Lecture 8: Disinfection

Water Treatment Technology

Water Resources Engineering
Civil Engineering
ENGC 6305

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Disinfection

1. Principles of Disinfection

A. Definition of Disinfection :

- Disinfection is the destruction of pathogenic microorganisms.
- It dose not apply to nonpathogenic microorganisms or to pathogens that might be in the spore state.
- disinfection should be distinguished from sterilization. Sterilization is the destruction of all living microorganisms and especially to the spore forming organisms.
- the chemical used for disinfection is called disinfectant.

B. Disinfection Mechanisms :

- Damage to the cell wall (Ozone, Chlorine)
- Alteration of the cell permeability (phenolic compounds)
- Alteration of the colloidal nature of the protoplasm (heat, radiation)
- Alteration of the organism DAN or RNA (radiation)
- Inhibition of enzyme activity (oxidizing agents such as chlorine).

Disinfection

C. Factors affecting the disinfection process:

- Contact time between the disinfectant and the microorganisms.
- The concentration and chemistry of the disinfectant.
- The surrounding environment such as pH, temperature, and the existing of other interfering substances in the water.
- The properties of pathogens

The contact time effect is expressed by the combined Chick's Watson equation (8.1):

$$\frac{dN_t}{dt} = -k' C^n N_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8.1)$$

$\frac{dN_t}{dt}$ = rate of change in the concentration of organisms with time

k' = die – off constant

C = concentration of didinfectant

n = coefficient of dilution

N_t = number of organisms at time (t)

t = contact time

Disinfection

the inegrated form of equation 8.1 *is* :

$$\frac{N_t}{N_0} = e^{-k'C^n t} \text{ ....(8.2) } or:$$

$$\ln\frac{N_t}{N_0} = -k' C^n t \text{ ....(8.3)}$$

The linearized form of equation (8.3) *is* :

$$\ln C = -\frac{1}{n}\ln t + \frac{1}{n}\ln\left[\frac{1}{k'}\left(-\ln\frac{N_t}{N_0}\right)\right]$$

The value of (n) can be obtained by plotting (C) versus (t) on log– log paper.

D. Classification of disinfectants :

- Oxidizing agents (ozone, halogens, halogen compounds)
- Organic compounds
- physical agents (heat, UV , pH)

E. Disinfection methods :

- Chlorination
- Ozonation
- Ultraviolet Radiation (UV)

Disinfection

Example 8.1

Application of the Modified Chick/Watson Equation Given the following chlorination test survival data for *E. coli*, expressed as a percentage, determine the values of the constants in the Chick and Watson equation [Eq. (12–6)] for 99 percent reduction. The results were obtained using a batch reactor.

	Percent survival				
	Contact time, min[a]				
Free Cl,[b] mg/L	1	3	5	10	20
0.05	97	82	63	21	0.3
0.07	93	60	28	0.5	—
0.14	67	11	0.7	—	—

[a] Test conditions pH = 8.5; temp = 5°C.

[b] HOCl (hypochlorous acid) and OCl^- (hypochlorite ion). See also discussion in Sec. 12–3.

Solution

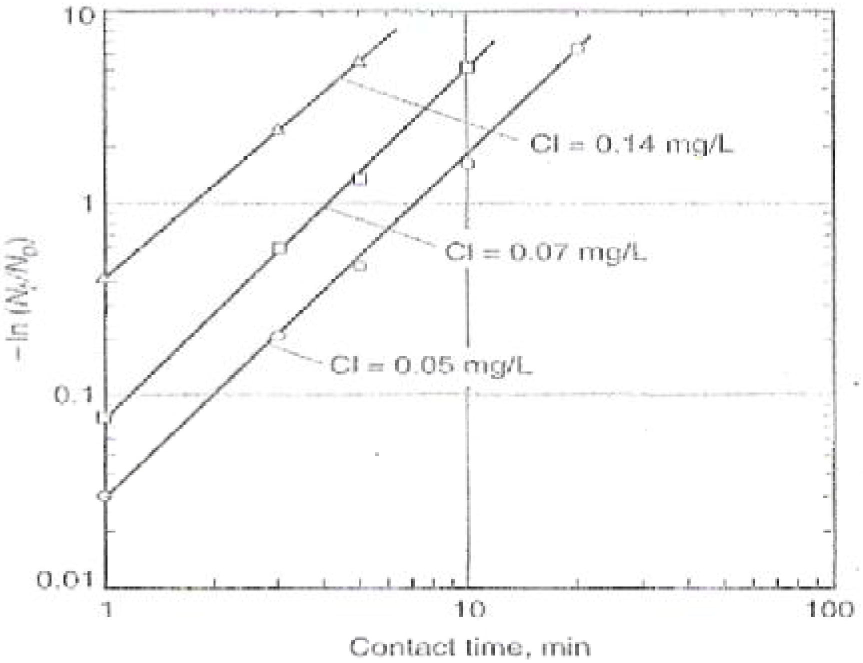
1. To determine the constants in the Chick and Watson equation form of Chick's law, convert the survival data to log removal values and then plot on arithmetic and log-log paper to determine the time required for a given degree of kill.

