# Lectures on sterilization and disinfection

- Principle of sterilization and disinfection
- Individual sterilization and disinfection processes
- Media-specific disinfection (water and wastewater)
- Media-specific disinfection (air and surfaces)
- Media-specific disinfection (infectious solids)

# Common disinfectants in water/wastewater treatment processes

- Free chlorine
- Combined chlorine
- Chlorine dioxide
- Ozone
- UV

# Key points

- Basic chemistry and principle
- Method of application
- Effectiveness on microbes
- Advantages/disadvantages

# Chemical disinfectants

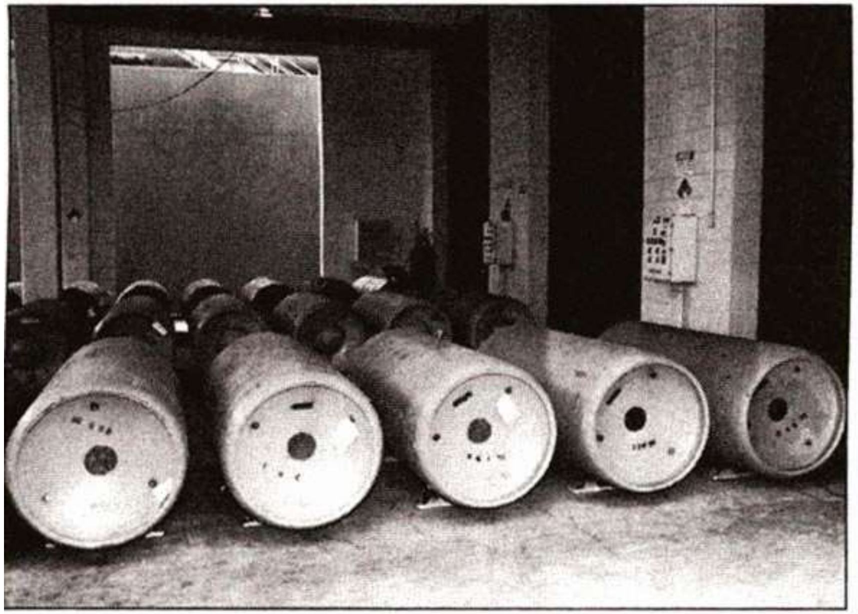
# Free chlorine: Chemistry

- Three different methods of application
  - $Cl_2$ (gas)
  - NaOCl (liquid)
  - $Ca(OCl)_2$ (solid)
- Reactions for free chlorine formation:

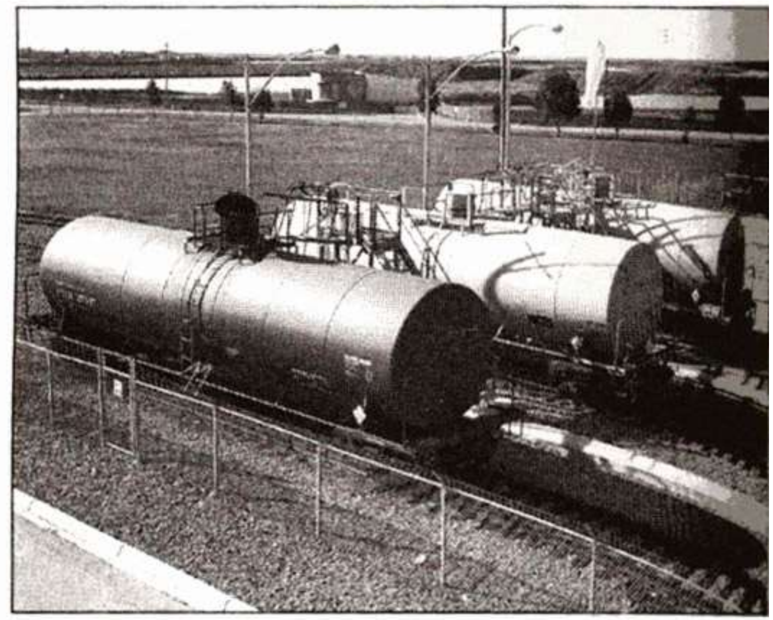
$$Cl_2\,(g) + H_2O \Leftrightarrow HOCl + Cl^- + H^+$$

$$HOCl \Leftrightarrow OCl^- + H^+ \text{ (at pH } >7.6)$$

# Chlorine application (I): containers

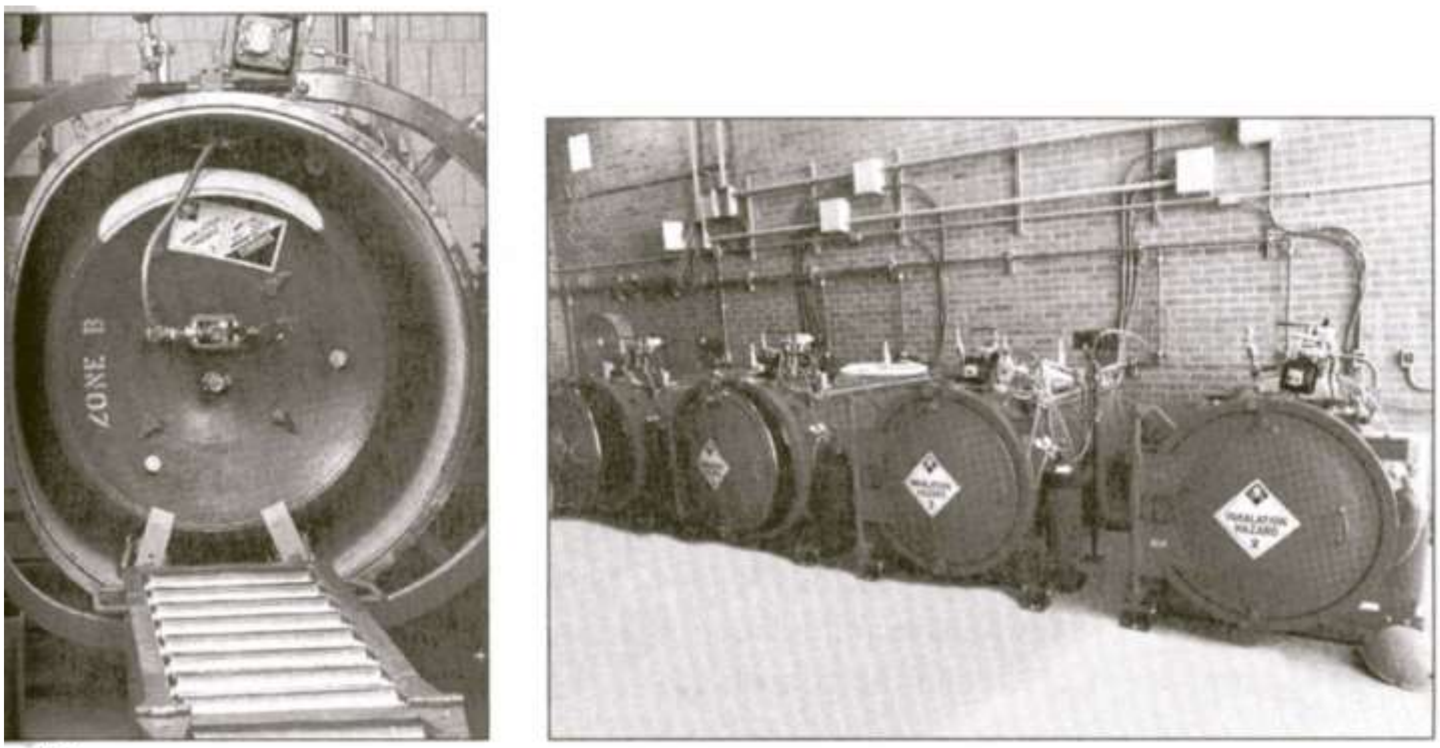


(a)



