

Controlling microorganism colonies is important in maintaining the performance of all water systems, especially ultra-pure systems where bacterial fouling is the leading cause of contamination. Regularly monitored bacterial control equipment is a necessity.

Disinfection may occur on a continuous or a periodic (shock) basis. Continuous disinfection is preferable to keep bacterial populations from reestablishing themselves. Shock treatments are used when continuous biocide would be harmful to the end user. In shock treatment, the biocide and its by-products are flushed from the system prior to re-start. Shock treatments generally remove a bacteria population but do not prevent it from recurring. Two important considerations when using biocides are 1) concentration and 2) dwell time. The higher the concentration, the shorter the dwell time needed for effective disinfection. Other factors that affect biocide effectiveness are pH, temperature, water hardness, chemical compatibility and cleanliness issues. Most systems require cleaning before disinfection. Cleaning removes most surface bacterial film but they quickly re-establish themselves (see Disinfection).

Chlorine is the most common **oxidizing biocide** because of its low cost and high effectiveness. Its properties are well understood, accepted, and readily available. Chlorine is most effective below a pH of 7. The major disadvantage is chemical storage and handling, especially larger systems that use chlorine gas.

Chlorine is most easily continually injected at 0.2 to 2 PPM. Shock treatments are usually 100-200 PPM for 30 minutes. Higher dosages can potentially corrode metal, and can present maintenance problems with mechanical devices (e.g. pumps).

Chlorine gas (Cl₂) is the most cost-effective source of chlorine for systems over 200 gpm of water. A drawback to using the gas is that a special room for chlorine storage and injection is required along with careful safety procedures. Other issues involve chemical compatibility with piping or tubing systems.

For smaller water systems, chlorine delivery includes liquid sodium hypochlorite (NaOCl) and calcium hypochlorite. Both are available at a variety of

concentrations. Typically the price of diluted chemicals is higher than concentrated chemicals due to the added costs of special handling of the more hazardous chemicals.

Chloramines (e.g. NH_2Cl) are produced by reacting ammonia with chlorine. Chloramines are much more stable compounds when compared to chlorine, and are used in some municipalities to ensure a residual of the disinfectant remains at the end of the distribution system. The disadvantage of chloramines over chlorine is the longer contact time required for the disinfection process.

Chlorine Dioxide (ClO_2), similar to chlorine in effectiveness, is used in membrane systems where it is compatible with some membranes that normal chlorine is not. It can degrade aromatic (hydrocarbon-ring) organic compounds such as humic and folic acids from surface water sources, but it is more expensive. It is somewhat corrosive and must be handled with care. The advantage is in its stability during storage at the usual concentrations for smaller water systems.

Hydrogen peroxide (H_2O_2) is an aggressive disinfectant and does not contribute any ions to the water system. In time, hydrogen peroxide degrades into H_2O and O_2 . This can be an advantage in ultra-pure water systems such as integrated circuit (IC) manufacture where low-level ionic contamination is problematic. Hydrogen peroxide can also be used on membranes that do not tolerate chlorine. Hydrogen peroxide requires high concentrations to be effective. It must be catalyzed by iron or copper, which are not necessarily desirable in ultra-pure water systems.

Bromine (Br), in the same halogen family as chlorine, has similar disinfection properties as chlorine but cost more. Bromine is used on a limited basis, most often for the disinfection of swimming pools, as it does not burn eyes like chlorine.

Iodine (I_2) is familiar to most as emergency treatment for potable (drinking) water or as a topical sterilizing agent for minor cuts and scrapes. Iodine (I_2) is not recommended on a continuous basis for potable water because of negative effects on human thyroids. It can be used at low concentrations (0.2 PPM) to control bacteria in RO water storage systems; however, it is twice as expensive as chlorine.