Disinfection

a. Convert the given percentage removal data to log removal values.

	$-\ln(N_t/N_o)$				
	Contact time, min				
Free Cl, mg/L	1	3	5	10	20
0.05	0.030	0.198	0.462	1.561	5.809
0.07	0.073	0.511	1.273	5.298	
0.14	0.400	2.207	4.962		

b. Plot the converted values on both arithmetic and log-log paper to determine the best fit of the data. After plotting the data, it was found that the data could be represented best by a straight line as shown on the following log-log plot.

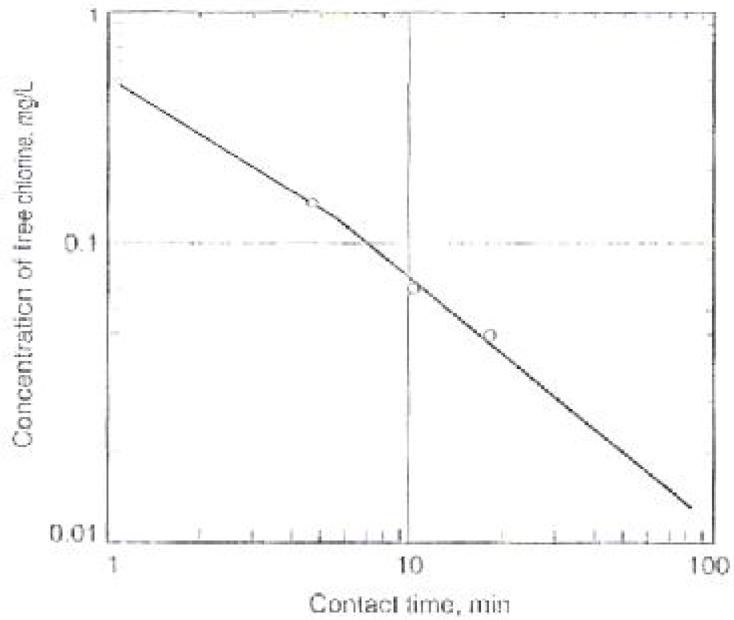


c. Determine the required contact time for a log inactivation value of 99 percent $[-\ln(N_t/N_o) = 4.61]$ for the various concentrations. The required values are:

Concentration, mg/L	Time, min
0.05	18.0
0.07	10.0
0.14	4.7

2. Determine the constants in the Chick and Watson equation using the data from Step 1.
   a. Plot the concentration versus time values determined in Step 1c.

Disinfection



b. Use the linear form of Eq. (12–7) to determine the constants

$$\ln C = -\frac{1}{n}\ \ln t + \frac{1}{n}\ \ln\left[\frac{1}{k'}\left(-\ln\frac{N_t}{N_o}\right)\right]$$

$$\ln C = -\frac{1}{n}\ \ln t + \frac{1}{n}\ (\text{constant})$$

From the above plot, the value of n equals

$$\text{Slope} = -\frac{1}{n} = -\frac{\log 0.5 - \log 0.011}{\log 100 - \log 1} = -\frac{[-0.30 - (-1.96)]}{2 - 0}$$

$$= -\frac{1.66}{2} = -0.83$$

$$n = 1.20$$

When $t = 1$, the Y-intercept $= \ln 0.5 = \frac{1}{n} \ln \left[\frac{1}{k'}\left(-\ln \frac{N_t}{N_o}\right)\right]$

$$n(\ln 0.5) = \ln \left[\frac{1}{k'}\left(-\ln \frac{N_t}{N_o}\right)\right]$$

$$1.20(-0.69) = \ln \left[\frac{1}{k'}(-\ln 0.01)\right]$$

$$0.44 = -\left[\frac{1}{k'}(4.61)\right]$$

$$k' = -\frac{1}{0.44}(4.61) = -10.48$$

$$\ln \frac{N_t}{N_o} = -10.48C^{1.20}\,t$$

Disinfection by Chlorination

1. Introduction on Chlorination:

-Chlorine is the most widely used disinfectant because it is effective at low concentrations, cheap and forms residual if applied in sufficient dosage.

-The principal chlorine compounds used in water and wastewater treatment are:

Chlorine (Cl_2), sodium hypochlorite ($NaOCl$), calcium hypochlorite [$Ca(OCl)_2$], and chlorine dioxide (ClO_2).

-Chlorine (Cl_2) can be used in gas or liquid form.

-The Cl_2 gas is liquefied by high pressure (5-10 atm) to the liquid form.

