Grundfos Disinfection Basics

By Harland R Pond, Business Development Manager – Water Treatment

From utility water to wastewater, whether used in industrial processes or for drinking, disinfection plays a prominent role in providing safe and useable water. Water free from pathogens and other microorganisms ensures processes run efficiently and people are kept safe from disease.

But when it comes to disinfection, there are a variety of options, a wide selection of chemicals or treatments one can use. In this article we will succinctly summarize the key aspects of different disinfectant solutions. Foremost we want to be clear that there is no perfect disinfectant. Each approach has clear advantages and drawbacks. Only by understanding the application, finances, the risks and the benefits of each approach can one select the best fit for their facility.

Disinfection Defined

First, let us be clear on the definition of disinfection compared to other words we often hear:

- ***Disinfection*** *is a reduction of microorganisms or germs by a factor of at least* 10^5 *or* ***99.999% elimination***
- ***Sterilization*** *is a* 10^6 *reduction or* ***99.9999% elimination***
- ***Sanitization*** *is a selective reduction is specific microorganisms (think salmonella)*

The EPA and state regulators may further define disinfection based on how it is applied, i.e maintain a 1.0 mg/mL residual of Cl_2, etc. Also, certain applications may use disinfectants but never reach the 99.999% elimination goal, such as in cooling towers.

Different Targets

Before one looks at different approaches, it must be clear that there are different types of Microorganisms we target in water. We generalize these into 3 different major groups:

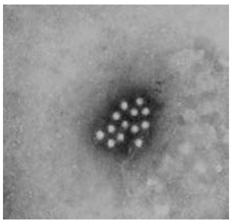

Fig 1 Virus: infectious agent that replicates itself

25-300nm
Ex: Hepatitis A

Fig 2 Bacteria: single cell microorganisms with no nucleus

.5-5µm
Ex: Legionella

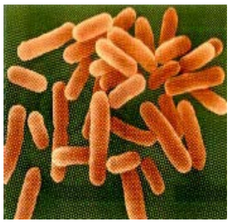

Fig 3 Protozoans: single-cell organisms with nucleus that typically move

5-20µm
Ex: Giardia

Each organism has a complicated biology and grows in different ways and in different environment. They respond differently to treatment, and can even become immune over time.

Different Needs – Different Disinfectants

With a broad variety of applications, microorganisms and process needs, there are many different requirements for disinfection treatment. A drinking water plant needs long lasting treatment that provides safe water all the way down the pipe. A cooling tower needs to be free of microbiology that forms slime on heat exchangers.

There are two major approaches to disinfection: physical treatment and chemical. We are often familiar with physical treatment; boiling your water to kill germs. We often forget that alcohol is one of the most widely used disinfectants – but not in water. Here is a basic list of disinfection treatments:

Physical Methods

- Dry heat
- Wet heat
- Filtration
- Radiation

Chemical Methods

- Halogen compounds
- Ozone / Peroxy compounds
- Quats / amphoteric tensides
- Alcohols / aldehydes
- Phenols / biguadinides

Do not worry about most of these, they are either not common in water, or are a technical approach to non-organic biocides – typically in utility or process water treatment.

Common Water Treatment Disinfectants

There is no single, magic disinfectant. All have their own strengths and weaknesses; the key is to understand these. We will now take a look at some of the most common water treatment disinfectants and their individual characteristics. Figure 4 summarizes these approaches into one single chart with the advantages and drawbacks of each platform. We have provided basic rankings to help assist you in understanding each approach. These are in no means definitive, but should provide some basic comparisons.

Chlorine

Chlorine gas is one of the earliest water disinfectants, with the first continuous application in Belgium around 1900. It was used in the US in 1912, but standardized for water treatment in 1918.

Physical

Cl_2 is a gas, although sometimes it is stored as a liquid for transport. It is educted into water from cylinders under vacuum. Chlorine is not the disinfectant but rather the neutral hypochlorous acid (HClO) is, which oxidizes organism membranes and other organic compounds.

Safety/Risk (☠☠☠)

Cl_2 is rather dangerous to work with, and was used as a poison in war. Primarily the issue is inhalation of the gas that causes severe lung damage. It can be safely fed, but requires strong safety procedures.

Effectiveness (+)

Chlorine is not that effective in disinfecting compared to other approaches, but very effective against bacteria under neutral conditions.

Cost ($)

The gas itself is fairly cheap, although large systems require a significant equipment investment.

