Disinfection

Lecture No. 8

1. General

A. Harmful Organism

- bacteria
- viruses
- amoebic cysts

B. Waterborne Diseases

- typhoid
- cholera
- bacillary dysentery

C. Agents and Means

1.) Chemical Agents

- phenol
- alcohol
- iodine
- chlorine
- bromine
- ozone
- heavy metals
- dyes
- soaps & detergents
- hydrogen peroxide
- alkalis and acids
- most are oxidizing agents, chlorine is most common by far

2.) Physical Agents

- heat (boiling)
- light (ultraviolet)

3.) Mechanical Means (Disinfection is incidental and a by-product)

- sedimentation, 25-75%
- chemical precipitation, 40-80%

4.) Radiation

- gamma rays
- cobalt-60

D. Factors Influencing the Action of Disinfectants

- type of disinfectant
- concentration of disinfectant

$C_n t_p$ = constant, empirical equation
C = concentration of disinfectant
n = constant
t_p = time required to effect a constant percentage kill
In general, if n is greater than 1, contact time is more important than dosage; if n equals 1, the effects of time and dosage are about the same.

- contact time

The longer the contact time, the greater the kill
Chick's law:
$dN/dt = -kN_t$
N_t = number of organisms
t = time
k = constant, $time^{-1}$
If N_0 is the number of organisms at t=0
$N_t/N_0 = e^{-kt}$
$\ln N_t/N_0 = -kt$

- temperature
- type of organisms
- concentration of organisms
- nature of suspending liquid

E. Mechanisms of Disinfectants

- damage to the cell wall, penicillin
- alteration of cell permeability, phenol, detergents
- alteration of the colloidal nature of the protoplasm, heat, radiation
- inhibition of enzyme activity, chlorine, bromine, oxidizing agents

2. Purpose

- With municipal water treatment, the purpose of disinfection is to kill the growing form of pathogenic microorganisms, not necessarily the resistant spore forms, through the use of chemicals or ozone.
- Pathogens are disease causing MOs.
- Disinfection is not sterilization which is the destruction of all MOs including spores.

3. Considerations

A. Surrogate Organisms

- Often the pathogens can not be measure directly because their numbers are relatively small. A bacterial organism, *Escherichia Coli*, present in the human body in vast numbers has been selected as a surrogate. The inference is that if *E. Coli* is present, pathogens are present.
- The most common method of assessing the safety of the drinking water is the coliform test. The EPA has proposed that the standard plate count be instituted as a routine test to screen for bacteria regrowth. The heterotrophic plate count, HPC, for the water in a distribution system should be less than 10 colonies per ml. The EPA is also emphasizing the inactivation of protozoan cysts such *Entamoeba histolytica*, *Giardia lamblia* as well as the *Cryptosporidium* and *Legionella* viruses. There was a major outbreak of *Cryptosporidium* is the spring of 1993, leading to many sicknesses and a number of deaths.

B. Alternative Disinfectants

1.) Chlorine

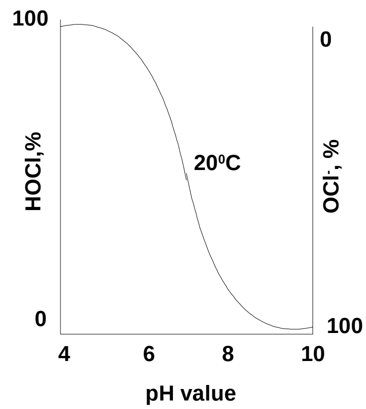
- Most common and understood method by far
- Chlorination has been practiced in this country since 1903 and will continue to be the primary disinfectant for years to come.
- When chlorine comes into contact with organic material, trihalomethanes, THMs, are formed. THMs are proven carcinogens and it is the production of THMs which is driving the search for other disinfectant agents.
- Chlorine is generally applied to the process water as an aqueous chlorine solution: chlorine gas is hydrolyzed to form hypochlorous acid, HOCl, and hypochlorite ion (OCl-) in ammonia free water. The quantity of HOCl and OCl- is called the *free available chlorine*. The relative concentration of these two species is a function of the pH of the water and to some degree, the temperature. Hypochlorous acid is 100 times more effective than hypochlorite ion as a germicide for enteric bacteria and amoebic cysts, yet hypochlorous acid is less effective in combating viruses as well as amoebic cysts and bacterial spores when compared to ozone and chlorine dioxide.