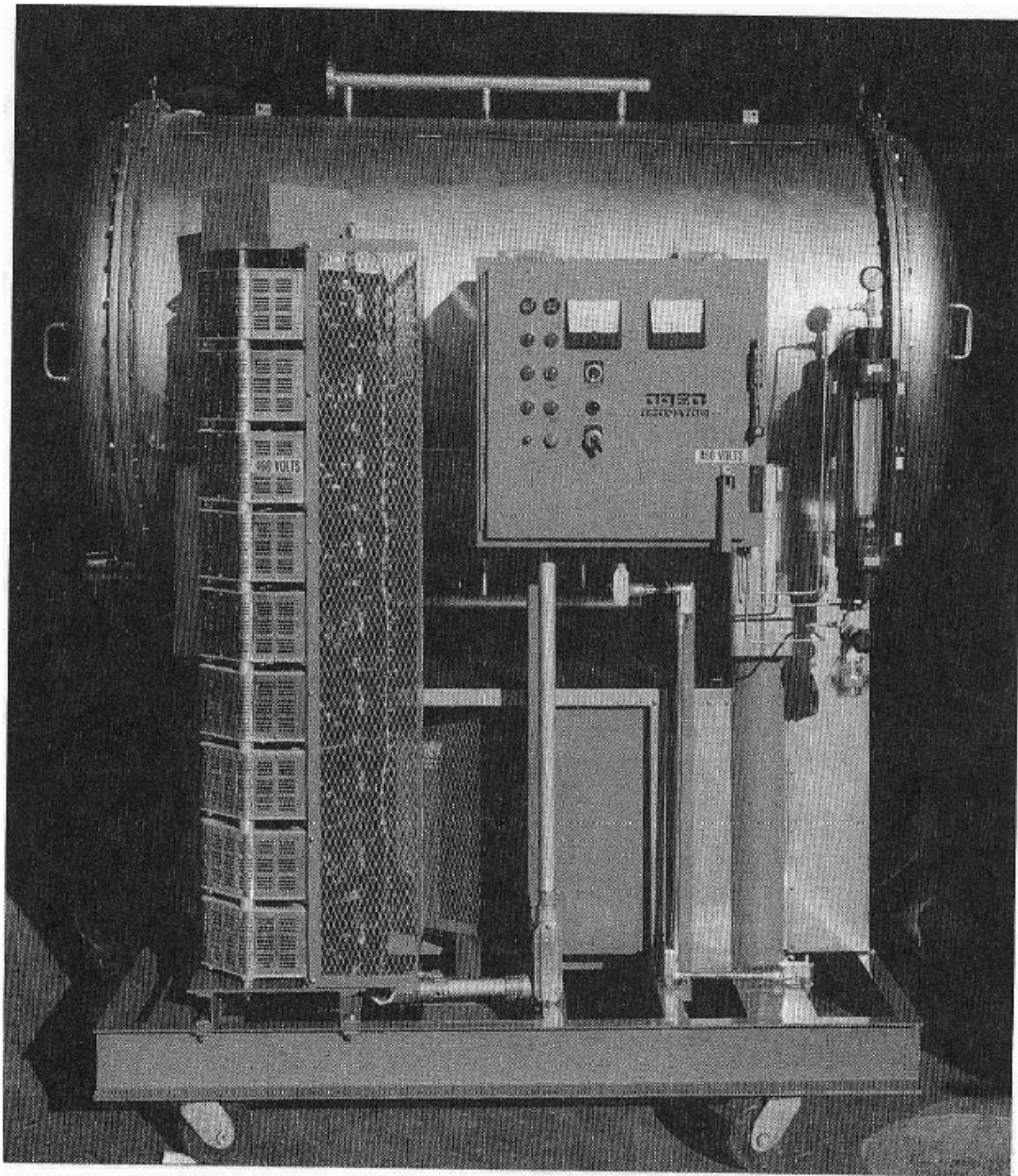


Figure 32 - Ozone Generator (Photo courtesy of Ozone Research & Equipment Corporation)