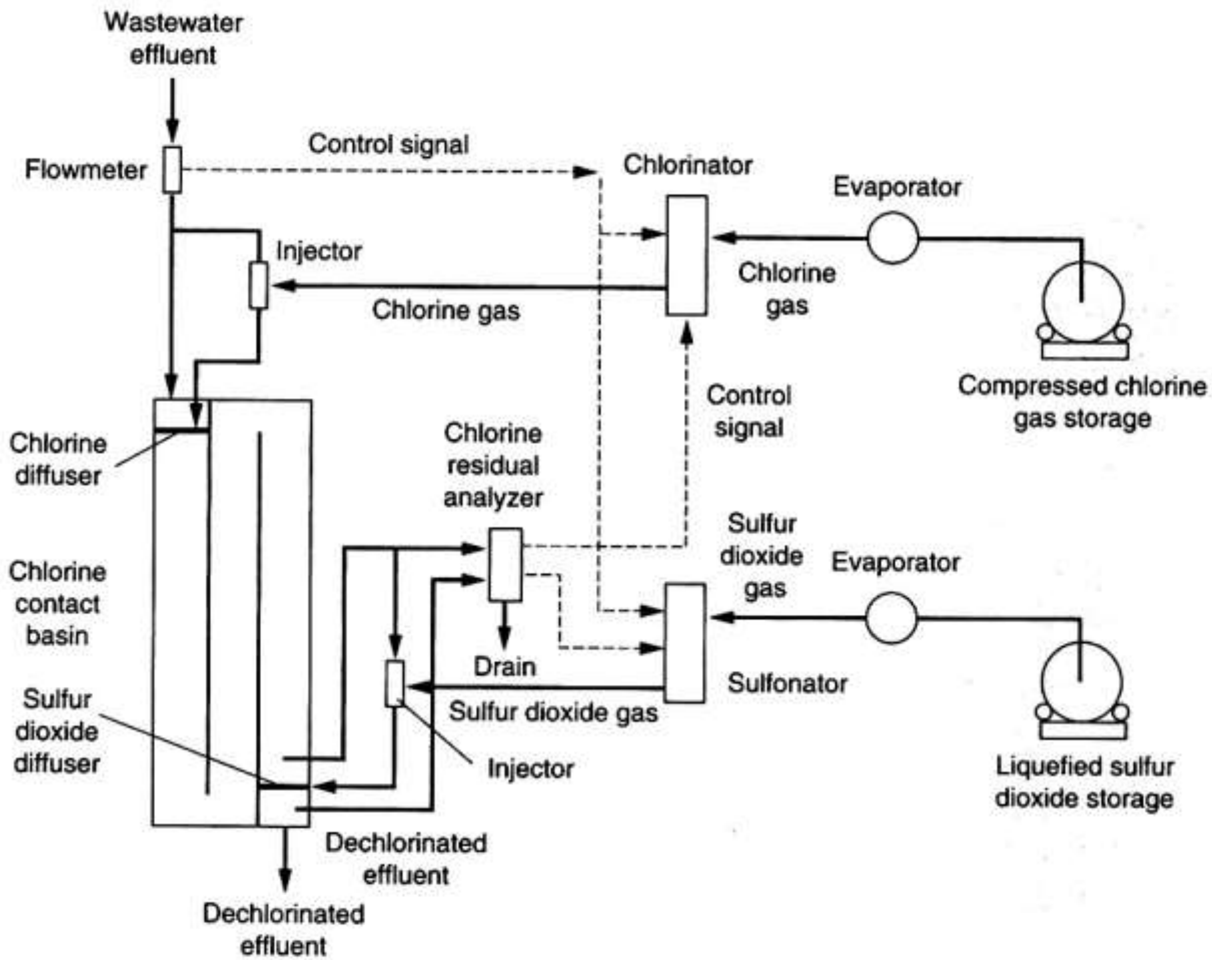
(b)

# Chlorine application (II): containment vessels




(a) (b)

# Chlorine application (III): flow diagram




(a)

# Chlorine application (IV): Injectors

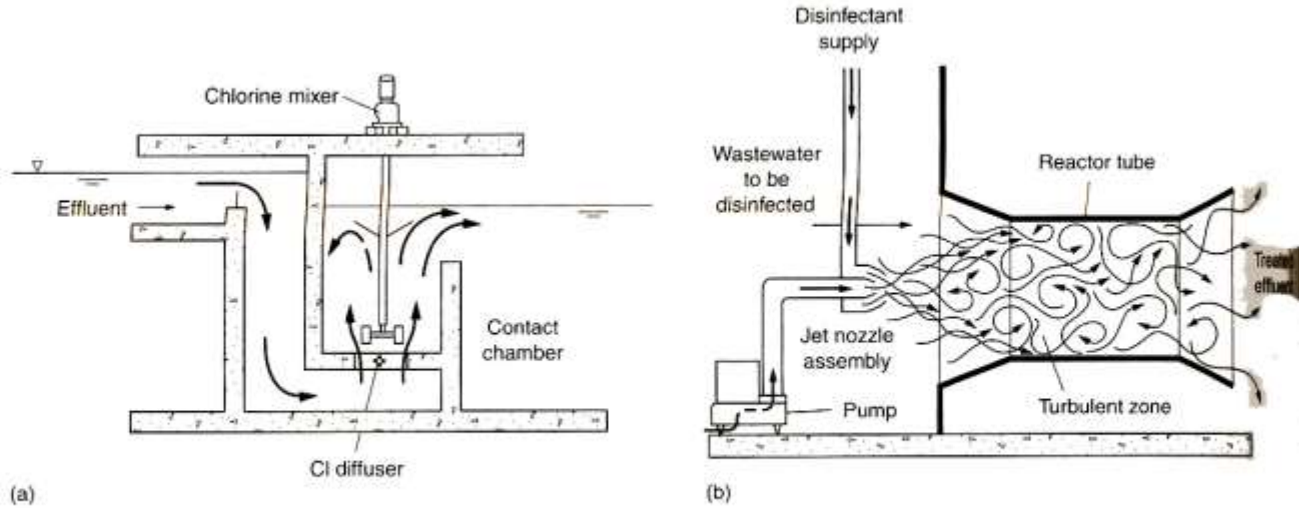



**Figure 12–22**

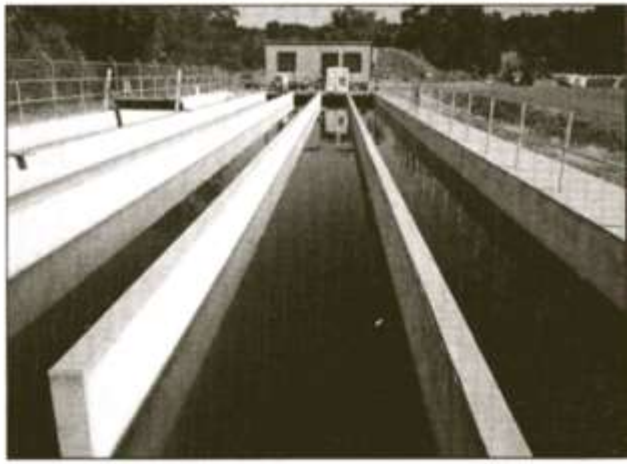
Typical mixers for the addition of chlorine: (*a*) in-line turbine mixer and (*b*) injector pump type. *(From Pentech-Houdaille.)* For additional types of chlorine mixers see Fig. 5–14 in Chap. 5.

# Chlorine application (V): Contact chambers

(a)

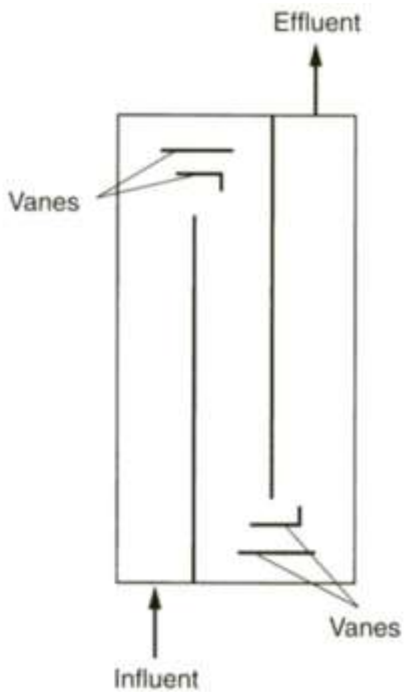
(b)

(c)



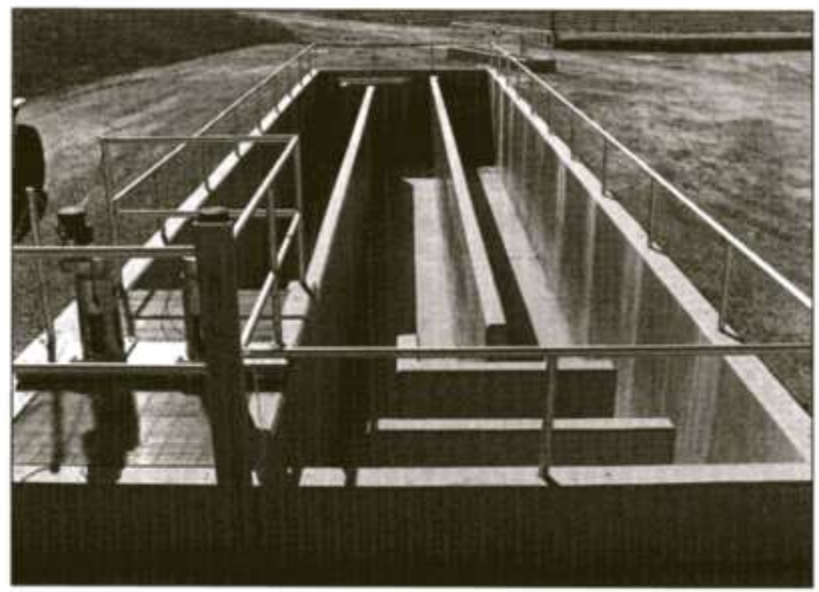
(d)

