

Chlorine Gas vs. Sodium Hypochlorite: What's the Best Option?

Mounting concerns about the safety, effluent toxicity, air emissions, and bioterrorism potential of chlorine gas use are compelling water treatment facilities to explore alternative disinfection systems.

BY JENY SHAH AND NAEEM QURESHI

CHLORINE GAS IS TOXIC and poses dangers to the public and operations staff. Originally, concern was for worker safety and accidental release of chlorine gas, but after Sept. 11, new concerns of deliberate attacks on

water systems emerged. The Federal Bureau of Investigation and the Department of Homeland Security have raised questions about chlorine gas storage and transportation because of its explosive nature and the use of the gas in explosive "chlorine bombs" in the Iraq war.

REGULATIONS

Legislation to bring water utilities under DHS Chemical Security Rules and Regulations may be introduced in Congress. Such legislation would authorize DHS to order water utilities to prepare Security Vulnerability Assessment and Site Security

Table 1: Comparison of Selected Disinfection Systems

Lakeville considered several disinfection alternatives based on its finished water quality and other considerations.

Disinfectant	Advantages	Limitations
Chlorine Gas	<ul style="list-style-type: none"> ■ Highly effective against most pathogens ■ Provides "residual" protection required for drinking water ■ Operationally the most reliable ■ Generally the most cost-effective option 	<ul style="list-style-type: none"> ■ By-product formation (THMs, HAAs) ■ Special operator training needed ■ Additional regulatory requirements (USEPA's Risk Management Program) ■ Not effective against <i>Cryptosporidium</i>
Sodium hypochlorite (5–15% FAC)	<ul style="list-style-type: none"> ■ Same efficacy and residual protection as chlorine gas ■ Fewer training requirements than chlorine gas ■ Fewer regulations than chlorine gas 	<ul style="list-style-type: none"> ■ Limited shelf-life ■ Same by-products as chlorine gas, plus bromate and chlorate formation ■ Higher chemical costs than chlorine gas ■ Corrosive, requires special handling ■ Crystallizes and can clog pipes, pumps, and valves
Calcium hypochlorite (65% FAC)	<ul style="list-style-type: none"> ■ Same efficacy and residual protection as chlorine gas ■ Much more stable than sodium hypochlorite allowing long-term storage ■ Fewer safety regulations 	<ul style="list-style-type: none"> ■ Same by-products as chlorine gas ■ Higher chemical costs than chlorine gas ■ Fire or explosive hazard if handled improperly



Chlorine is a toxic gas, so there's a risk of a release associated with its use. The problem is avoided by the use of sodium hypochlorite, which eliminates the danger of large-scale gas leaks from high-pressure chlorine cylinders and containers.

Plans for DHS approval. Under this program, DHS might ask utilities to reexamine their water disinfection choices based on a vulnerability assessment, threshold quantities of hazardous chemicals used by the system, location of water treatment plants, population served by the utility, and on-site controls used by the system.

In anticipation of a DHS program, many US water utilities are now examining their use of disinfectants, conducting comprehensive vulnerability assessments, and taking actions to protect against potential water supply contamination or service disruption. Regulations also require treatment facilities to prepare

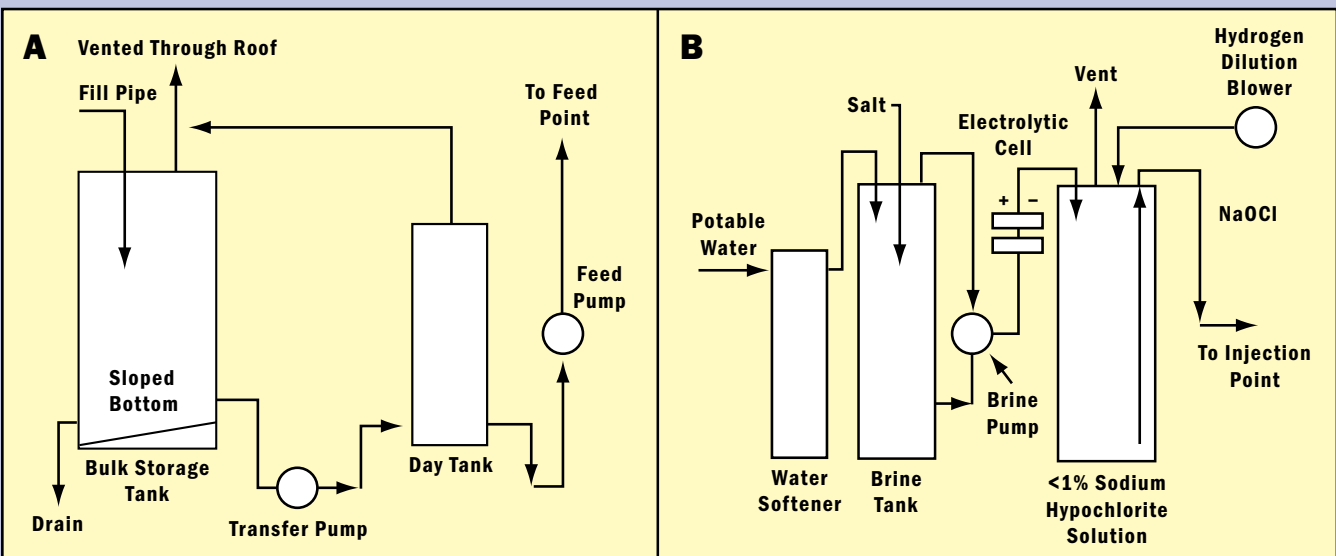
and regularly update a Risk Management Plan to identify chlorine gas health risks and an Emergency Response Plan in the event of a chlorine leak.