Residual (🕑🕑)

Chlorine has a moderate lasting effect in water, decent for distribution networks.

Other effects

Chlorine has two major drawbacks. The first is it is pH dependent, dissociating to ClO^- above pH 6.5 or Cl_2 below pH 3.5. This makes it ineffective in more basic water. In fact a rise from pH 7 to 8 requires double the amount of Cl_2 to maintain effectiveness! This increases the use of Cl_2 in neutral water.
Secondly, Cl_2 in water can create dangerous byproducts such as THMs (tri halo methanes), chlorophenols and AOXs which can cause cancer or other issues.

Sodium Hypochlorite

Sodium hypochlorite, or bleach, was developed in the 19th Century and used increasingly as a disinfectant in the last half Century. It is the most common water disinfectant in the US, and chemical pumped with chemical feed pumps.

Physical

Bleach is a stabilized salt solution of sodium hypochlorite, from which chlorine gas dissociates solution It is available in a variety of strengths, the strongest being 12.5%, although 5% is often used in water applications. Caustic and metals are part of the solution, to stabilize it at a high pH (near 13) and as byproducts. Like chlorine, hypochlorous acid (HClO) is the actual disinfectant, with sodium hypochlorite converting to the acid and caustic in water. Bleach can be produced on location, using electrochlorination. Onsite Sodium Hypochlorite Generators (OSHG) generate bleach using salt and water with electricity to create a purer and dilute, stable form of bleach. Hydrogen gas is typically a by-product and must be handled safely.

Safety/Risks (☠)

Bleach is much safer as a chlorine agent, with fewer gas issues. However the liquid is very caustic and still oxidative. This can cause skin damage. Additionally, the liquid off-gasses naturally and can cause breathing problems. OSHG units can eliminate chlorine handling, and a dilute bleach solution is very safe to use. However, the handling of hydrogen must be done carefully, or else explosions can occur in equipment. Often rooms are required to be explosion proof, depending on the equipment.

Effectiveness (+)

Bleach, like chlorine, is not that effective in disinfecting compared to other approaches. Often bleach from OSHG generators is purer, eliminating caustic agents (raises pH) and metals.

Cost ($$)

Bleach is relatively less expensive, although customers pay for water to be shipped. The strength of bleach decreases with time – especially in warmer weather – decreasing the cost value. Chemical feed and control equipment is required for proper feed. OSHG equipment has significant capital costs, but can drastically reduce operation costs because of the cheap electricity and salts. Plus operators do not need to ship water or have degrading bleach. Economics can be balanced easily with operational cost savings.

Residual (◷ ◷)

Bleach has a moderate lasting effect in water, decent for distribution networks.

Other effects

Bleach has the same issues as chlorine such as pH dependence and byproducts such as THMs (tri halo methanes), chlorophenols and AOXs. There are also feed issues related to the off-gassing tendencies of bleach. These can cause especially diaphragm pumps to lock up with gas and stop feed. However, even peristaltic pumps can be inaccurate and cause premature failure with bleach off-gassing. Equipment like off-gassing valves or peristaltic pumps can help. However system design can be tremendously helpful.

Calcium Hypochlorite

Calcium hypochlorite is a portable form of hypochlorous acid disinfection, a solid bleaching agent that offers some advantages over bleach or chlorine. It is very common in the swimming pool market where it is easily handled by home consumers. In 1894, Moriz Traube recognized it as being able to render water 'germ free', making it one of the first recognized disinfectants.

Physical

Calhypo is a calcium salt, yellow-white in color, and is available in powdered or large tablet form. It dissolves readily in water and has twice the available chlorine than bleach per molecule. Often it is packed with caking agents in a pellet form, which requires regulated dissolving for drinking water. The disinfectant is still hypochlorous acid with all the pros and cons associated with it.

Safety/Risks (☠)

Handling solid tablets is safer and easier than liquids or bleaches, and means this oxidant is safer to handle. However it can still be dangerous when handled (see the 3 on the square below). But in typical applications safety is better than other options.

Effectiveness (+)

Similar to bleach and chlorine, the chemical is mildly effective.

Cost ($$)

Tablets are a much more expensive form of chemistry, although customers do not ship water associated with bleach. But there are a selective numbers of vendors in the US and the price per pound can be high.

Residual (◷◷)

Calhypo has a moderate lasting effect in water, decent for distribution networks.