# Chlorine application (VI): Contact chambers




Plan view of
chlorine contact basin

(a)



(b)

# Free chlorine: effectiveness (I)

TABLE 2 Inactivation of Health-related Bacteria in Water by Free Chlorine

| Bacteria | Water | $Cl_2$ Residual (mg/l) | Temp. (°C) | pH | Time (min.) | Reduction (%) | Est. C·t* | Reference |
|---|---|---|---|---|---|---|---|---|
| E. coli | BDF | 0.2 | 25 | 7.0 | 15 | 99.998-99.996 | ND | Ram and Malley, |
| E. coli | BDF + N-organics | 0.2 | 25 | 7.0 | 15 | 99.999-99.992 | ND | 1984 |
| E. coli | BDF | 0.1 | 23 | 10 | 3.5 | 90 | 0.6 | Haas et |
| E. coli | " 0.1M $KNO_3$ | 0.1 | 23 | 10 | 0.8 | 90 | 0.15 | al., 1986 |
| E. coli | BDF, <7 um* | 0.5 | 5 | 7.0 | 30 | ND | 0.9 | Berman et |
| E. coli | BDF*, >7 um | 0.5 | 5 | 7.0 | 30 | ND | 2.7 | al., 1988 |
| E. coli | CDF* | 1.5 | 4 | ? | 60 | ca.99.9 | ca. 2.5 | LeCheval- |
| E. coli + GAC* | CDF | 1.5 | 4 | ? | 60 | <<10 | >>60 | lier |
| HPC | CDF | 1.7 | 4 | ? | 60 | >99.995 | 2.5 | et al., |
| HPC + GAC | CDF | 1.7 | 4 | ? | 60 | <10 | >>60 | 1984b |
| HPC | treated* | 0.25-1.3 | 24 | 8.0 | 15 | 99.82 (42->99.99) | ND | Wolfe et al. |
| HPC | treated | 0.25-1.3 | 24 | 8.0 | 30 | 99.94 (46->99.99) | ND | 1984 |
| C. jejuni | BDF | 0.1 | 4 | 8.0 | 5 | 99.98->99.998 | ND | Blaser et al., 1986 |
| L. pneumophila (water grown) | tap | 0.25 | 20 | 7.7-7.8 | 58 | 99 | 15 | Kuchta et al., |
| L. pneumophila (media grown) | tap | 0.25 | 20 | " | 4 | 99 | ca. 1.1 | 1985 |
| L. pneumophila | tap | 4-6 | 25 | ? | 52 | 99.9 | ND | Muraca et al., 1987 |
| M. chelonei | BDF | 0.3 | 25 | 7.0 | 60 | 40 | >>60 | Carson et |
| M. chelonei | | 0.7 | 25 | 7.0 | 60 | 99.95 | 46 | al., 1978 |
| M. chelonei | BDF | 1.0 | ? | 7.0 | 60 | 96 | ca. 80 | Pelletier |
| M. fortuitum | BDF | 0.15 | ? | 7.0 | 60 | 0 | >720 | and |
| M. fortuitum | BDF | 1.0 | ? | 7.0 | 30 | 99.4 | ca. 28 | Du Moulin 1987 |
| M. intra-cellulare | BDF | 0.15 | ? | 7.0 | 60 | 70 | >>480 | " |

*C·t = product of disinfectant concentration (C) in mg/l and contact time (t) in minutes for 99% inactivation; ND = not done or no data; BDF = buffered demand-free; CDF = chlorine demand free; <7 µm = with <7 µm particles; >7 µm = with >7 µm particles; GAC = granular activated carbon; treated = conventionally treated surface water.

# Free chlorine: effectiveness (II)

TABLE 3 Inactivation of Health-related Viruses and Protozoan Cysts in Water by Free Chlorine

| Microbe | Water | $Cl_2$ Residual (mg/l) | Temp. (°C) | pH | Time (min.) | Reduction (%) | Est. C·t* | Reference |
|---|---|---|---|---|---|---|---|---|
| VIRUSES: | | | | | | | | |
| Parvo- H-1 | PBS* | 0.2 | 20 | 7.0 | 6 | 99.9 | 0.53 | Churn et |
| Parvo- H-1 | PBS* | 0.2 | 10 | 7.0 | 11 | 99.9 | 0.85 | al., 1984 |
| SA11, disp.* | BDF* | ca. 0.5 | 5 | 10 | 1.1-1.65 | 99 | 0.63 | Berman and |
| ", cell-ass.* | BDF | ca. 0.5 | 5 | 10 | 2.4-4.4 | 99 | 1.8 | Hoff, 1984 |
| Rota, Wa | treated | 0.75 | 22 | 8.3-8.6 | 60 | 94.3 | ND | Raphael et al., 1987 |
| Human rota- | effluent | 1.1 | 15 | 7.2 | 15 | 40 | >>15 | Harekah & |
| Human rota- | effluent | 2.2 | 15 | 7.2 | 10 | 60 | >>15 | Butler, 1984 |
| Rota, SA11 | BDF | 0.1 | 4 | 8.0 | 0.5 | 99.9 | 0.03 | Vaughn et |
| Rota, Wa | BDF | 0.1 | 4 | 8.0 | 0.65 | 99.9 | 0.03 | al., 1986 |
| Rota, SA11 | BDF | 0.4-0.28 | 25 | 10.0 | 1.1 | 99.99 | ca. 4.0 | Grabow |
| Hepatitis A | BDF | 0.42-0.06 | 25 | 6 | 0.7 | 99.99 | ca. 3.0 | et al., |
| Hepatitis A | BDF | 0.4-0.28 | 25 | 10 | 2.5 | 99.99 | ca. 5.5 | 1983 |
| Hepatitis A | BDF | 0.5 | 5 | 6.0 | 6.5 | 99.99 | ca. 1.8 | Sobsey et |
| Hepatitis A | BDF | 0.5 | 5 | 10.0 | 49.6 | 99.99 | ca. 12.3 | al., 1988 |
| Coliphage MS2 | BDF | 0.5 | 5 | 6.0 | 1.2 | 99.99 | ca. 0.25 | " |
| Coliphage MS2 | BDF | 0.5 | 5 | 10.0 | 26.5 | 99.99 | ca. 6.9 | " |
| PROTOZOAN CYSTS: | | | | | | | | |
| G. lamblia | BDF | 1-4 | 5 | 7.0 | 3-32 | 90 | 90-170 | Jarroll et |
| G. lamblia | BDF | 1.5 | 25 | 6.0-8.0 | 47 | 99 | <15 | al., 1981 |
| G. lamblia | BDF | 2.5 | 5 | 6.0-8.0 | 19-26 | 90 | ca. 120 | Rice et al., 1982 |
| G. lamblia | BDF | 0.2-3.0 | 5.0 | 6.0 | --- | 99 | 54-87 | Hibler et |
| G. lamblia | BDF | 0.2-3.0 | 5.0 | 7.0 | --- | 99 | 83-133 | al., 1987 |
| G. lamblia | BDF | 0.2-3.0 | 5.0 | 8.0 | --- | 99 | 119-192 | " |
| G. muris | BDF | 2.5 | 5 | 6.0 | 30 | 90 | >150 | Rice et |
| G. muris | BDF | 2.5 | 5 | 8.0 | 48 | 90 | >150 | al., 1982 |
| G. muris | BDF | 23.8-78.5 | 5 | 7.0 | 5.7-42.6 | 99 | 449-1012 | Leahy |
| G. muris | BDF | 2.8-7.1 | 25 | 7.0 | 3.6-16 | 99 | 25.5-44.8 | et al., |
| G. muris | BDF | 11.1 | 25 | 9.0 | 15.6 | 99 | 177 | 1987 |
| G. muris | BDF | 4.4 | 25 | 5.0 | 16.3 | 99 | 71 | |
| Naegleria (2 species) | | 0.5-1.0 | 25 | 7.3-7.4 | 1-3 hr? | 99.99 | 12-18 | de Jonckheere |
| Acanthamoeba (2 species) | | 4-8 | 25 | 7.3-7.4 | 24 hr. | 99.99 | 960-7200 | and van de Voorde, 1976 |
| N. gruberi | BDF | 2.64 | 25 | 5.0 | 2.8 | 99 | 7.3 | Rubin |
| N. gruberi | BDF | 2.2 | 25 | 7.0 | 5.2 | 99 | 11.4 | et al., |
| N. gruberi | BDF | 15.4 | 25 | 9.0 | 15.4 | 99 | 177 | 1983 |
| Crypto-sporidium | gut homog. in PBS | 30,000 | 4 | ca. 7.0 | 18 hr. | <95 | >>18 hrs. | Campbell et al., 1982 |

*PBS = phosphate buffered saline; for other abbrevations see footnote to Table 2.