Hydrolysis:

$$Cl_2 + H_2O \Leftrightarrow HOCl + H^+ + Cl^-$$

Ionization:

$$HOCl \Leftrightarrow H^+ + OCl^-$$



Given: The above graph
Find: What is the most effective pH range for dosing chlorine
Since HOCl is 2 orders of magnitude more effective than OCl^-,
the most effective pH would be towards the acidic end
Note: There is a problem with corrosion at the acidic pHs

2.) Choramines

- Chlorine reacts with ammonia to form chlroamines which less effective disinfectants than chlorine. The chlorine in these compounds is called *combined available chlorine*.
- Ammonia reactions:

NH_3 + HOCl → NH_2Cl (monochloramine) + H_2O
NH_2Cl + HOCl → $NHCl_2$ (dichloramine) + H_2O
$NHCl_2$ + HOCl → NCl_3 (nitrogen trichloride) + H_2O

3.) Chorine Dioxide

- Effective bactericide, equal to or slightly better than hypochlorous acid. Chlorine dioxide has proven to be more effective in achieving inactivation of viruses than chlorine.
- Chlorine dioxide is an unstable and explosive gas and must be generated on site. Generation of chlorine dioxide involves reacting sodium chlorite ($NaClO_2$) with chlorine to produce gaseous chlorine dioxide as follows:

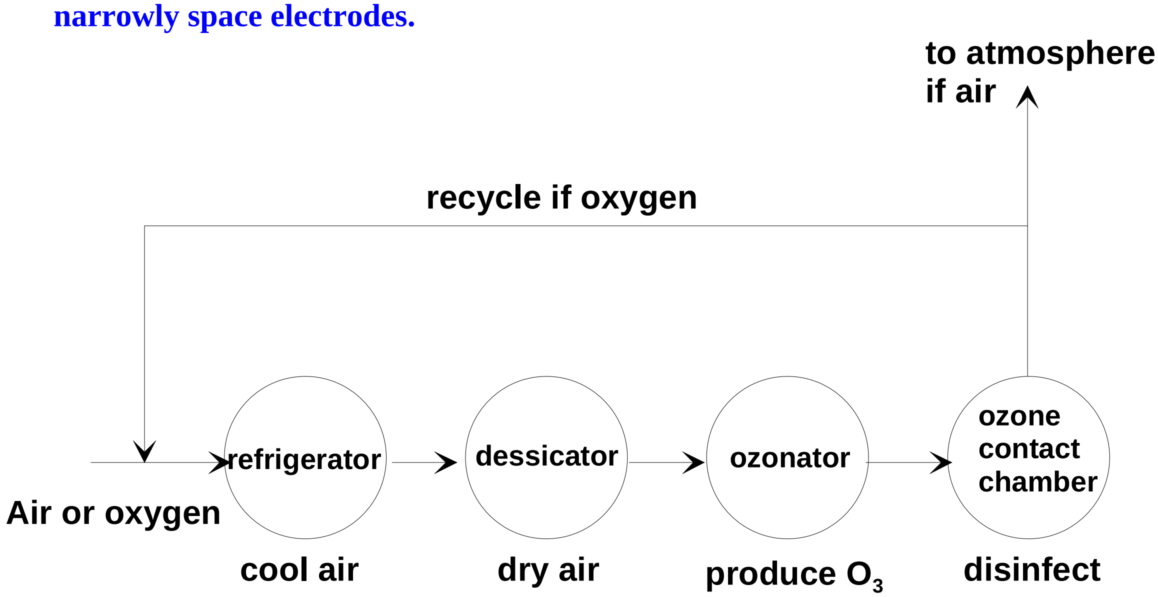
$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$$

- The active disinfecting agent in a chlorine dioxide system is free dissolved chlorine, ClO_2.