Disinfection by Chlorination

2. Chemistry of Chlorine in water:

-Chlorine gas reacts readily with water to form hypochlorous acid and hydrochloric acid:

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

The produced hypochlorous acid then dissociates to yield hypochlorite ion:

$$HOCl \rightarrow H^+ + OCl$$

The relative distribution of HOCl and OCl^- is a function of pH and temperature see (Fig 8.1). Both HOCl and OCl^- are excellent disinfectants but HOCl is more effective.

-Both HOCl & OCl^- react with ammonia if exists in water to produce chloramines:

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O \quad \text{(monochloramine)}$$

$$NH_2Cl + 2HOCl \rightarrow NHCl_2 + H_2O \quad \text{(dichloramine)}$$

$$NHCl_2 + 3HOCl \rightarrow NCl_3 + H_2O \quad \text{(Trichloramine)}$$

-Both HOCl & OCl^- react with reducing compounds such as Fe^{+2}, Mn^{+2}, NO^{-2} , and the chlorine will be reduced to the non effective chlorid ion Cl^- .

Disinfection by Chlorination

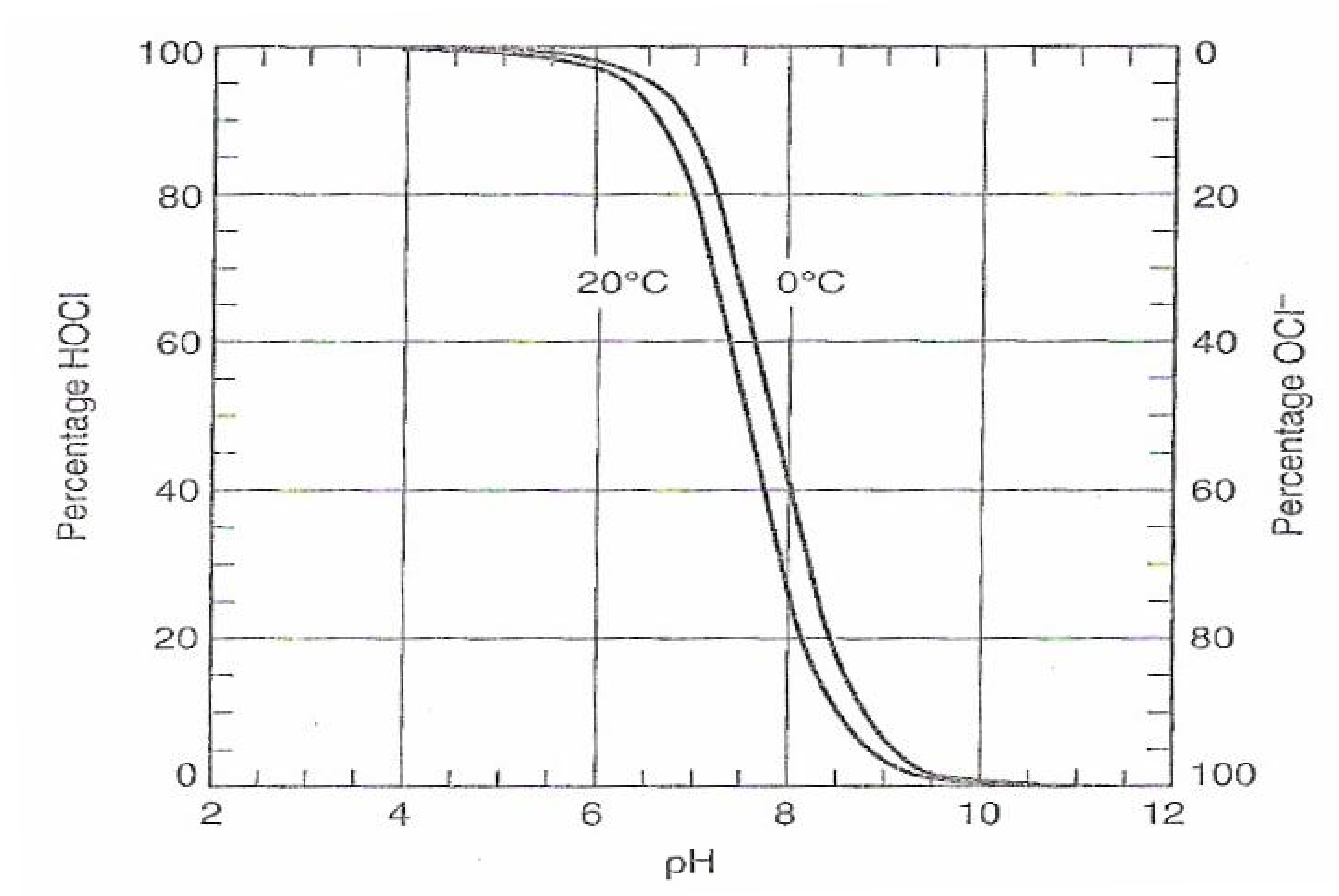


Figure 8.1 Relative amount of HOCl and OCl^- as a function of pH at 20°.