# Free chlorine: advantages and disadvantages

- Advantages
  - Effective against (almost) all types of microbes
  - Relatively simple maintenance and operation
  - Inexpensive
- Disadvantages
  - Corrosive
  - High toxicity
  - High chemical hazard
  - Highly sensitive to inorganic and organic loads
  - Formation of harmful disinfection by-products (DBP’s)

# Free chlorine: other applications

- Swimming pool/spa/hot tube water disinfection
- Industrial water disinfection (canning, freezing, poultry dressing, and fish processing)
- (Liquid and solid chlorine)
  - General surface disinfectant
    - Medical/household/food production

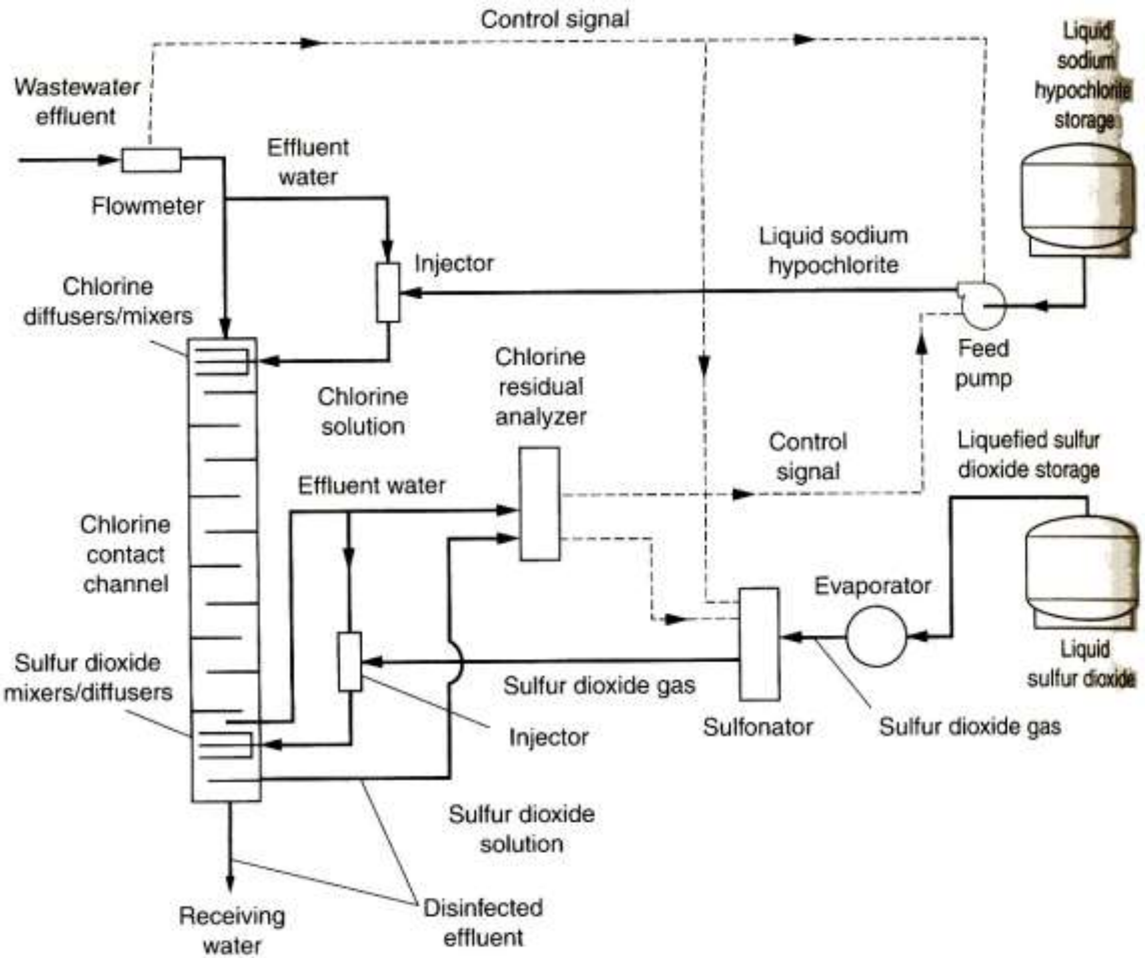
Questions?

# Chloramines: Chemistry

- Two different methods of application (generation)
  - chloramination with pre-formed chloramines
    - mix hypochlorite and ammonium chloride ($NH_4Cl$) solution at $Cl_2$ : N ratio at 4:1 by weight, 10:1 on a molar ratio at pH 7-9
  - dynamic chloramination
    - Reaction of free chlorine and ammonia *in situ*
- Chloramine formation
  - $HOCl + NH_3 \Leftrightarrow NH_2Cl$ (monochloramine) $+ H_2O$
  - $NH_2Cl + HOCl \Leftrightarrow NHCl_2$ (dichloramine) $+ H_2O$
  - $NHCl_2 + HOCl \Leftrightarrow NCl_3$ (trichloramine) $+ H_2O$

  - $\frac{1}{2} NHCl_2 + \frac{1}{2} H_2O \Leftrightarrow \frac{1}{2} NOH + H^+ + Cl^-$
  - $\frac{1}{2} NHCl_2 + \frac{1}{2} NOH \Leftrightarrow \frac{1}{2} N_2 + \frac{1}{2} HOCl + \frac{1}{2} H^+ + \frac{1}{2} Cl^-$

# Application of chloramines (preformed monochloramines): flow diagram



# Chloramines: effectiveness

**TABLE 4 Inactivation of Health-related Microbes in Water by Chloramines**

| Microbe | Water | Residual (mg/l) | Temp. (°C) | pH | Time (min.) | Reduction (%) | Est. C·t* | Reference |
|---|---|---|---|---|---|---|---|---|
| BACTERIA: | | | | | | | | |
| E. coli | BDF* | 1.9-2.2 | 5 | 9.0 | 51-59 | 99 | 113 | Scarpino, 1984 |
| E. coli | BDF | 1.0 | 22 | 6.0 | 5-8 | 99 | ND* | Ward et al., |
| E. coli | BDF | 1.0 | 22 | 8.0 | 29-46 | 99 | ND | 1984 |
| K. pneumoniae | BDF | 1.0 | 22 | 8.0 | 8.5-22 | 99 | ND | " |
| S. typhimurium | BDF | 1.0 | 22 | 8.0 | 12-14 | 99 | ND | " |
| HPC | treated* | 1.6 | 24 | 8.0 | 15 | 95 (35-99.73) | ND | Wolfe et al., |
| HPC | treated | 1.6 | 24 | 8.0 | 30 | 99.68 (88.4->99.99) | ND | 1985 |
| Coliforms, S. typhimurium & S. sonnei | tap + 1% sewage | 0.4-1.5 | 20 | 6.0 | ND | 90 | 8.5 | Snead et |
| " | " | " | " | 8.0 | ND | 90 | 40 | al., 1980 |
| M. fortuitum | BDF | 3.25 | 20 | 7.0 | 50 | 90 | 2667 | Engelbrecht et al., 1977 |
| M. fortuitum | BDF | 3.0 | 17 | 7.0 | ca. 116 | 90 | ND | Pelletier |
| M. avium | BDF | 3.0 | 17 | 7.0 | 1320 | 90 | ND* | and |
| M. Intra-cellulare | BDF | 3.0 | 17 | 7.0 | 660 | 90 | ND | Du Moulin, 1988 |
| VIRUSES: | | | | | | | | |
| Polio 1 | BDF | 5-22 | 5 | 9.0 | 170 | 99 | 1420 | Scarpino, 1984 |
| Polio 1 | 1° effl. | 1-10 | 25 | 7.5 | 60-308 | 99 | ca. 345 | Fujioka et al., 1983 |
| Polio 1 | tap | 0.5 | 24 | 7.0-8.2 | 15 | 50 | ND | Keswick |
| Polio 1 | + 10% effl. | 0.5 | 24 | " | 15 | 0 | ND | et al., |
| Polio 1 | + 10% effl. | 2.0 | 24 | " | 15 | 99.7 | ND | 1985 |
| Hepatitis A | BDF | 10 | 5 | 8.0 | 117 | 99.99 | ca. 592 | Sobsey et |
| Coliphage MS2 | BDF | 10 | 5 | 8.0 | >>60 | | ca. 2100 | al., 1988 |
| Rotavirus SA11 | | | | | | | | |
| dispersed | BDF | 10 | 5 | 8.0 | 366-402 | 99 | 4034 | Berman and |
| cell-assoc. | BDF | 10 | 5 | 8.0 | 570-636 | 99 | 6124 | Hoff, 1984 |
| PROTOZOAN CYSTS: | | | | | | | | |
| G. muris | BDF | 1.5-2.6 | 3 | 6.5-7.5 | 188-296 | 99 | 430-580 | Meyer, 1982 |
| G. muris | BDF | 6.35 | 5 | 7.0 | 220 | 99 | ca. 1400 | Rubin, 1988 |
| G. muris | BDF | 1.5-30 | 15 | 9.0 | --- | 99 | ca. 600 | Rubin, 1988 |
| G. muris | BDF | " | " | 6.0-7.0 | --- | 99 | ca. 1000 | Rubin, 1988 |

