Comparing Chlorine Disinfection Methods

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Up until the late 1970s, chlorine was virtually the only disinfectant used to treat drinking water. Chlorine was considered an almost ideal disinfectant, based on its proven characteristics:

• Effective against most known pathogens

• Provides a residual to prevent microbial re-growth and protect treated water throughout the distribution system

• Suitable for a broad range of water quality conditions

• Easily monitored and controlled

• Reasonable cost

More recently, drinking water providers have faced an array of new challenges, including:

Treating resistant pathogens such as Giardia and Cryptosporidium

Minimizing disinfection by-products

New environmental and safety regulations and

Strengthening security at treatment facilities

To meet these new challenges, water system managers must design unique disinfection approaches to match each system's characteristics and source water quality. While chlorination remains the most commonly used disinfection method by far, water systems may use alternative disinfectants, including chloramines, chlorine dioxide, ozone, and ultraviolet radiation. No single disinfection method is right for all circumstances, and in fact, water systems may use a variety of methods to meet overall disinfection goals at the treatment plant, and to provide residual protection throughout the distribution system.

The sections below describe various disinfection technologies, and discuss the major advantages and limitations associated with each.

CHLORINATION

Chlorine is applied to water in one of three forms: elemental chlorine (chlorine gas), hypochlorite solution (bleach), or dry calcium hypochlorite. All three forms produce free chlorine in water.

Advantages

• Highly effective against most pathogens

• Provides a residual to protect against recontamination and to reduce bio-film growth in the distribution system

- Easily applied, controlled, and monitored
- Strong oxidant meeting most preoxidation objectives
- Operationally the most reliable
- The most cost-effective disinfectant

Limitations

- By-product formation (THMs, HAAs)
- Will oxidize bromide to bromine, forming brominated organic by-products
- Not effective against Cryptosporidium
- Requires transport and storage of chemicals

Elemental Chlorine

Elemental chlorine is the most commonly used form of chlorine. It is transported and stored as a liquefied gas under pressure. Water treatment facilities typically use chlorine in 100 and 150-lb cylinders or one-ton containers. Some large systems use railroad tank cars or tanker trucks.

Advantages

- Lowest cost of chlorine forms
- Unlimited shelf-life

Limitations

- Hazardous gas requires special handling and operator training
- Additional regulatory requirements, including EPA's Risk Management Program and the Occupational Safety and Health Administration's Process Safety Management program

Sodium Hypochlorite

Sodium Hypochlorite, or bleach, is produced by adding elemental chlorine to sodium hydroxide. Typically, hypochlorite solutions contain from 5 to 15% chlorine, and are shipped by truck in one to 5,000 gallon containers.

Advantages

- Solution is less hazardous and easier to handle than elemental chlorine
- Fewer training requirements and regulations than elemental chlorine

Limitations

• Limited shelf-life

• Potential to add inorganic by-products (chlorate, chlorite and bromate) to water

• Corrosive to some materials and more difficult to store than most solution chemicals

• Higher chemical costs than elemental chlorine

Calcium Hypochlorite

Calcium hypochlorite is another chlorinating chemical used primarily in smaller applications. It is a white, dry solid containing approximately 65% chlorine, and is commercially available in granular and tablet forms.

Advantages

• More stable than sodium hypochlorite, allowing longer storage

• Fewer training requirements and regulations than elemental chlorine

Limitations

• Dry chemical requires more handling than sodium hypochlorite

• Precipitated solids formed in solution complicate chemical feeding

• Higher chemical costs than elemental chlorine

• Fire or explosive hazard if handled improperly

• Potential to add inorganic by-products (chlorate, chlorite and bromate) to water

Onsite Hypochlorite Generation

In recent years some municipalities have installed on-site hypochlorite generators that produce weak hypochlorite solutions (~0.8%) using an electrolytic cell and a solution of salt water.

Advantages

• Minimal chemical storage and transport

Limitations

• More complex and requires a higher level of maintenance and technical expertise

• High capital cost

• Operating costs are often higher than for commercial hypochlorite

• Requires careful control of salt quality

• Weak solution requires high volume chemical feed and control

• By-products in generated hypochlorite may be difficult to monitor and control

• System backup may be more difficult and costly

CHLORINE-BASED ALTERNATIVE DISINFECTANTS

Chloramines

Chloramines are chemical compounds formed by combining a specific ratio of chlorine and ammonia in water. Because chloramines are relatively weak as a disinfectant, they are almost never used as a primary disinfectant. Chloramines provide a durable residual, and are often used as a secondary disinfectant for long distribution lines and where free chlorine demand is high. Chloramines may also be used instead of chlorine in order to reduce chlorinated by-product formation and to remove some taste and odor problems.