Disinfection by Chlorination

-Both HOCl & OCl^- react with reducing natural organic maters producing trihalomethanes (THMs) including:

Chloroform ($CHCl_3$) , bromoform (CHBr3) bromodichloromethane ($CHCl_2Br$), dibromochloromethane ($CHClBr_2$). The THMs are carcinogenic compounds and their total concentration in drinkingwater should not be more than 0.1 mg/l.

-THMs are one of the disinfection by products DBPs that should be minimized or removed before supplying the water to the consumers.

-Another dangerous DBPs is the halogenated acetic acids HAAs as it may cause cancer.

-THMs and HAAs can be minimized by removing the organic matter before disinfection. THMs and HAAs can be removed from water by GAC.

Disinfection by Chlorination

3. Break point chlorination :

-As illustrated in the previous section, chlorine reacts with the substances existing in water. Figure 8.2 shows the stages of these reactions.

-On Fig 8.2, The chlorine dosage is presented on the x-axis and the residual chlorine is presented on the y-axis.

-When chlorine is added it reacts first with the reducing compounds such as Fe^{+2}, Mn^{+2}, NO^{-2} , and the chlorine will be reduced to the none effective chloride ion Cl^- (from zero to point A on the figure).

- When adding more chlorine it will react with NH_3 to form chloramines as shown in the chlorine chemistry (from point A to B).

-When adding more chlorine some chloramines are oxidized to nitrogen gas and the chlorine is reduced to the none effective Cl^- ion.(from point B to C).

-Continued addition of chlorine will produced free available chlorine (at point C). point C is called the break point.