# Chloramines: advantages and disadvantages

- Advantages
  - Less corrosive
  - Low toxicity and chemical hazards
  - Relatively tolerable to inorganic and organic loads
  - No known formation of DBP
  - Relatively long-lasting residuals
- Disadvantages
  - Not so effective against viruses, protozoan cysts, and bacterial spores

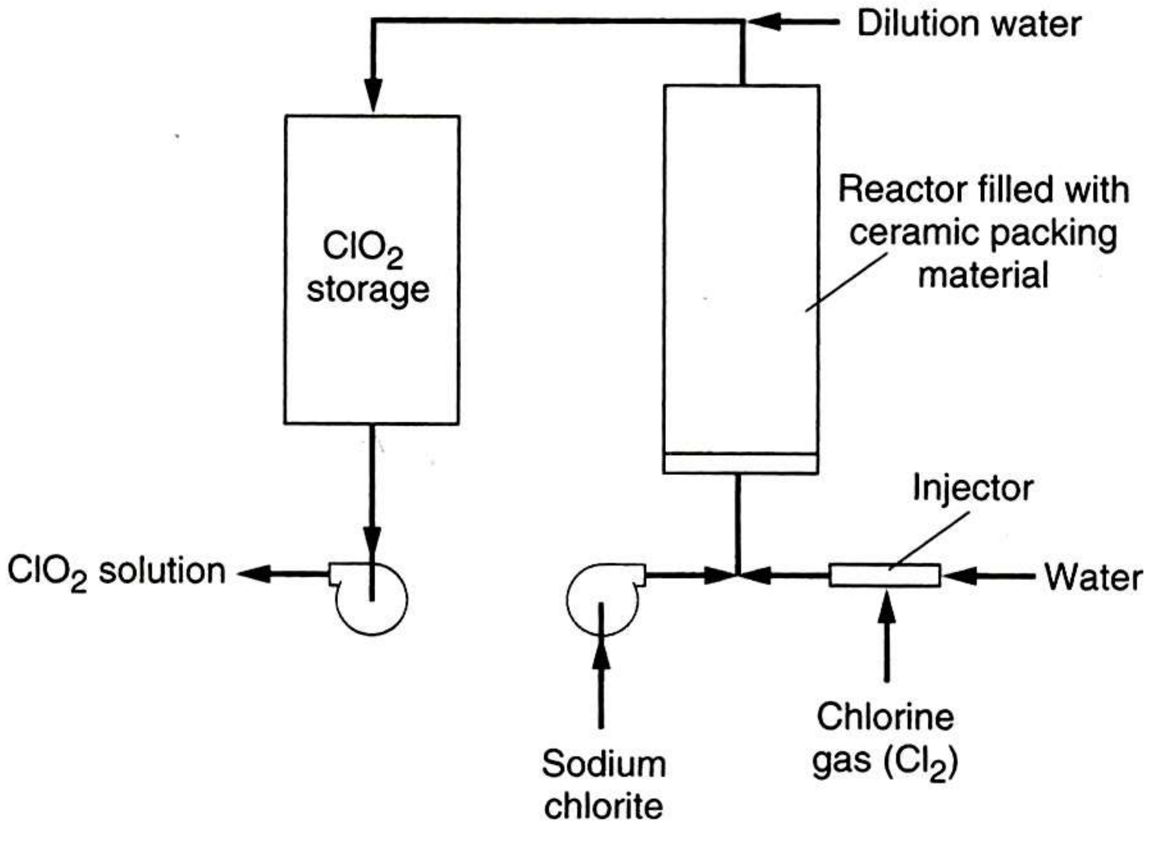
# Chloramines: other applications (organic chloramines)

- Antiseptics
- Surface disinfectants
  - Hospital/household/food preparation
- Laundry and machine dishwashing liquids

# Chlorine dioxide: Chemistry

- The method of generation
  - On-site generation by reaction of chlorine (either gas or liquid) with sodium chlorite
- Formation of chlorine dioxide
  - $2\ NaClO_2 + Cl_2 \rightarrow 2\ ClO_2 + 2\ NaCl$
  - Highly soluble in water
  - Strong oxidant: high oxidative potentials
    - 2.63 times greater than free chlorine, but only 20 % available at neutral pH
      - » $ClO_2 + 5e- + 4H^+ = Cl^- + 2H_2O$ (5 electron process)
      - » $2ClO_2 + 2OH^- = H_2O + ClO_3^- + ClO_2^-$ (1 electron process)

# Generation of chlorine dioxide



# Application of chlorine dioxide: flow diagram

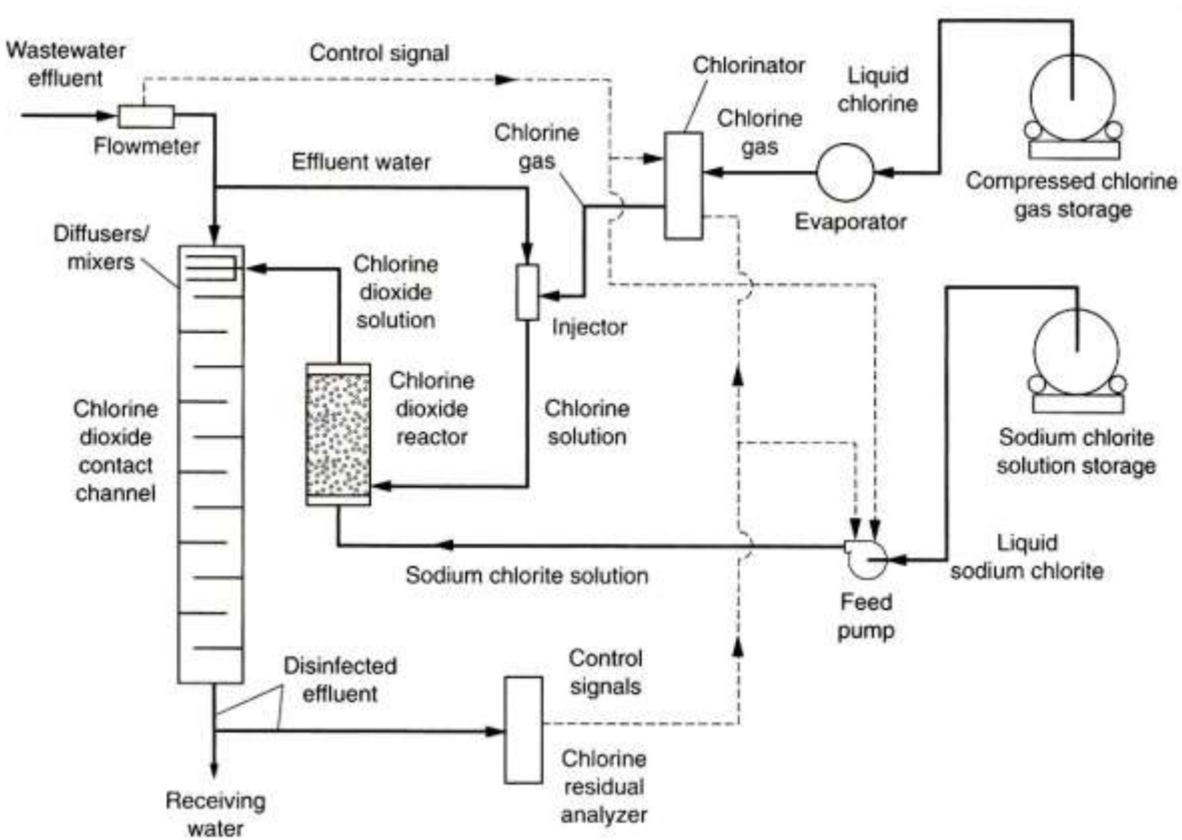



**Figure 12–20**

Typical flow diagram for the addition of chlorine dioxide.

