

**The Islamic University of Gaza
Faculty of Engineering
Civil Engineering Department**

**Environmental Engineering
(ECIV 4324)**

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Water Treatment Part E

Disinfection

Pathogens can either be removed by treatment processes such as granular filtration or inactivated by disinfection agents.

Disinfection

The term disinfection in drinking- water practice refers to two activities:

- 1. Primary disinfection : the inactivation of microorganisms in the water .**
- 2. Secondary disinfection : maintaining a disinfectant residual in the treated-water distribution system (also called residual maintenance).**

CURRENT DISINFECTION METHODS

Generally, disinfectants can be classified as oxidizing agents (for example, chlorine and ozone), cations of heavy metals (silver or copper) and physical agents (heat or UV radiation). The most commonly used disinfectant is free chlorine.

CURRENT DISINFECTION METHODS

Four other common disinfectants are combined chlorine, ozone, chlorine dioxide and ultraviolet (UV) light. Combined chlorine is often limited to secondary disinfection.

Table / 8.20

Effectiveness, Regulatory Limits, Typical Application, and Chemical Source of the Five Most Common Disinfectants

Issue	Disinfectant				
	Free Chlorine	Monochloramine	Chlorine Dioxide	Ozone	UV Light
Effectiveness					
Bacteria	Excellent	Good	Excellent	Excellent	Good
Viruses	Excellent	Fair	Excellent	Excellent	Fair
Protozoa	Fair to poor	Poor	Good	Good	Excellent
Endospores	Poor to good	Poor	Fair	Excellent	Fair
Frequency of use as primary disinfectant	Most common	Common	Occasional	Very common	Increasingly common
Regulatory limit on residuals	4 mg/L	4 mg/L	0.8 mg/L	—	—
Formation of chemical by-products					
Regulated by-products	Forms 5 trihalomethanes (THMs) and 4 haloacetic acids (HAAs)	Traces of THMs and HAAs	Chlorite	Bromate	None
By-products that may be regulated in the future	Several	Cyanogen halides, nitrosodimethylamine (NDMA)	Chlorate	Biodegradable organic carbon	None known
Typical application Dose, mg/L	1–6	2–6	0.2–1.5	1–5	20–100 mJ/cm ²
Chemical source	Delivered as liquid gas in tank cars, 1 ton and 68 kg cylinders as calcium hypochlorite powder for very small applications. On-site generation from salt and water-using electrolysis.	Same sources as for chlorine. Ammonia is delivered as aqua ammonia solution, liquid gas in cylinders, or as solid ammonium sulfate. Chlorine and ammonia are mixed in treatment process.	Same sources as for chlorine. Chlorite as powder or stabilized liquid solution. ClO ₂ is manufactured with an on-site generator.	Manufactured on-site using a corona discharge in very dry air or pure oxygen. Oxygen is usually delivered as a liquid. Oxygen is also manufactured on-site in some very large plants.	Uses low pressure or low-pressure–high-intensity UV (254 nm) or medium-pressure UV (several wavelengths) lamps in the contactor.
Typical contactor	In the past was added at beginning of plant and residual carried through. Increasingly, individual contactors are used.	In the past was added at beginning of plant and residual carried through. Increasingly, individual contactors are used.	In the past was added at beginning of plant and residual carried through. Increasingly, individual contactors are used.	Has always been added in specially engineered contactors. These contactors are using more compartments.	Lamps are placed in gravity channels or in specially manufactured UV reactors. Because the contact time is so short, reactors must be tested.

DISINFECTION KINETICS

$$\frac{dN}{dt} = -K \times N$$

$$\ln \left(\frac{N}{N_0} \right) = -K \times t$$

Table / 8.21

Important Chemical Reactions Associated with Common Disinfectants

Disinfectant	Important Chemical Reactions	Considerations
Free chlorine When gaseous chlorine is added to water, it rapidly reacts with water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl). Hypochlorous acid and hypochlorite ion together are often referred to as <i>free chlorine</i> (free chlorine = HOCl + OCl⁻). Both of these chemical species are active disinfecting agents; however, hypochlorous acid (HOCl) is much more effective than OCl⁻ for disinfection.	$\text{Cl}_{2(g)} + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{HCl} \quad (8.13)$ $\text{HOCl} \rightarrow \text{H}^+ + \text{OCl}^- \quad K_a = 10^{-7.5} \quad (8.14)$	As can also be seen from the equilibrium constant for Equation 8.13 and Figure 8.16, HOCl is the predominant form of free chlorine at a pH less than 7. Consequently, a treatment plant operator will attempt to maintain the pH at 7 or slightly lower to increase the disinfection power of the added chlorine. Although chlorine disinfection is very effective and cost-advantageous, use of chlorine has some concerns. One of them is by-product formation; chlorine will react with dissolved organic matter that occurs naturally in waters to form carcinogenic THMs.