Ozone (O_3) has double the oxidizing power as chlorine gas. Ozone is made on-site by discharging high-voltage electric lamps in the presence air (Figure 32). In this process, oxygen (O_2) in the air is excited into a higher, unstable form O_3 , which is a highly reactive state of oxygen. Ozone must be injected on a continuous basis, as it has a brief half-life of 20 minutes in solution. In most applications residual ozone must be removed, prior to the water reaching the consumer, by exposing the ozonated water to **ultraviolet**

light (UV). The UV light breaks down the high-energy ozone bonds back to simple oxygen.

A relatively new disinfectant, **Peracetic acid (CH₂COOOH)** is used mainly in dialysis equipment disinfection as a replacement for formalin. Peracetic acid is compatible with some non-chlorine-tolerant membranes, and is a small enough molecule to pass through the membrane pores to disinfect the downstream side. It breaks down to acetic acid and water. Disadvantages include higher cost, instability, and lack of familiarity with existing users.

Formalin (H₂CO) has been used for years as a disinfectant because of its stability, effectiveness against a wide range of bacteria, and mild corrosivity. As a suspected carcinogen, it is being phased out due to government regulations limiting human exposure. A low concentration solution, typically 0.5%, is used as a storage agent for RO and UF membranes, ion exchange resins, and storage and distribution systems. In higher concentrations (~5%), formalin is used as a shock treatment to sanitize dialysis and other hospital systems.

Quaternary ammonium compound is most commonly used in pharmaceutical, food, and medical facilities as a sanitizing agent. They are stable, non-corrosive, non-irritating, and active against a wide variety of microbes over a wide range of pH. They may cause foaming problems in mechanical operations and form films which are difficult to remove, requiring long rinse times. Finally, they are not compatible with some types of polymer membranes.

Acid anionic **surfactants** have limited biocide activity against the gram-negative bacteria usually found in pure water systems.

Physical Treatments

Historically, **heat** is the commonly used tool for bacterial control. It is inexpensive and very effective when systems are properly engineered. Temperatures of 80°C are commonly used in pharmaceutical facilities for storage and re-circulation of USP purified and WFI water. Heat treatment above 80°C is also used to control microorganisms in activated carbon systems.

Treatment with **ultraviolet light** is a popular form of disinfection due to ease of use. Water is exposed, at a controlled rate, between ultraviolet light waves. The UV light mutates the DNA leading to bacteria destruction. With proper maintenance, UV systems are simple and reliable for a high reduction in bacteria, (99%+), and are compatible with membrane and DI systems which may be incompatible with chemicals.

UV is used to reduce microbial loading of membrane systems and to maintain low bacterial counts in high-purity water storage and re-circulation systems. If ozone has been added to water, UV is effective in destroying residual ozone molecules prior to end user application.

The disadvantage of UV is a lack of residual, as it is effective only if the microbes are in direct exposure with the UV light. Proper system design and operation is required to assure bacteria destruction. Inadequate UV light source may only mildly damage the bacteria, and allow them to re-colonize. Water should be void of suspended solids that can "shadow" bacteria, preventing adequate UV contact, hence degradation.

Most bacteria have physical diameters in excess of 0.2 μ . Thus, a 0.2 μ or smaller rated **filter** can mechanically remove most bacteria continuously from a flowing system. Point-of-use micro-filtration is commonly used in pharmaceutical, medical, and microelectronics applications as back-up against bacterial contamination. To be used as a sterilizing filter, filters must have an absolute micron rating (i.e. complete retention of particles equal to or larger than the filter micron rating), and they must be validated.

The filter must be integrity tested when in place to ensure that the filter is properly sealed and defect-free. The greatest advantage of micro-filtration is that neither chemicals nor heat are required. Filters must be changed on a regular basis to prevent the possibility of grow-through or pressure breakthrough. However there is moderate cost associated with this method.