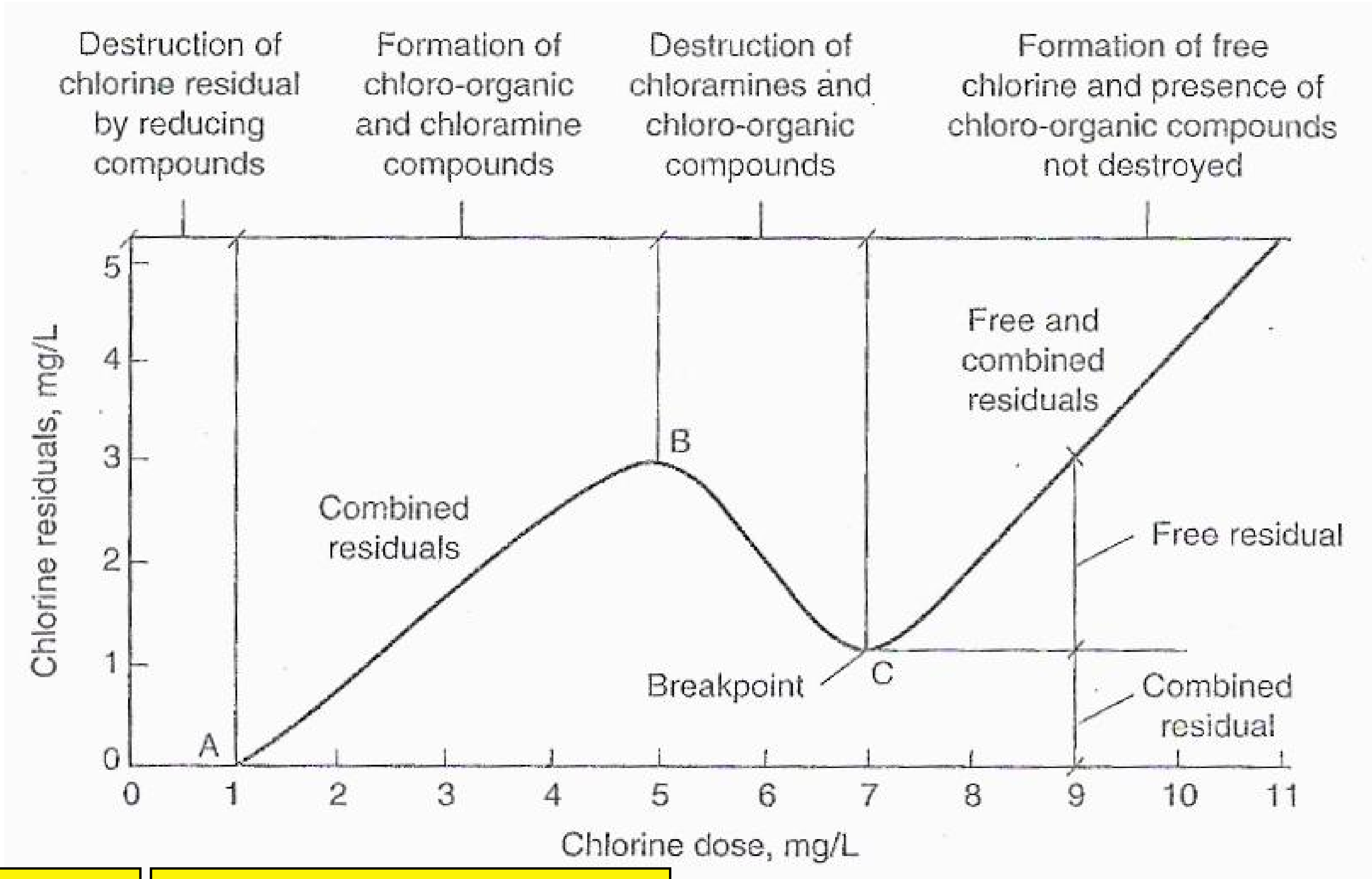


Figure 8.2 Break-point chlorination

Disinfection by Chlorination

-The chlorine added is called the dosage.
- the amount used to oxidize the materials existing in water is called the demand.
- The residual = dosage – demand
-The residual between points A to C is called combined residual because the chlorine is in the form of chloramines. From point C and up a free chlorine residual start to appear in water in addition to the combined residual. The free Chlorine residual is composed of un-reacted forms of chlorine $HOCl$ and OCl^-.
-The total residual after the break point = free + combined.
-Since the free residual is much more effective in disinfection, all the regulations require a free residual of at least 0.20 mg/l at the farthest tap in the system. The residual chlorine in the produced water is typically 2 – 5 mg/l.
- since free residual appears only after the breakpoint, so we need to decide the breakpoint dosage. Thus the required dosage = breakpoint dosage + free residual

DISINFECTION
UV APPLICATIONS

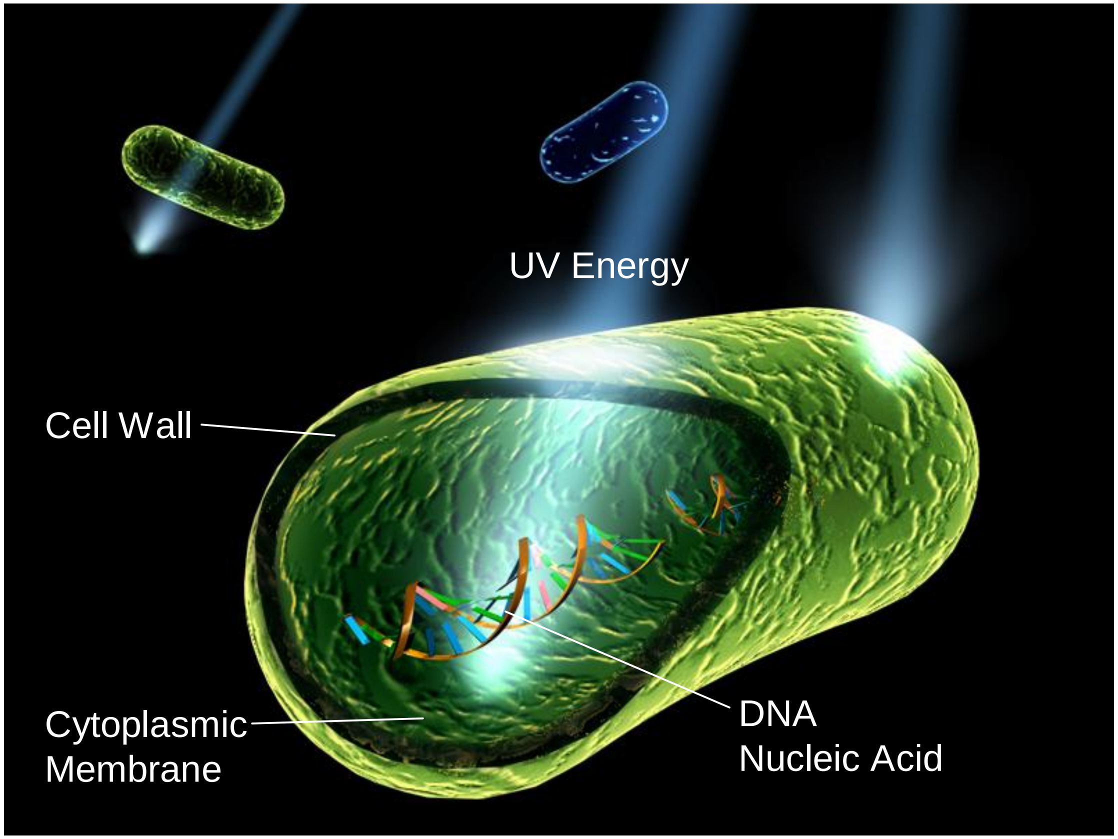
How does UV disinfect?

UV light at the 254 nm wavelength penetrates the cell wall of the microorganism

The amount of UV delivered to the organism is called the intensity.