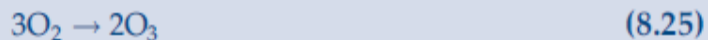
Combined chlorine When chlorine and ammonia (NH₃) are both present in water, they react to form three <i>chloramine compounds</i> (NH₂Cl, NHCl₂, NCl₃) according to the three reactions on the right. These three chloramines together are referred to as combined chlorine. (combined chlorine = NH₂Cl + NHCl₂ + NCl₃). The total chlorine residual is the sum of the combined chlorine and any free chlorine residual.	<i>Monochloramine formation:</i> $\text{HOCl} + \text{NH}_3 \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O} \quad (8.15)$ <i>Dichloramine formation:</i> $\text{HOCl} + \text{NH}_2\text{Cl} \rightarrow \text{NHCl}_2 + \text{H}_2\text{O} \quad (8.16)$ <i>Trichloramine formation:</i> $\text{NHCl}_2 + \text{HOCl} \rightarrow \text{NCl}_3 + \text{H}_2\text{O} \quad (8.17)$	The formation of these species depends upon the ratio of Cl₂ to NH₃-N. At a high ratio of Cl₂ to NH₃-N, the oxidation of ammonia to nitrogen gas and nitrate ion occurs. $3\text{HOCl} + 2\text{NH}_3 \rightarrow \text{N}_{2(\text{g})} + 3\text{H}_2\text{O} + 3\text{HCl} \quad (8.18)$ $4\text{HOCl} + \text{NH}_3 \rightarrow \text{HNO}_3 + \text{H}_2\text{O} + 4\text{HCl} \quad (8.19)$ The reactions are also dependent upon chlorine dosage, temperature, pH, and alkalinity. At low pH values, other reactions become more significant, such as these: $\text{NH}_2\text{Cl} + \text{H}^+ \rightarrow \text{NH}_3\text{Cl}^+ \quad (8.20)$ $\text{NH}_3\text{Cl}^+ + \text{NH}_2\text{Cl} \rightleftharpoons \text{NHCl}_2 + \text{NH}_4^+ \quad (8.21)$
Chlorine dioxide This chemical does not produce significant amounts of trihalomethanes (THMs) as by-products from reactions with organics.	$2\text{NaClO}_2 + \text{Cl}_{2(\text{g})} \rightarrow 2\text{ClO}_{2(\text{g})} + 2\text{NaCl} \quad (8.22)$ $2\text{NaClO}_2 + \text{HOCl} \rightarrow 2\text{ClO}_{2(\text{g})} + \text{NaCl} + \text{NaOH} \quad (8.23)$ $5\text{NaClO}_2 + 4\text{HCl} \rightarrow 4\text{ClO}_{2(\text{g})} + 5\text{NaCl} + 2\text{H}_2\text{O} \quad (8.24)$	Chlorine dioxide is explosive at elevated temperatures, on exposure to light, or in the presence of organic substances. Chlorine dioxide does not produce THMs; however, it produces inorganic products such as chlorite (ClO₂⁻) and chlorate (ClO₃⁻), which have health concerns at certain levels of exposure.

Table / 8.21**(continued)**

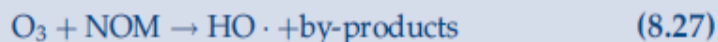
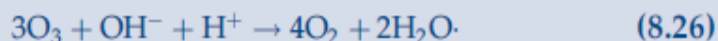
Disinfectant	Important Chemical Reactions	Considerations
Chlorine dioxide <i>(continued)</i> Chlorine dioxide also has a higher oxidizing power than chlorine; however, at neutral pH values typical of most waters, it has only about 70% of the oxidizing capacity of chlorine.		ClO_2 is generated on-site using sodium chlorite with gaseous chlorine (Cl_2), aqueous chlorine (HOCl), or acid (usually hydrochloric acid, HCl).

Ozone

Ozone is a stronger oxidant than the other three disinfectants.



Ozone can decompose to the hydroxyl radical ($\text{HO}\cdot$), which is formed by the reactions with high concentrations of hydroxide ion (OH^-) or natural organic matter (NOM).



Ozone is a highly reactive gas and decays rapidly under ambient conditions. Therefore, it has to be generated on-site, commonly by electrical discharges in the presence of O_2 .

Ozone reacts with microbes by direct oxidation or through the action of hydroxyl radicals generated as in Equations 8.26 and 8.27. Hydroxyl radicals are scavenged by carbonate species (HCO_3^- , CO_3^{2-}) and reduced metal ions (e.g., Fe^{2+} , Mn^{2+}). High pH conditions or high concentrations of organic matter favor hydroxyl radical oxidation reactions. Ozone disinfection is primarily dependent on its direct reactions, and the residual of ozone is important. Low pH, high alkalinity, low concentrations of organic matter, and low temperature will increase the stability of aqueous ozone residuals. Unfortunately, use of ozone will not result in a residual that can continue the disinfection process in the water distribution system. In addition, ozonation of waters containing bromide produces bromate (BrO_3^-), which is believed to be a carcinogen to humans.

UV radiation

This is electromagnetic radiation having a wavelength between 100 and 400 nm.

Light in the UV spectrum can be divided into vacuum UV, short-wave UV (UV-C), middle-wave UV (UV-B), and long-wave UV (UV-A).

The region of the wavelength of 200–300 nm is a germicidal range where deoxyribonucleic acid (DNA) absorbs UV.

The photons in UV light react directly with the nucleic acids in the form of DNA and damage DNA. This will inhibit further transcription of the genetic code of the cell and prevent its successful reproduction. However, microorganisms may evolve to repair UV-induced damage through photoreactivation and dark repair mechanisms. Therefore, reactivation is an important consideration in UV disinfection.

The performance of UV disinfection systems is highly influenced by dissolved substances and particulate matter in waters, which have to be considered in UV reactor design.