ALTERNATIVE TECHNOLOGIES

To minimize the risks associated with handling, storing, and using toxic

Sodium Hypochlorite System Schematics

A commercial system (A) requires bulk storage of chemicals, but an on-site generated system (B) requires little storage because sodium hypochlorite solution can be generated as needed. However, the capital cost of an on-site generation system is nearly three times the cost of a commercial system.



PHOTOGRAPHS: MELANIE SCHIFF, AWWA

Disinfection

Table 2. Capital Cost Comparison of Chlorine Gas and Sodium Hypochlorite Disinfection Systems

Because system benefits are similar and the capital cost of an on-site system is much higher, Lakeville opted to use commercially available NaOCl as an alternative to chlorine gas disinfection.

Disinfection System	Chlorine Gas	Commercial NaOCl	On-Site Generated NaOCl (average commercial system cost)
Cost of equipment	\$5,000	\$171,200	\$488,300
Cost required to modify existing layout	–	–	\$20,000
Cost of changing pipes to feed chemicals	–	\$10,000	\$10,000
Cost of installation	\$2,000	\$85,600	\$244,150
Total Capital Cost	\$7,000	\$266,800	\$762,450

chlorine gas and to address DHS concerns, the city of Lakeville, Minn., conducted a study to evaluate alternative disinfection technologies. The city of Lakeville provides water to more than 50,000 residents. The treatment plant was built in 1998 and expanded in 2001 to

increase capacity from 10 mgd to a rated capacity of 20 mgd. Another expansion will increase plant capacity to 30 mgd by 2011.

Using gravity filters to produce up to 1.14 mil gal/hr, the Lakeville plant uses chlorine gas for disinfection because

it is cost-effective and can inactivate a range of pathogens, sustain residual disinfection properties, and control taste and odor problems. The study evaluated alternative disinfection systems for the city's water treatment plant, considering the plant's existing system, safety, security, cost-efficiency, and finished water quality.

The Lakeville study didn't evaluate ultraviolet, ozone, chloramine, or chlorine dioxide systems based on site and cost constraints. As detailed in Table 1 (page 24), calcium hypochlorite [Ca(OCl)₂] and sodium hypochlorite (NaOCl) systems provide similar benefits, but Ca(OCl)₂ is more hazardous because of a higher available percentage of chlorine [65 percent for Ca(OCl)₂ vs. 5–15 percent for NaOCl] and a higher capital cost. Therefore, the study focused on NaOCl, a proven technology that, like chlorine gas, provides residual protection but is safer than chlorine gas and less expensive than all other alternative disinfection systems. Installing an NaOCl system would require the city of Lakeville to make few modifications to its existing system, and finished water quality would be similar to what is presently produced.

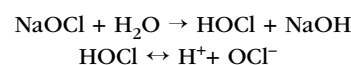
Table 3. Annual Cost Comparison for Operating and Maintaining Disinfection Systems

The amounts are shown in 2007 dollars for Lakeville's existing 20-mgd plant.