4.) Ozone

- **Ozone, O_3, is an allotrope of O_2, oxygen**
- **The half-life of ozone is 20-30 minutes in an aqueous solution of distilled water at 20°C.**
- **Among commonly available disinfectants, ozone is the most powerful oxidant and disinfectant. Used in over 1000 plants mostly in Europe.**

- **In practice, ozone is used heavily in Europe and is often used in conjunction with a secondary disinfectant such as chlorine or choramine, since ozone is not capable of providing a residual disinfectant to combat MOs in the distribution system. Very recent demonstration studies conducted at the Weymouth Filtration Plant in LaVerne, Ca. suggest the combination of ozone and hydrogen peroxide, referred to as perozone, may be a powerful and cost effective combination.**
- **Ozone is particularly good for taste, odor, color producing agents.**
- **Ozone is chemically unstable and must be generated on site. Ozone is generated either from air or pure oxygen when a high voltage is applied across the gap of narrowly space electrodes.**



- **Ozone chemistry:**

Produce ozone:

$$O_2 \rightarrow (\text{high voltage})\ O + O$$
$$O + O_2 \rightarrow O_3$$

Ozone disinfection:

$$O_3 + H_2O \rightarrow HO_3^+ + OH^-$$

$$HO_3^+ + OH^- \rightarrow 2HO_2$$

$$O_3 + HO_2 \rightarrow HO + HO + HO_2 \rightarrow H_2O + O_2$$

The free radicals formed, HO_2 and HO have great oxidizing powers.

- **The complete destruction of viruses takes place at residuals of .3mg/l at exposure time of 3 minutes. The French use two contactors: first, 8-12 minutes at a .4mg/l residual; the second at 4-8 minutes with a .4mg/l residual.**
- **A typical ozone dosage is 1.0 to 5.3 kg/1000m^3.**
- **Typical power consumption is 10-20 Kw.h/kg of O_3.**
- **Ozone can NOT be used as a sole terminal disinfectant because the residual does not persist and experience has shown that a lack of disinfectant results in a proliferation of organisms in the distribution system.**
- **Cost is at least 2-3 x chlorination.**

Example:

Given: A water treatment plant using ozone. Q=25MGD
Find:
1.) How much ozone is needed, lbs/day
2.) What is the size of the tank.
3.) What is the power requirement.

1.) How much ozone is needed, lbs/day
Assume .4mg/l dosage
Erreur ! = X mg/l x 8.34 Erreur ! x Q(MGD)
Erreur ! = .4 mg/l x 8.34 Erreur ! x 25(MGD)
Erreur ! = 83.4lbs/day

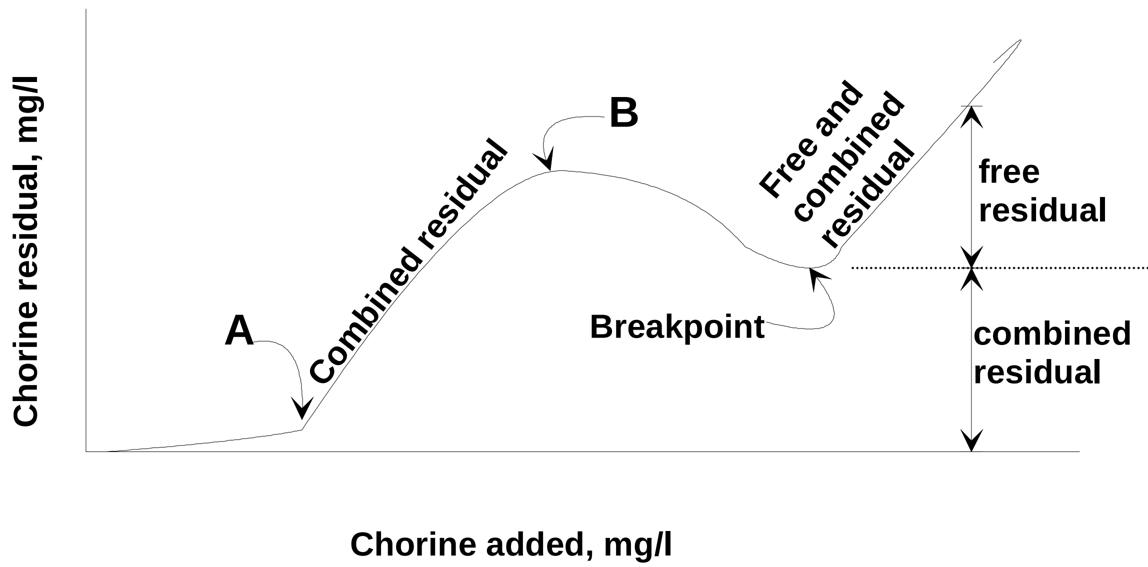
2.) What is the size of the tank.
Assume t = 8-12minutes, say 10 minutes
V = Qt = 25MGD x 1.547cfs/MGD x 10min x 60s/min
V = 23,205ft^3