# Chlorine dioxide: effectiveness

TABLE 6 Inactivation of Health-Related Microbes in Water by Chlorine Dioxide

| Microbe | Water | $ClO_2$ Residual (mg/l) | Temp. (°C) | pH | Time (min.) | Reduction (%) | C·t | Reference |
|---|---|---|---|---|---|---|---|---|
| BACTERIA: | | | | | | | | |
| *E. coli* | BDF* | 0.3-0.8 | 5 | 7.0 | 0.6-1.8 | 99 | 0 .48 | Cronier, 1977 |
| *E. coli* | PBS* | 0.4-0.8 | ? | 7.0 | 5 | >99.999 | ND | Fujioka *et* |
| Fec. colif. | effl. | 1.9 | ? | ? | 10 | 99.94 | ND | *al.*, 1986 |
| Fecal strep. | effl. | 1.9 | ? | ? | 10 | 99.5 | ND | " |
| *C. perfringens* | effl. | 1.9 | ? | ? | 10 | 0 | ND | " |
| *E. coli* | BDF | 0.3-0.5 | 5 | ? | 15 | 99.9-99.999 | ND | Berg *et al.*, |
| *L. pneumophila* | BDF | 0.5-0.35 | 23 | ? | 15 | 99.9-99.99 | ND | 1982; 1985 |
| *K. pneumonia* | BDF | ca. 0.12 | 23 | ? | 15 | 99.3-99.7 | ND | Harakeh *et* *al.*, 1985 |
| VIRUSES: | | | | | | | | |
| Coliphage f2 | BDF | 1.5 | 5 | 7.2 | 2 | 99.994 | ND | Olivieri *et* |
| Polio 1 | BDF | 2.0 | 5 | 7.2 | 5-10 | 99-99.96 | ND | *al.*, 1985b |
| Polio 1 | BDF | 0.4-14.3 | 5 | 7.0 | 0.2-11.2 | 99 | 0.2-6.7 | Scarpino *et* *al.*, 1979 |
| Polio 1 | PBS | 0.4-0.8 | ? | 7.0 | 5 | 99.9-99.97 | ND | Fujioka *et* |
| Polio 1 | effl. | 1.9 | ? | ? | 10 | 99.4 | ND | *al.*, 1986 |
| Rota SA11: | | | | | | | | |
| dispersed | BDF | 0.5-1.0 | 5 | 6.0 | 0.2-0.6 | 99 | 0.2-0.3 | Berman and |
| cell-assoc. | BDF | 0.45-1.0 | 5 | 6.0 | 1.2-4.8 | 99 | 1.0-2.1 | Hoff, 1984 |
| cell-assoc. | BDF | 0.46-0.52 | 5 | 10.0 | 0.3-0.4 | 99 | 0.16-0.2 | " |
| Hepatitis A | BDF | 0.14-0.23 | 5 | 6.0 | 8.4 | 99 | 1.7 | Battigelli & |
| Hepatitis A | BDF | 0.2 | 5 | 9.0 | <0.33 | >99.9 | <0.04 | Sobsey, |
| Coliphage MS2 | BDF | 0.15 | 5 | 6.0 | 34 | 99 | 5.1 | in |
| Coliphage MS2 | BDF | 0.15 | 5 | | <0.33 | >99.95 | <0.03 | preparation |
| PROTOZOAN CYSTS: | | | | | | | | |
| *N. gruberi* | BDF | 0.8-1.95 | 5 | 7.0 | 7.8-19.9 | 99 | 15.5 | Chen *et al.*, |
| *N. gruberi* | BDF | 0.46-1.0 | 25 | 5.0 | 5.4-13.2 | 99 | 6.35 | 1985 |
| *N. gruberi* | BDF | 0.35-1.26 | 25 | 7.0 | 4.0-14.2 | 99 | 5.51 | " |
| *N. gruberi* | BDF | 0.42-1.1 | 25 | 9.0 | 2.5-6.7 | 99 | 2.91 | " |
| *G. muris* | BDF | 0.1-5.55 | 5 | 7.0 | 1.3-168 | 99 | 10.7 | Leahy, 1985; |
| *G. muris* | BDF | 0.26-1.2 | 25 | 5.0 | 4.0-24 | 99 | 5.8 | 1987; |
| *G. muris* | BDF | 0.21-1.12 | 25 | 7.0 | 3.3-28.8 | 99 | 5.1 | Rubin, 1988 |
| *G. muris* | BDF | 0.15-0.81 | 25 | 9.0 | 2.1-19.2 | 99 | 2.7 | " |

*BDF = buffered demand free; PBS = phosphate buffered saline

# Chlorine dioxide: advantages and disadvantages

- Advantages
  - Very effective against all type of microbes
- Disadvantages
  - Unstable (must be produced on-site)
  - High toxicity
    - $2ClO_2 + 2OH^- = H_2O + ClO_3^-$ (Chlorate) + $ClO_2^-$ (Chlorite): in alkaline pH
  - High chemical hazards
  - Highly sensitive to inorganic and organic loads
  - Formation of harmful disinfection by-products (DBP's)
  - Expensive

# Chlorine dioxide: other applications

- Hospital/household surface disinfectant
  - ‘stabilized’ chlorine dioxide and ‘activator’
- Industrial application
  - bleaching agent: pulp and paper industry, and food industry (flour, fats and fatty oils)
  - deordoring agent: mildew, carpets, spoiled food, animal and human excretion
- Gaseous sterilization

# Ozone: Chemistry

- The method of generation
  - generated on-site
  - generated by passing dry air (or oxygen) through high voltage electrodes (ozone generator)
  - bubbled into the water to be treated.
- Ozone
  - colorless gas
  - relatively unstable
  - highly reactive
    - reacts with itself and with $OH^-$ in water

# Generation of ozone

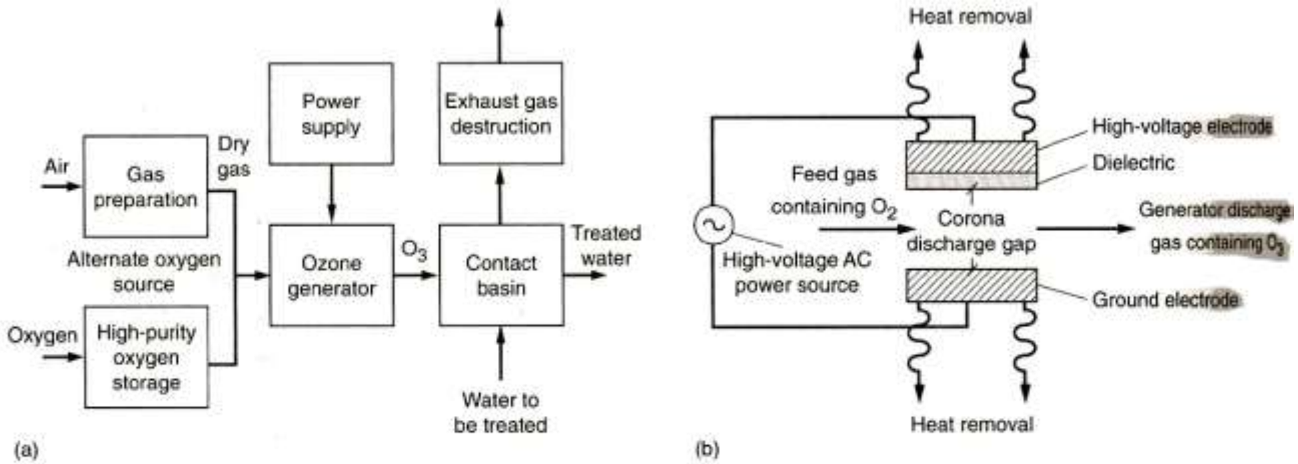


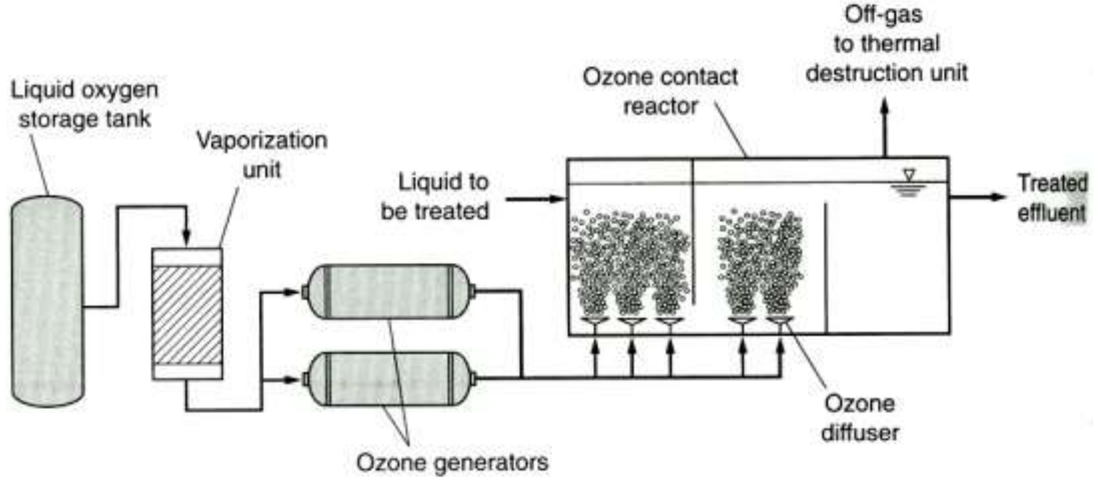

**Figure 12–29**

Elements of ozone disinfection system: (*a*) schematic flow diagram for complete ozone disinfection system and (*b*) schematic detail of the generation of ozone. *(Adapted from U.S. EPA, 1986.)*

# Application of ozone: flow diagram

**Figure 12–30**

Typical flow diagram for the application of ozone for disinfection.