The UV energy permanently alters the DNA structure of the microorganism in a process called *thymine dimerization*

The microorganism is "inactivated" and rendered unable to reproduce or infect



DISINFECTION

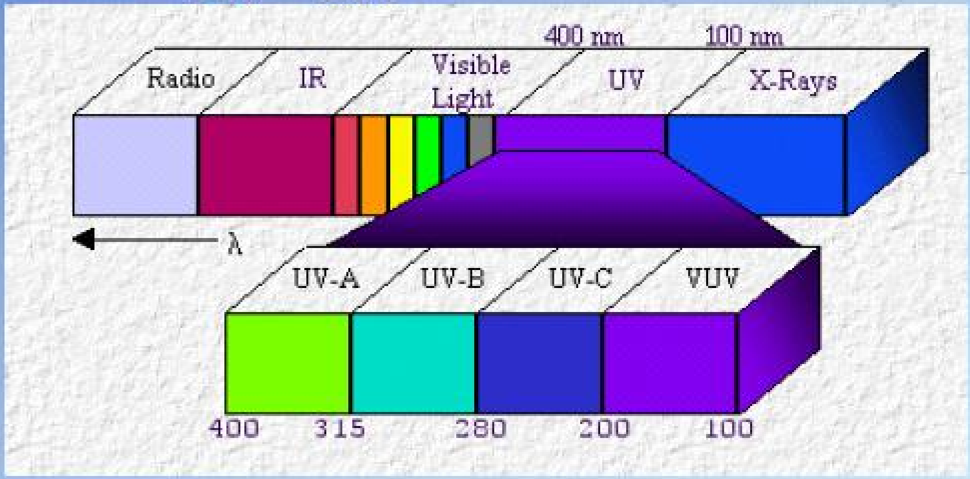
UV APPLICATIONS

What is UV Disinfection?

- Inactivation of pathogenic organisms by UV radiation to prevent replication (physical disinfection)
- UV penetrates cell wall and damages DNA/RNA
- Effective for protozoa *(Giarida & Crypto),* bacteria *(E.coli)* and viruses

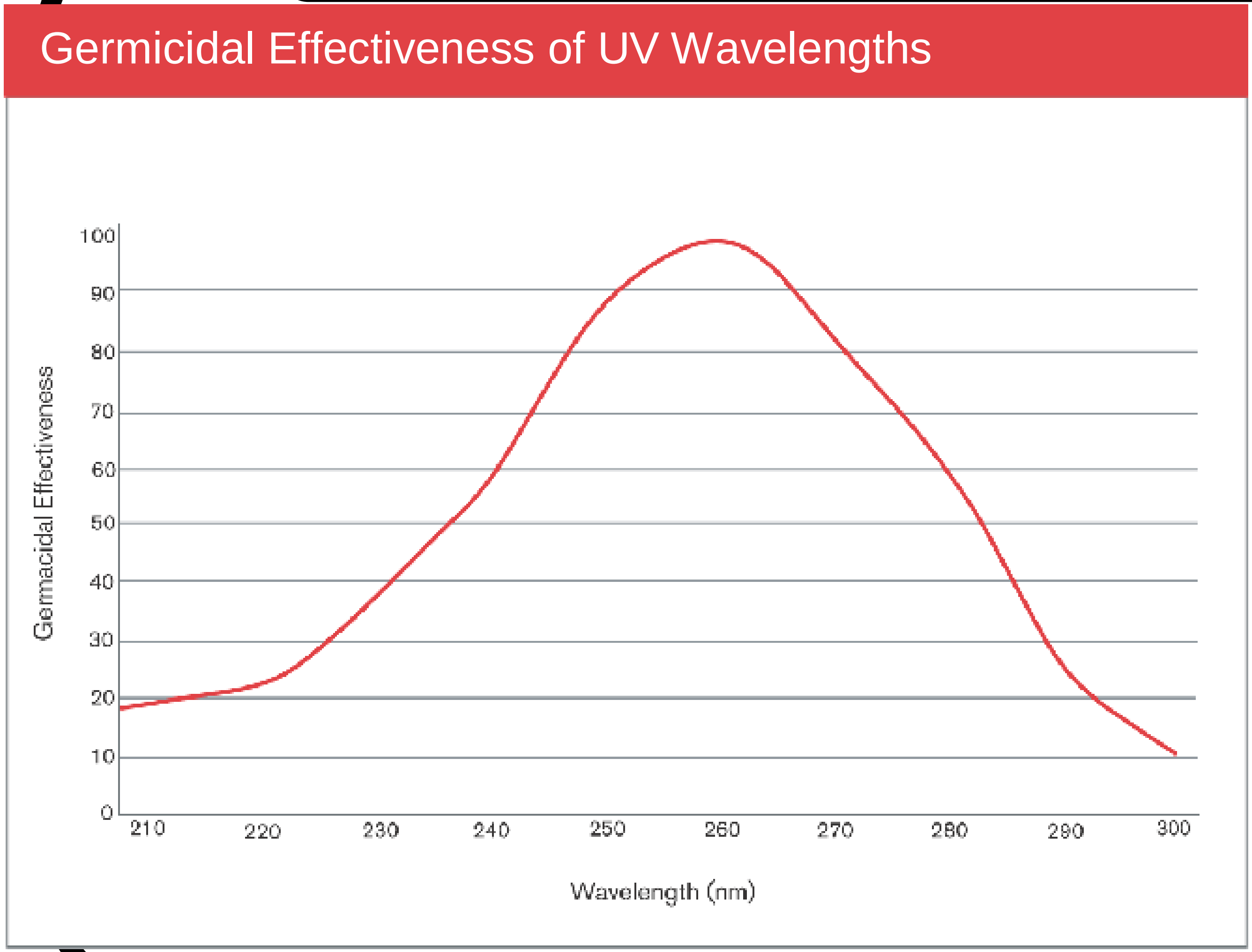
What is UV?