3.) What is the power requirement.
Typical power consumption is 10-20 Kw.h/kg of O_3., say 15
Power = 15 Kwh/kg x 83.4lbs/day x kg/2.2lb
Power = 569 Kwh/day

C. Breakpoint Reaction(Wastewater topic)

- The maintenance of a residual (combined or free) for the purpose of disinfection is complicated by the fact that free chlorine not only reacts with ammonia but is also a strong oxidizing agent.
- As chlorine is added, readily oxidizable substance, such as Fe and Mn, H_2S and organic matter react with chlorine and reduce most of it to choride ion, Point A on the graph.

- After meeting this immediate demand, the chlorine continues to react with the ammonia to chloramines, Points A to B.
- Between Point B and the breakpoint, chorine is reduced to choride ion and some chloramines are oxidized to nitrogen trichloride and others.
- Continued addition of chlorine past the breakpoint will result in a directly proportional increase in the free available chlorine (unreacted hypochlorite).
- The amount of chlorine that must be added to reach a desired level of residual is called the chlorine demand.



D. Disinfectant Residual-Contact Time Relationship

- Two factors are of primary importance in disinfecting: the concentration of the disinfectant residual and the contact time expressed as follows:

$$C \times t = \text{constant}$$

where:
C=disinfectant residual, mg/l
t =contant time, minutes

A low concentration of disinfectant with a long contact time accomplishes the same goal as using a high residual concentration with a short contact time. See T3.2.9-1, p.299.

Example:

Given: By inspection of T3.2.9-1, p.299
Find: The most powerful oxidant
Ozone as indicated by the smallest Ct's is clearly the most powerful oxidant

Given: A treatment plant normally doses chlorine dioxide using a 1.5 hour residual. Due to a snow storm and the concomitant lack of chemical delivery, they must use 1/2 the amount of chlorine that they normally do. T=5°C.
Find: What is the new t. Consider *Giardia Lamblia* as an indicator.
From: T3.2.9-1, p.299.

Ct (@T=5°C.) = 13
C = 13/1.5h x 60min/h
C = .144mg/l

new C = .144mg/l / 2
C = .0722 mg/l

Ct (@T=5°C.) = 13
t = 13/.0722 mg/l
t = 180 minutes = 3hr

E. Disinfection By-products

- All disinfectants react with any element that is oxidizable in water. THMs and other halogenated organics are produced by chlorination. Aldehydes are formed by ozonation.
- The maximum allowable level of THM is .1mg/l

F. Dechlorination

- Dechlorination is the practice of removing the total combined chlorine residual. It would not be typically in used in water treatment but is standard practice in waste water treatment
- The object of dechlorination is to reduce the toxic effects of chorinated effluents on the downstream water systems.
- Sulfur dioxide, SO_2, is the most common dechlorination agent; activated carbon, Na_2SO_3, sodium sulfite, and $Na_2S_2O_5$, sodium metabisulfite have also been used.
- Sulfur dioxide reacts with chlorine as follows:

$$SO_2 + H_2O \rightarrow HSO_3- \ + \ H^+$$
$$HOCl + HSO_3^- \ \rightarrow Cl- \ + SO_4^{-2} \ + 2H^+$$
$$SO_2 + HOCl + H_2O \ \rightarrow Cl + SO_4^{-2} \ + 3H^+$$

The stochiometric weight ratio is SO_2:Cl_2::.9:1; in practice, 1 mg/l of SO_2 is needed to neutralize 1 mg/l of Cl_2. The reaction time is instantaneous which usually means about a 5 minute detention time.