# Ozone: reactivity



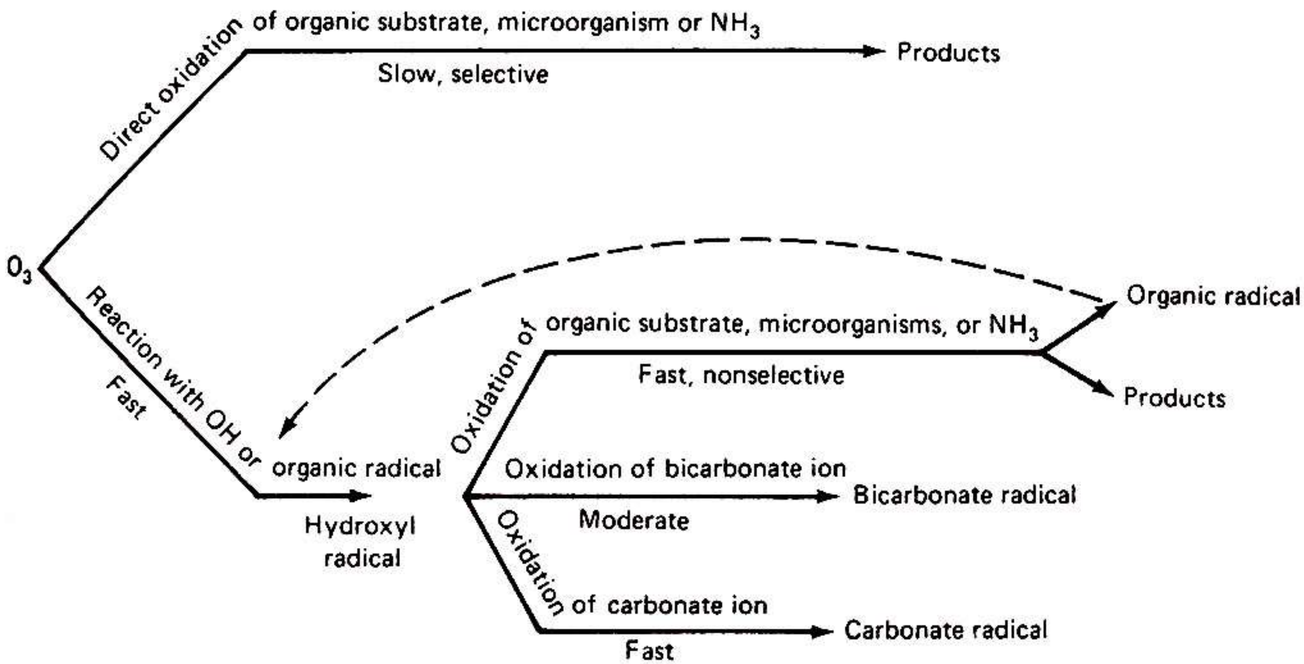



**FIGURE 10.19** Reaction pathways of ozone in water. (*Source: J. Hoigne and H. Bader, "Role of Hydroxyl Radical Reactions in Ozonation Processes in Aqueous Solutions,"* Water Resources Bulletin, *vol. 10, 1976, p. 377.*)

# Ozone: effectiveness

TABLE 5 Inactivation of Health-related Microbes in Water by Ozone

| Microbe | Water | $O_3$ Residual mg/l | Temp. (°C) | pH | Time (min.) | Reduction (%) | Est. C·t | Reference |
|---|---|---|---|---|---|---|---|---|
| E. coli | ? | 0.04-0.07 | 1 | 7.2 | 0.08-0.5 | 99 | 0.006-0.02 | Katzenelson et al., 1974 |
| Tot. colif. | effl. | 5.0 | 12.6 | 7.1 | 18 | 99.89 | ND | Netzer et |
| Fecal strep. | effl. | 5.0 | 12.6 | 7.1 | 18 | 99 | ND | al., 1979 |
| E. coli | effl. | 0.29-0.36 | 24 | 7.4 | 0.6 | 99.94 | ND | Farooq and |
| S. typhi- | | | | | | | | Akhlaqe, 1983 |
| murium | effl. | " | " | " | " | 99.9998 | ND | " |
| M. fortuitum | effl. | 0.29-0.36 | 24 | 7.4 | 0.6 | 89 | ND | " |
| M. fortuitum | BDF* | 0.8-1.08 | 24 | 7.0 | 0.58 | 99 | 0.53 | Farooq et al., 1977 |
| VIRUSES: | | | | | | | | |
| Polio 1 | BDF | 0.15-0.2 | 5 | 7.2 | 0.4-1.5 | 99 | 0.2 | Roy et al., |
| Polio 2 | BDF | 0.15 | 25 | 7.2 | 4.83 | 99 | 0.72 | 1982 |
| Polio 1 | effl. | 0.29-0.36 | 24 | 7.4 | 0.6 | 99.5 | ND | Farooq and Akhlaque, 1983 |
| Polio 1 | effl. + $HCO_3$ | 0.2 | 20 | 7.0 | 10-15 | 97 | | Harakeh and |
| Polio 1 | effl. | 0.2 | 20 | 7.0 | 10-15 | 80 | | Butler, 1985 |
| Rota SA11 | BDF | 0.1-0.3 | 4 | 6.0-8.0 | 0.12-0.19 | 99 | 0.019-0.064 | Vaughn et |
| Human rota | BDF | 0.05-0.3 | 4 | 6.0-9.0 | 0.0.12-0.19 | | 0.006-0.036 | al., 1987 |
| Rota SA11 | effl. | 0.26 | 15 | 7.2 | 15 | 96 | ND | Harakeh and |
| Human rota | effl. | 0.26 | 15 | 7.2 | 15 | 40 | ND | Butler, |
| Human rota | effl. | 0.4 | 15 | 7.2 | 15 | 99.99 | ND | 1985 |
| PROTOZOAN CYSTS*: | | | | | | | | |
| G. muris | BDF | 0.15-0.7 | 5 | 7.0 | 2.8-12.9 | 99 | 1.94 | Wickramanayake |
| G. lamblia* | BDF | 0.11-0.48 | 5 | 7.0 | 0.94-5.0 | 99 | 0.53 | et al., 1984; |
| N. gruberi | BDF* | 0.55-2.0 | 5 | 7.0 | 2.1-7.8 | 99 | 4.23 | 1985 |
| N. (6 sp.) | DW* | 0.4 | 25 | 7.0 | 4 | >98.9 | ND | Langlais and |
| A. polyphaga* | DW | 0.4 | 25 | 7.0 | 4 | 95 | ND | Perrine, |
| A. (3 sp.) | DW | 0.4 | 25 | 7.0 | 4 | >98.9 | ND | 1986 |

*BDW = buffered demand free water; DW = distilled water; G. = Giardia; N. = Naegleria; A. = Acanthamoeba.

# Ozone: advantages and disadvantages

- Advantages
  - Highly effective against all type of microbes
- Disadvantages
  - Unstable (must be produced on-site)
  - High toxicity
  - High chemical hazards
  - Highly sensitive to inorganic and organic loads
  - Formation of harmful disinfection by-products (DBP’s)
  - Highly complicated maintenance and operation
  - Very expensive