Range	Wavelength	
UVA	315 – 400	Suntan
UVB	280 – 315	Sunburn
UVC	200 – 280	Germicidal
VUV	100 – 200	



- Optimum to inactivate microbes = 250-270 nm

DISINFECTION
UV APPLICATIONS



- Efficiency of UV light for microbial disinfection peaks at the wavelength of 254 nm
- Above and below this wavelength, the drop-off in effectiveness is quite rapid

Types of UV Lamps

- Low-Pressure (LP)
  - Older Technology, monochromatic, no cleaning
- Low-Pressure, High-Output (LPHO)*
  - Newer technology, Open channel systems
  - Monochromatic, 30-40% Efficient
- Medium-Pressure (MP)
  - Ave. 10 times more power input than LPHO
  - Polychromatic, 10-20% Efficient
  - > 1000° F, 3-5 min. cool-down
  - Closed vessel systems

Advantages of UV Disinfection

- No hazardous chemicals storage
- No known byproducts
- No residuals to remove
- Not affected by pH or temperature
- Requires short contact time (seconds vs. minutes) = smaller contact chamber
- No danger of overdosing
- Low maintenance

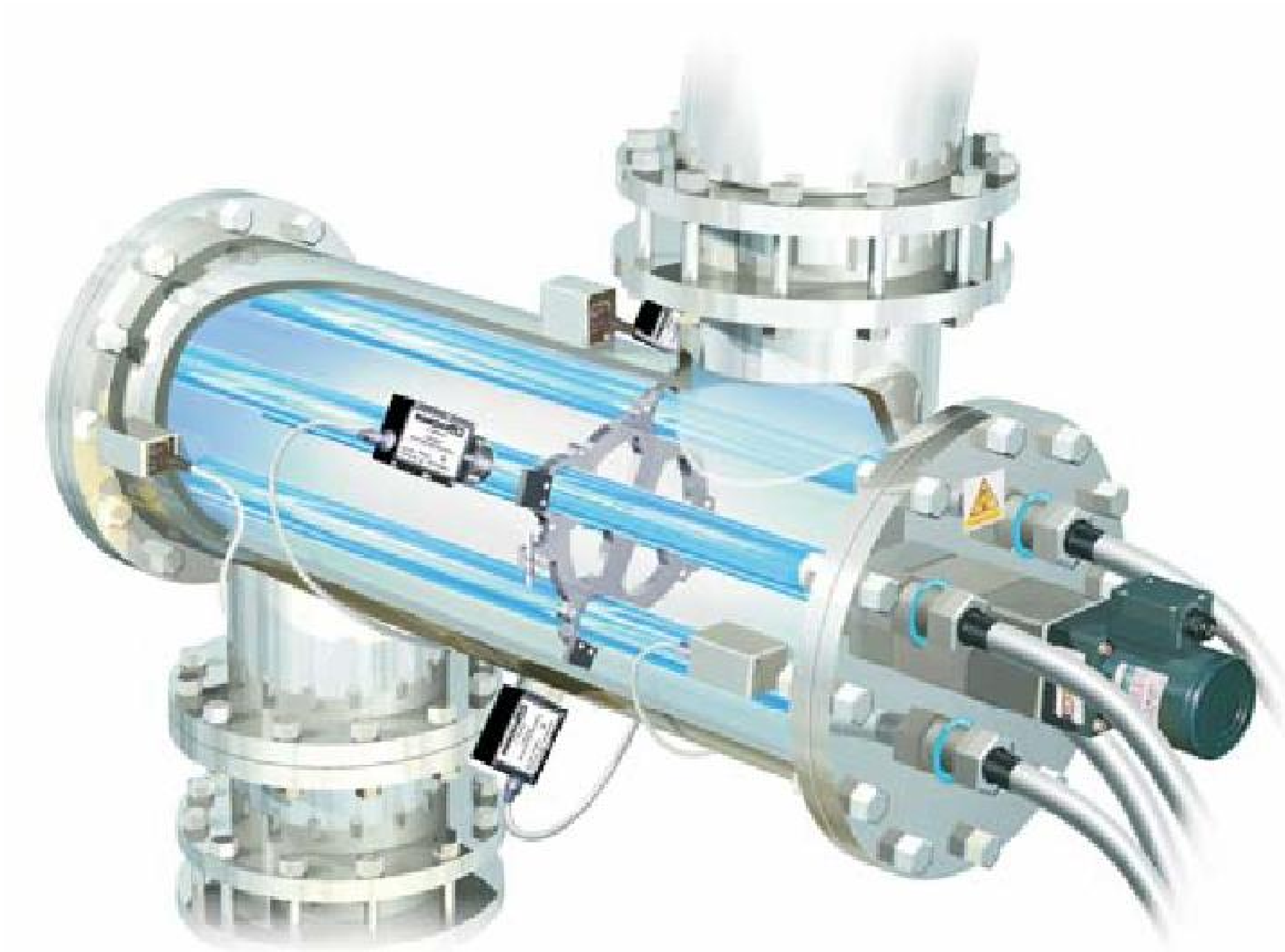
Disadvantages of UV Disinfection

- Higher Equipment Cost
- No disinfectant residual *(Drinking Water)*
- Not as effective for certain viruses *(eg: Adenovirus) - (Drinking water)*

Types of UV Systems

- Open Channel –horizontal or vertical

- Closed Chamber



UV Modules

Fig. 1 – Horizontal: Chemical Wipers, Ballasts in top

Fig. 2 – Vertical: Mech. Wipers, Ballasts in top

Fig. 2 – Horizontal: Mech. Wipers, Ballasts Remote

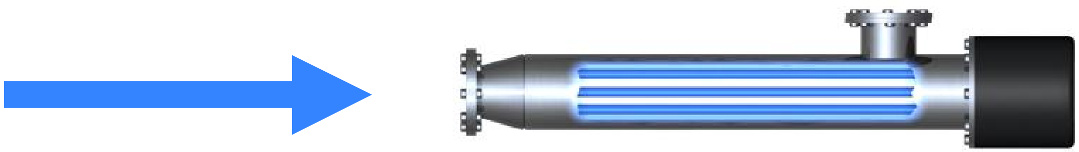
UV Channel – Existing Chlorine Tank

UV DOSE CALCULATION