Other effects
Calhypo has the same issues as chlorine such as pH dependence and byproducts such as THMs (tri halo methanes), chlorophenols and AOXs. Additionally there can be feed problems. It is difficult to manage the dissolving of the tablet effectively in water, and often chlorine residuals can swing. The tablets often have caking agents and other chemicals that can clog or hamper the dissolving, feed equipment.

Chlorine Dioxide
Chlorine dioxide is an extremely effective oxidant, used in bleaching applications since 1920 and in drinking water since 1944. Although evidence point to use in water in Belgium in 1900. Its disinfection and by-product properties are much better than bleach and chlorine, however there are some unique challenges.

Physical
Chlorine dioxide is a gaseous chemical, dissolved in water for disinfection. In fact it was used in the disinfection of the Senate Hart office building and Postal Facility for anthrax remediation – in gas form. It is stable in water up to about 30g/L, after which it can leave solution and be explosive. Gas concentrations are also highly oxidative, strong and can be explosive above 300g/m^3. However in low concentrations the chemical is very safe and effective. ClO_2 has a free electron that acts as a free radical, improving its strength. The chemical must be produced on site, as it cannot be transported in solution. There are a variety of ways to manufacture ClO_2, each with some advantages and drawbacks, including using acid and sodium chlorite; chlorine gas and sodium chlorite; and electrogeneration with sodium chlorite.

Safety/Risks (☠☠)
ClO_2 can cause severe breathing problems and irritation to skin and lungs. In strong water concentrations it can bleach and damage skin. The explosive nature has been mentioned, but the precursor chemicals, when improperly mixed can be extremely reactive and have been known to cause terrific damage. Sodium chlorite is also combustable on organic materials – like leather. In solution ClO_2 goes from light yellow-green color, to yellow-orange and finally to red as concentration increases.

Effectiveness (++)
Chlorine dioxide is extremely effective against organic compounds (such as for color and odors); microorganisms like bacteria, viruses, etc.; and biofilm. ClO_2 is an excellent biopenetrant and dispersant, able to breakup biofilms and slime, making it excellent with heat exchangers and for legionella control. The solution is also pH independent, able to work at low and high pHs, better for cooling towers (eliminates acid feed), drinking water and with low-pH biofilms. Typically the chemical is 2.5 x's more effective than bleach or chlorine.

Cost ($$$)
The chemicals to make ClO_2 are relatively expensive, especially sodium chlorite. But the real cost comes from the requirement of capital generation and safety equipment to generate the materials on site. However, much less is used compared with other disinfectants.

Residual (🕒🕒🕒)
ClO_2 has a strong lasting effect in solution, although it will degrade over time to chlorite and salts. This chlorite reversion restricts feed residuals to 0.8 ppm in drinking water, so as the 0.4ppm chlorite limit is not passed. The chemical is safer for discharge to waterways.

Other effects
Users need equipment to make ClO_2 on location. This can be electrogenerators with expensive equipment, or very low cost, eduction mixers. Typically something in-between is very cost effective. However, large scale, accurate generation is typically not common for drinking water.

Ozone
Ozone (O_3) was identified in the late 19th century and recognized as a powerful oxidant. It was first primarily used in industrial applications such as for bleaching or breaking carbon bonds, but as production became cheaper, became widely used in water treatment.

Physical
Ozone is a pale blue gas at typical temperatures, and slightly soluble in water, mostly because of its diamagnetic structure (all electrons are paired), maxing at 1 g/L. The gas can explode in high concentrations, although these are non-typical. Ozone is a strong oxidant and good for microbio and impurity removal, as also inorganic reduction. Ozone has a sharp odor, similar to chlorine, and can be detected at low levels. The chemical must be produced on-site and quickly degrades into oxygen. There are a variety of ways to manufacture O_3, but the most typical is the corona discharge method. This passes O_2 through an electrical discharge field where ozone is produced. These often can use ambient oxygen as a source, but can be susceptible to humidity and temperature variations. Some units use liquid oxygen for higher efficiency generation.

Safety/Risks (☠)
Ozone can be dangerous to people and animals, especially to organic membranes. It can cause headaches, burning eyes and respiratory issues. Most generators are not particularly dangerous because of their design and low concentration. Adequate ventilation is required. Ozone will also attack latex and plastics at low concentrations. Typically it is not stored on-site, but generated on demand. Ozone cannot be kept in drinking water and must be removed before distribution.
Effectiveness (+++)
Ozone is a powerful oxidant and very effective against microbio growth, viruses and inorganics. It will effectively remove color and odors also. It is roughly 50% more effective than Cl_2 but works much faster at killing bacteria and other growth.
Cost ($$)
Typical industrial ozone generators are not that expensive, especially if they use ambient oxygen. Yet increasing efficiencies requires added equipment. Power and maintenance costs can be quite high however.
Residual (◷)
Ozone will quickly deteriorate into O_2 in water. It must be removed however before discharge or use in drinking water. One exception is bottled water where the long transport times will ensure O_2 conversion.