Advantages

• Reduced formation of THMs, HAAs

• Will not oxidize bromide to bromine forming brominated by-products bn

• More stable residual than free chlorine

• Excellent secondary disinfectant, has been found to be better than free chlorine at controlling coliform bacteria and biofilm growth

• Lower taste and odor than free chlorine

Limitations

• Weak disinfectant and oxidant

• Requires shipment and handling of ammonia or ammonia compounds as well as chlorinating chemicals
• Ammonia is toxic to fish, and may pose problems for aquarium owners
• Will cause problems for kidney dialysis if not removed from water

Chlorine Dioxide

Chlorine dioxide (ClO 2) is generated on-site at water treatment facilities. In most generators sodium chlorite and elemental chlorine are mixed in solution, which almost instantaneously forms chlorine dioxide. Chlorine dioxide characteristics are quite different from chlorine. In solution it is a dissolved gas, which makes it largely unaffected by pH but volatile and relatively easily stripped from solution. Chlorine dioxide is also a strong disinfectant and a selective oxidant. While chlorine dioxide does produce a residual it is only rarely used for this purpose.

Advantages

• Effective against Cryptosporidium

• Up to five times faster than chlorine at inactivating Giardia

• Disinfection is only moderately affected by pH

• Will not form chlorinated by-products (THMs, HAAs)

• Does not oxidize bromide to bromine (can form bromate in sunlight)

• More effective than chlorine in treating some taste and odor problems

• Selective oxidant used for manganese oxidation and targeting some chlorine resistant organics

Limitations

• Inorganic by-product formation (chlorite, chlorate)

• Highly volatile residuals

• Requires on-site generation equipment and handling of chemicals (chlorine and sodium chlorite)

• Requires a high level of technical competence to operate and monitoring equipment, product and residuals

• Occasionally poses unique odor and taste problems

• High operating cost (chlorite chemical cost is high)

NON-CHLORINE ALTERNATIVE DISINFECTANTS

Ozone

Ozone (O 3) is generated on-site at water treatment facilities by passing dry oxygen or air through a system of high voltage electrodes. Ozone is one of the strongest oxidants and disinfectants available. Its high reactivity and low solubility, however, make it difficult to apply and control. Contact chambers are fully contained and non-absorbed ozone must be destroyed prior to release to avoid corrosive and toxic conditions. Ozone is more often applied for oxidation rather than disinfection purposes.

Advantages

• Strongest oxidant/disinfectant available

• Produces no chlorinated THMs, HAAs

• Effective against Cryptosporidium at higher concentrations

• Used with Advanced Oxidation processes to oxidize refractory organic compounds

Limitations

• Process operation and maintenance requires a high level of technical competence

• Provides no protective residual

• Forms brominated by-products (bromate, brominated organics)

• Forms non-halogenated by-products (ketenes, organic acids, aldehydes)

• Breaks down more complex organic matter; smaller compounds can enhance microbial regrowth in distribution systems and increase DBP formation during secondary disinfection processes.

• Higher operating and capital costs than chlorination

• Difficult to control and monitor particularly under variable load conditions

Ultraviolet Radiation

Ultraviolet (UV) radiation, generated by mercury arc lamps, is a non-chemical disinfectant. When UV radiation penetrates the cell wall of an organism, it damages genetic material, and prevents the cell from reproducing. Although it has a limited track record in drinking water applications, UV has been shown to effectively inactivate many pathogens while forming limited disinfection by-products.

Advantages

• Effective at inactivating most viruses, spores and cysts

• No chemical generation, storage, or handling

• Effective against Cryptosporidium

• No known by-products at levels of concern

Limitations

• No residual protection

• Low inactivation of some viruses (reoviruses and rotaviruses)

• Difficult to monitor efficiency

• Irradiated organisms can sometimes repair and reverse the destructive effects of UV through a process known as photo-reactivation

• May require additional treatment steps to maintain high-clarity water

• Does not provide oxidation, or taste and odor control

• High cost of adding backup/emergency capacity

• Mercury lamps may pose a potable water and environmental toxicity risk

The Future of Chlorine Disinfection

In response to new regulations, emerging science on microbial contaminants, as well as safety and security concerns related to treatment chemicals, water system managers will continue to evaluate chlorine and other disinfection methods. Despite these challenges, a number of factors indicate that drinking water chlorination will remain a corner-stone of waterborne disease prevention.

• Disinfection is unquestionably the most important step in drinking water treatment, and chlorine's wide range of benefits cannot be provided by any other single disinfectant.

• It is uncertain that alternative disinfectants reduce potential DBP risks significantly (IPCS 2000). All chemical disinfectants produce by-products. Generally, the best approach to control disinfection by-products is to remove natural organic precursors prior to disinfection (EPA 2001).

• To comply with the forthcoming Long Term 2 Enhanced Surface Water Treatment Rule, some systems with high levels of Cryptosporidium in their source water may choose to adopt alternative disinfection methods (e.g., chlorine dioxide, ozone, or UV). However, most water systems are expected to meet disinfection requirements without changing treatment technologies.

• The U.S. EPA's forthcoming Groundwater Rule, as well as efforts to strengthen Canadian drinking water standards following the E coli. outbreak in Walkerton, ON will likely increase the use of chlorination for ground water systems.

• Only chlorine-based disinfectants provide residual protection, an important part of the multi-barrier approach to preventing waterborne disease.

• World leaders increasingly recognize safe drinking water as a critical building block of sustainable development (see Sidebar). Chlorination can provide cost-effective disinfection for remote rural villages and large cities alike, helping to bring safe water to those in need.

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