UV Dose is a product of:

Intensity (quantity of UV light per unit area falling on a surface) **and**
Residence Time (contact time in the reaction chamber)

UV DOSE = Intensity x Residence Time



UV Dose is expressed in: μWsec/cm^2 (Microwatt seconds/cm^2)
mWsec/cm^2 (Milliwatt seconds/cm^2)
mJ/cm^2 (Millijoules/cm^2)

Average UV Dose Required for Inactivation (mJ/cm^2)

Pathogen	1-Log	2-Log	3-Log	4-Log
Cryptosporidium parvum oocysts	1.3	2.5	4.3	5.7
Giardia lamblia cysts	0.3	0.7	1.3	1.7
Vibrio cholerae	0.8	1.4	2.2	2.9
Shigella dysenteriae	0.5	1.2	2	3
Escherichia coli 0 157:H7	1.5	2.8	4.1	5.6
Salmonella typhi	1.8 - 2.7	4.1 - 4.8	5.5 - 6.4	7.1 - 8.2
Shigella sonnei	3.2	4.9	6.5	8.2
Salmonella enteritidis	5	7	9	10
Hepatitis A virus	4.1 - 5.5	8.2 - 13.7	12.3 - 22	16.4 - 29.6
Poliovirus Type 1	4.1 - 6	8.7 - 14	14.2 - 23	21.5 - 30
Coxsackie B5 virus	6.9	13.7	20.6	30
Rotavirus SA 11	7.1 - 9.1	14.8 - 19	23 - 25	36

Disinfection by Ozonation

- OZONE is the Strongest oxidant/disinfectant available.
- More effective against microbes than chlorination.
- But, costly and difficult to monitor and control under different condition.

- **Ozonation process:**
  - Ozone (O_3) is generated on-site at water treatment facilities by passing dry oxygen or air through a system of high voltage electrodes.

Disinfection by Ozonation


OZONIA
OZONE

- Percentage Kill
- Initial number = 1,000,000 bacteria
- 90% (1 Log) = 100,000 remain
- 99% (2 Log) = 10,000 remain
- 99.9% (3Log) = 1,000 remain
- 99.99% (4Log) = 100 remain
- 99.999% (5 Log) = 10 remain