UV
Ultraviolet light or UV are light waves between 200-400nm in wavelength. This range is broad, and has a variety of uses. Short wavelength UV – around 150-250nm is excellent as a germicide and was first used in 1903 to kill tuberculosis. It was first used in water disinfection in 1915 in the US. At 254nm UV will break molecular bonds within DNA to kill cells or keep them from reproducing. This is similar to a bad sunburn – but for microorganisms.
Physical
UV has a wide spectrum, but short wavelengths are important for disinfection. UV is produced in a water stream to treat water as it flows through. Typically installations balance power usage, efficiency and residence time to effectively treat water. Mercury vapor lamps emit UV at 254nm (sometimes also at 185nm for oxidation). Enough lamps are required to treat effectively. There are different lamps available that trade-off efficiency and power usage with broader spectrum light.
Production of UV is susceptible to power fluctuations, which can render treatment useless. Transformers and other equipment may be required to ensure proper treatment.
Safety ( )
UV treatment presents an issue with direct exposure, typically to eyes and skin. Proper shielding can prevent this. However, UV is also known to produce ozone in solution that can present problems.
Effectiveness (+)
UV is moderately effective, typically very good with microorganisms and preventing some of their future growth. Unclear water can present problems in treatment, and UV is not good at oxidation typically.
Cost ($$)
The majority of costs center around generation, electrical costs and bulb replacements. It is typically similar in price scope to other disinfection methods.
Residual ( )
UV is a once-through treatment system. Any post-treatment contamination will not be dealt with and therefore UV is not ideal for open systems. In drinking water networks additional residual treatment may be required.
Other effects
Solar UV testing has shown to be effective for small water amounts. This typically includes setting small water bottles in the sun for 6+ hours.

Conclusion
As you can see, there is a lot involved when selecting the proper disinfectant for an application. In drinking water applications the local agencies may dictate specific treatment requirements, however an understanding of the drawbacks and tradeoffs are required. In all cases, local code and laws will determine the proper approach.

It is important that any water treatment solution provider, a chemical treatment company, an engineering consultancy, a manufacturer, provide end-users with options to determine the best course for their facility. Remember, no single approach is ideal, and you must be prepared to find trade-offs.

We are all increasingly committed to providing safe and sustainable water for society's use. Research is constantly underway to find new solutions that eliminate past drawbacks. We encourage you to continue to learn, and hope this article has presented you a basis from where to begin.

Grundfos

Grundfos is a market leading provider of water treatment and pump solutions with a commitment to responsible, sustainable business. We provide a variety of unique technologies and approaches for disinfection and water treatment for some of the above described approaches. These include safe, OSHG systems with safe hydrogen handling; safe and dilute ClO_2 generation; a simpler, clean approach to UV; and superior bleach handling chemical feed pumps. Additionally through our Water Technologies Center in California we are constantly looking for and financially supporting new technologies.

www.grundfos.us
wt.grundfos.com

Figure 4: Table of Disinfectants

Disinfection agent	General disinfection effect	Residual effect	pH dependency	By-products	Investment cost	Advantages	Disadvantages
Chlorine (gas)	+	Hours	Extreme	Chloramines, chlorophenols, THM, AOX	++	Chlorine gas as low priced agent	Chlorine resistant germs, demanding gas storage
Chlorine (electrolytic)	+	Hours	Extreme	Chloramines, chlorophenols, THM, AOX	+	Cheap reagent (salt NaCl)	Chlorine resistant germs, salt storage
Calcium Hypochlorite	+	Hours	Extreme	Chloramines, chlorophenols, THM, AOX	+	Easy tablets with no liquid	Degradation, clogs and cost
Chlorine dioxide	++	Days	Medium	Chlorite, chlorate	++	No germ resistance, destroys biofilms	Min. two chemicals to handle
UV	+	None	None	Evtl. nitrite	++	No chemicals	Germs could regenerate after LP radiation
Ozone	+++	Minutes	Medium	Aldehydes, bromate	+++	Removal of odor, color and organic substances	Must be removed from drinking water