For some years, disinfection with ultraviolet (UV) rays has been successfully used in municipal wastewater treatment. It also has potential for drinking water applications.

Its most likely application seems to be for groundwater where water clarity and other factors are most favorable.

White devotes more than 80 pages to uses of UV as a disinfectant, observing in the introduction that his text was originally written to describe its use for the effluent of a secondary or tertiary wastewater treatment plant. However, the predicted shortage of water in the arid U.S. western states has led to a number of projects, especially in California, focusing on water reuse systems that convert properly treated wastewater for use as drinking water. For such applications, he states that UV probably will be the final polishing agent.

U.S. EPA has recently shown support for this method of treating drinking water and trial installations are under way. It may have broader disinfectant uses but studies to date are inconclusive.

Filtration Processes

Conventional filtration has been used for many years in water treatment to remove solids by passing the water through beds of sand or other inert porous media. Use of more costly membranes processes for finer filtration of drinking water is now becoming more attractive because of the increasingly stringent regulations.

The Safe Water Treatment Rule (SWTR) led to investigations of ever finer filtering capabilities known as microfiltration, ultrafiltration, nanofiltration and reverse osmosis. All of these processes for mandated microbial and turbidity removal are very costly, with the cost increasing as the filtering gets finer.

Microfiltration separates out particulates of more than 0.1 mm or less than 10.0 mm in size. It is an effective process for removing *Giardia* and *Cryptosporidium* from raw waters—primarily from surface waters. However, it does not remove viruses and all bacteria that are of even smaller sizes. Therefore, it is necessary to complement microfiltration with a post-membrane process such as chlorination.

Ultrafiltration can overcome some of the limitations of microfiltration due to its even smaller pore sizes. It overlaps both microfiltration on one end and reverse osmosis on the other end of the separation processes scale. It separates out particulates in the 0.01 to 0.1 mm range.

Nanofiltration is a membrane treatment process that falls between reverse osmosis and ultrafiltration on the filtration/separation scale. It is capable of removing particles in the 0.001 to 0.01 mm range. It is capable of removing divalent ions such as calcium and magnesium in a process called membrane softening.

At the finest end of the filtration scale is reverse osmosis, which also is the most expensive of the fine filtration processes. It is used only on the most difficult of raw waters such as the reduction of dissolved ions in water. The method separates out particulates less than 0.001 mm.

Reverse osmosis uses a semi-permeable membrane through which the water to be purified is forced under pressure. The membrane repels most of the other dissolved materials. One significant application of reverse osmosis involves the desalinization of seawater or brackish underground aquifers. A plant using this process has been in operation on Marco Island, Fla., for a number of years, supplementing other sources of drinking water.

References are available at www.waterinfocenter.com.

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