Disinfection System	Chlorine Gas	Commercial NaOCl	On-Site Generated NaOCl (average commercial system cost)
Cost of chemicals	\$24,120	\$60,780	\$47,250
Cost of electricity	–	–	\$8,910
Cost of electrodes	–	–	\$10,000
Cost of maintenance	\$4,500	\$6,330	\$4,908
Total O&M Cost	\$28,620	\$67,110	\$71,068

SODIUM HYPOCHLORITE

NaOCl, also known as liquid bleach, is a chemical compound that adds chlorine to water. When added to water, NaOCl undergoes a chemical reaction that forms hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻). The sum of HOCl and hypochlorite ions is free available chlorine (FAC), which acts as a disinfectant.



The main advantage of selecting NaOCl over chlorine gas is that the disinfectant is produced and stored in liquid form, eliminating the danger of large-scale gas leaks from high-pressure

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Table 4. Total Present Worth Analysis for a 20-mgd Sodium Hypochlorite Disinfection System

The average capital cost of installing a new on-site NaOCl system (\$762,450) is nearly three times the cost of a commercially available NaOCl system (\$266,800).

Disinfection System	Chlorine Gas	Commercial NaOCl	On-Site Generated NaOCl (average commercial system cost)
Capital cost	—	\$266,800	\$762,450
Present-worth O&M cost	\$328,270	\$769,750	\$815,140
Total Present Worth	\$328,270	\$1,036,550	\$1,577,590

chlorine cylinders. With the plant's conversion to NaOCl, the city will require fewer safety regulations and won't be required to develop and maintain a Risk Management Plan.

Commercially purchased NaOCl contains 5–15 percent FAC; NaOCl generated on-site contains less than 1 percent FAC. Both systems were evaluated. The figures on page 25 compare the schematics of each, with chemical storage requirements and capital cost being the main difference.

Commercially obtained chemicals require bulk storage of a 30-day supply, based on the Lakeville plant's demand. Chemicals generated on-site require little storage, because NaOCl can be generated as needed. However, the capital cost of an on-site generation system—which entails installing an entire system, including salt storage and electricity—is nearly three times the cost of a commercial system.

Sodium hypochlorite is a form of chlorine. Because the dosage is calculated based on the amount of chlorine and residual chlorine required in finished water, there won't be any difference in the inactivation of organisms or the quality of finished water.

Gaseous chlorine reacts as an acid, whereas hypochlorite solutions tend to

be slightly alkaline. Because gaseous Cl₂ has low pH, it depresses the pH of drinking water. On the other hand, the presence of caustic soda in sodium hypochlorite increases the water's pH. This difference exists only at the point of disinfectant application and when the chemicals are blended in the water. There isn't a significant change in the finished water's pH.

LIMITATIONS

NaOCl limitations include

- **Scaling:** The tendency of NaOCl solution to be alkaline can produce a scaling potential in water with excessive hardness levels. Phosphate can be added to prevent scaling.
- **Corrosivity:** NaOCl can be extremely corrosive to wood and most metals, so it's important to store the solution in plastic, fiberglass, rubber-lined containers or tanks. Piping and pumping equipment must also be made of corrosion-resistant materials.
- **Degradation:** NaOCl degrades over time, resulting in reduced strength. Periodic monitoring is required to adjust feed rates to compensate for this effect.
- **Piping:** The piping and fittings must be made of rigid PVC or CPVC, not metal. Piping must be assembled

carefully to protect against leaks at connections.

COST COMPARISON

The preliminary cost of an NaOCl system includes NaOCl dosage, storage within existing structures, chemical feed system, capital cost of system conversion, and operating and maintenance costs. Table 2 compares the capital costs of chlorine gas, commercial NaOCl, and on-site NaOCl generation. Table 3 compares the two systems' operating and maintenance costs. The amounts are shown in 2007 dollars for the existing 20-mgd plant. Table 4 shows the approximate amount that the city of Lakeville must invest today for its existing 20-mgd treatment plant to produce the designated amount after 20 yr at an interest rate of 6 percent.

THE BOTTOM LINE

The study concluded that an NaOCl system is the best alternative disinfection system for the Lakeville water treatment plant, because it provides residual protection and is safer and less hazardous than chlorine gas and less expensive than all other alternative disinfection systems.

NaOCl can be purchased commercially or generated on-site, with each method offering the same benefits except for chemical storage requirements. Commercially available NaOCl requires chemical storage space and careful dosing and storage because of potential chemical degradation. On-site generation systems require little storage of chemicals, so degradation isn't a problem. The average capital cost of installing a new on-site NaOCl system (\$762,450) is nearly three times the cost of a commercially available NaOCl system (\$266,800). Because system benefits are similar and the capital cost of an on-site system is much higher, the city of Lakeville opted to use commercially available NaOCl as an alternative to chlorine gas disinfection.