G. Cost

- Chlorine is cheapest; ozone most expensive.

Example:

Given: A 50 MGD water plant.
Find: What is the difference in construction costs between chlorine disinfection and ozone disinfection?
Consult T3.2.9-4, p.301
50 MGD does not appear as a plant size option, but 10 and 100 do appear. It is tempting to make a linear interpretation, but linear is probably not accurate. It might be best to plot the values, apply a best fit curve/line and pick off 50MGD. For the sake of argument assume: the chlorine system is $100,000 and the ozone is $130,000.

Δcost = \$130,000 - \$100,000
Δcost = \$30,000
Note: This estimate is probably worthless from an absolute dollar point of view but does have some validity for comparison purposes.

4. Design Criteria

- see pps. Starting with p. 301
- For chlorine, typical parameters are:

depth: 10-12’, use 12’
width: 8-10’ use 8’
length: as required
t: 10-40 minutes, use 20 for water; 30-90 minutes, use 60 minutes for wastewater
dosage: 2-20 mg/l, use 4-10 mg/l say 6.

5. Example

Given: A water treatment plant. Q=7.8MGD which must be chlorinated at 12.7mg/l. Chlorine is delivered in 1-ton cylinders @ \$961/ton. t =20 minutes.
Find:
1.) The amount of chlorine required, daily, monthly
2.) Yearly cost
3.) Design the disinfection system
4.) How much sulfur dioxide is required, tons/month

1.) The amount of chlorine required, daily, monthly
a.) daily
Erreur ! = X mg/l x 8.34 **Erreur !** x Q(MGD)
Erreur ! = 12.7 mg/l x 8.34 **Erreur !** x 7.8(MGD)
Erreur ! = 826 lb/day

b.) monthly
= 826 lb/day x 365days/yr x 1yr/12months
= 25,129 lbs/month x 1ton/2000lbs
= 12.56 tons/month

2.) yearly cost
cost = 12.56 tons/month x 12 months/year x \$961/ton
cost = \$144,842/year

3.) Facility Design
~~V~~ = Qt = 7.8×10^{6} gal/day x 20min x 1day/24h x 1h/60min x **Erreur !**
~~V~~ = $14{,}483 ft^{3}$
~~V~~ = LWD assume standard WD= L(12ftx8ft) = $14{,}483 ft^{3}$
L = 151ft

L=50’x3=150’
D=12’
W=8’

4.) Sulfur Dioxide
SO_2:Cl_2::.9:1; in practice, 1 mg/l of SO_2 is needed to neutralize 1 mg/l of Cl_2
therefore, same as chlorine:
12.56tons/month

HOMEWORK No.8, Disinfection
Read Chapter 3 pp. 292-313
Problems:

8A. Given: A water treatment plant using ozone. Q=66 MGD
Find:
1.) How much ozone is needed, lbs/day
2.) What is the size of the tank.
3.) What is the power requirement.

8B. Given: The chlorine residuals measured when various dosages of chlorine were added to a water and are given below:

Dosage mg/l	.1	.5	1	1.5	2	2.5	3
Residual mg/l	0	.4	.8	.4	.4	.9	1.4

Find:
1.) The breakpoint dosage
2.) The design dosage to obtain a residual of .75mg/l free available chlorine

8C. Given: A treatment plant normally doses chlorine at pH 8. T=25°C. The existing tank can provide a detention time of 1 hour.
Find: What is the required C. Consider *Giardia Lamblia* as an indicator.

8D. Given: A 100 MGD water plant. Disinfect with ozone at 1 mg/l using an oxygen feed.
Find: What is the cost.

8E. Given: A water treatment plant. Q= 3.81 MGD which must be chlorinated at 12.7mg/l. Chlorine is delivered in 1-ton cylinders @ $961/ton. t =20 minutes.
Find:
1.) The amount of chlorine required, per year
2.) Yearly cost @ $.26/lb
3.) Design the disinfection system: d=12’, w=8’, t=20min, dosage=6mg/l
4.) What is the sulfur dioxide dosage for declorination

8F. Given: Design the disinfection system for your project.