# Ozone: other applications

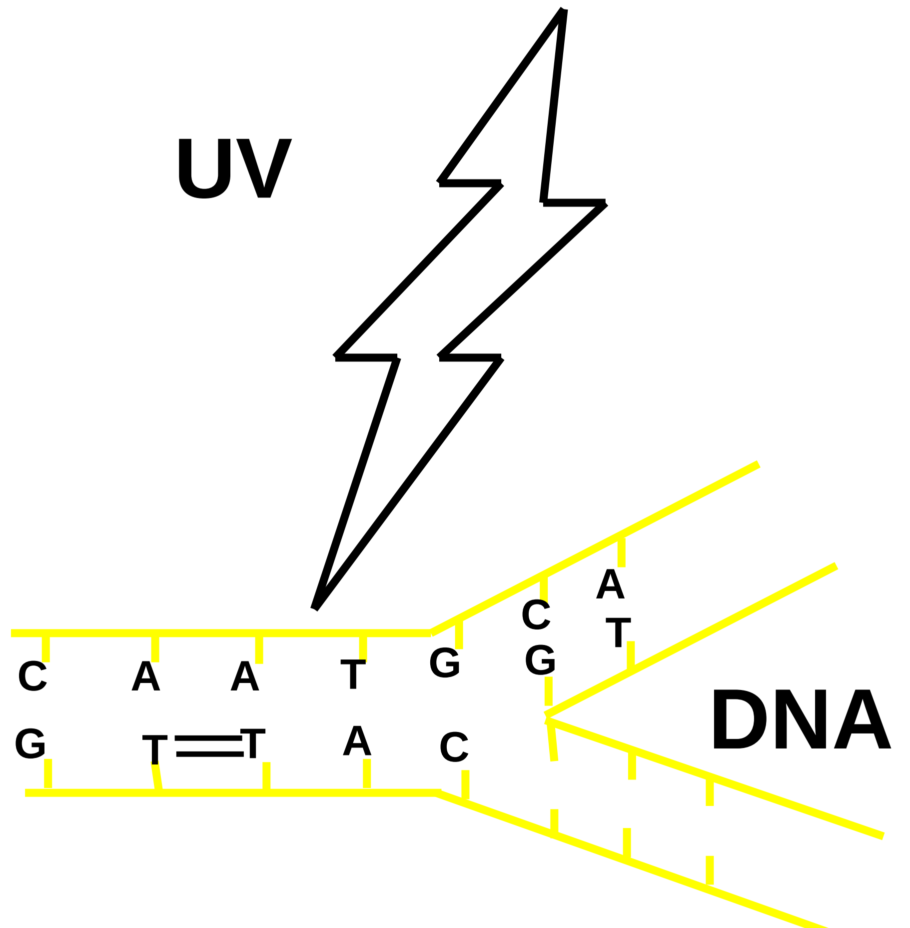
- Industrial applications
  - aquaria, fish disease labs, and aquaculture
  - cooling towers
  - pharmaceuticals and integrated circuit processing (ultra-pure water)
  - pulp and paper industry
- Gaseous sterilization
  - cleaning and disinfection of healthcare textiles

Questions?

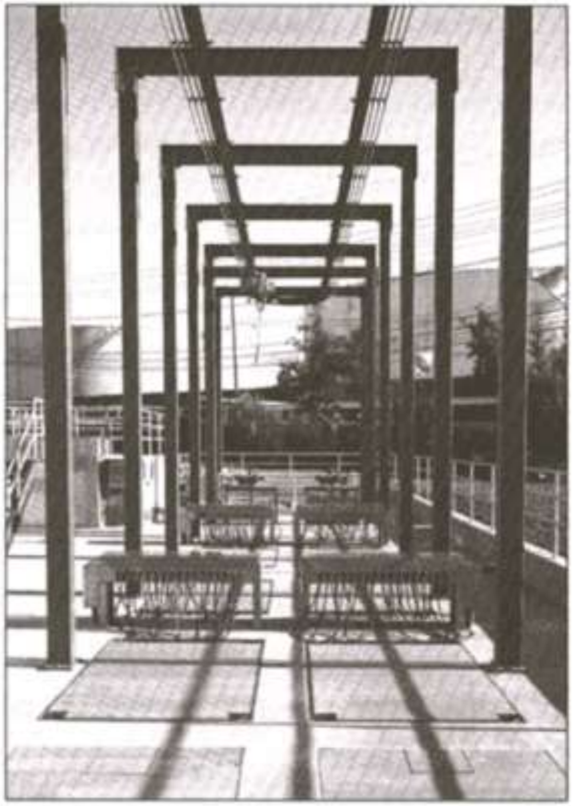
# Physical disinfectants

# Ultraviolet irradiation: mechanism

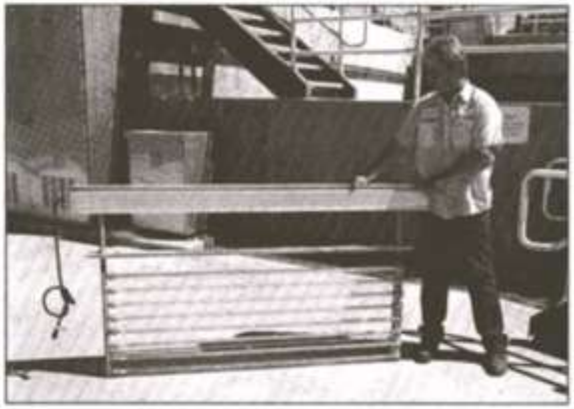
- Physical process
- Energy absorbed by DNA
  - pyrimidine dimers, strand breaks, other damages
  - inhibit replication



# Low-pressure (LP) UV: wastewater



(a)

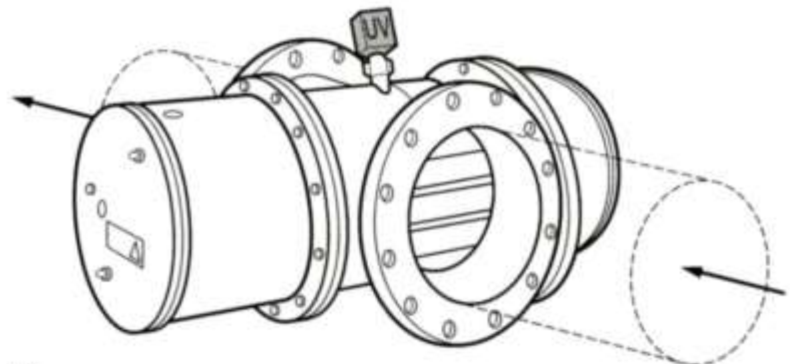


(b)

# Medium-pressure (MP) UV: drinking water

**Figure 12–36**

Typical closed-channel UV disinfection system with lamps placed perpendicular to the flow: (*a*) Isometric cutaway view of disinfection reactor and (*b*) view of typical installation. *(Courtesy Aquionics Inc.)*




(a)

(b)

# UV disinfection: effectiveness

TABLE 7 Inactivation of Health-Related Microbes in Water by Ultraviolet Radiation

| Microbe | Water | UV Dose ($mW\text{-}s/cm^2$) | Temp. ($^oC$) | pH | Reduction (%) | Reference |
|---|---|---|---|---|---|---|
| BACTERIA: | | | | | | |
| E. coli | BDW* | 6.5 | room | ? | 99.9 | Chang, |
| Total coliforms | effl. | 8.2 | room | ? | 99.9 | et al., |
| HPC | effl. | 14 | room | ? | 99.9 | 1985 |
| B. subtilis spores | BDW | 60 | room | ? | 99.9 | " |
| Total coliforms | effl. | 6.5 | ? | ? | 99 | Qualls et |
| Total coliforms | effl. | 9.6-52 | ? | ? | 99.97 | al., 1985 |
| Total coliforms | filt. effl. | 5.7 | ? | ? | 99 | " |
| Total coliforms | tea | 7.2-28 | ? | ? | >99.95 | Tobin et |
| HPC | tea | 7.2-28 | ? | ? | 88-96 | al., 1983 |
| Fecal coliforms | sewage | ca. 275 | ? | ? | 99.9 | Zukovs |
| Enterococci | sewage | ca. 275 | ? | ? | 99.9 | et al., |
| P. aeruginosa | sewage | ca. 280 | ? | ? | 99.9 | 1986 |
| E. coli recA-, uvrA- | on medium | 10.3 | ? | ? | 99.9 | Knudson, |
| E. coli, B/r | " | 0.1 | ? | ? | 99.9 | 1985 |
| Legionella (6 sp.) | " | 0.8-5.5 | ? | ? | 99.9 | " |
| L. pneumophila | tap | 30 | 25 | ? | 99.9 | Muraca et al., 1987 |
| L. pneumophila | dist. water | 1.8 | room | ? | 99.9 | Butler et |
| Y. enterocolitica | dist. water | 2.7 | room | ? | 99.9 | al., 1987 |
| C. jejuni | dist. water | 5.0 | room | ? | 99.9 | " |
| VIRUSES: | | | | | | |
| Polio 1 | PBS* | 21 | room | 7.5 | 99.9 | Chang et |
| Rota SA11 | PBS | 25 | room | 7.5 | 99.9 | al., 1985 |
| Polio 1 | BDW | 29 | ? | 7.2 | 99.9 | Harris et |
| Reo 1 | BDW | 45 | ? | 7.2 | 99.9 | al., 1987 |
| PROTOZOAN CYSTS: | | | | | | |
| Giardia lamblia | BDW | 63 | ? | ? | 70 | Rice and Hoff, 1981 |
| A. castellanii | BDW | 100 | room | ? | 99.9 | Chang et al., 1985 |

*BDW = buffered distilled water; PBS = phosphate buffered saline

# UV disinfection: advantages and disadvantages

- Advantages
  - Very effective against bacteria, fungi, protozoa
  - Independent on pH, temperature, and other materials in water
  - No known formation of DBP
- Disadvantages
  - Not so effective against viruses
  - No lasting residuals
  - Expensive

# UV disinfection: other applications

- Disinfection of air
- Surface disinfectant
  - Hospital/food production
- Industrial application
  - Cooling tower (Legionella control)
  - Pharmaceuticals (disinfection of blood components and derivatives)

# Disinfection Kinetics

# Disinfection Kinetics

- Chick-Watson Law:

$$\ln N_t/N_o = -kC^n t$$

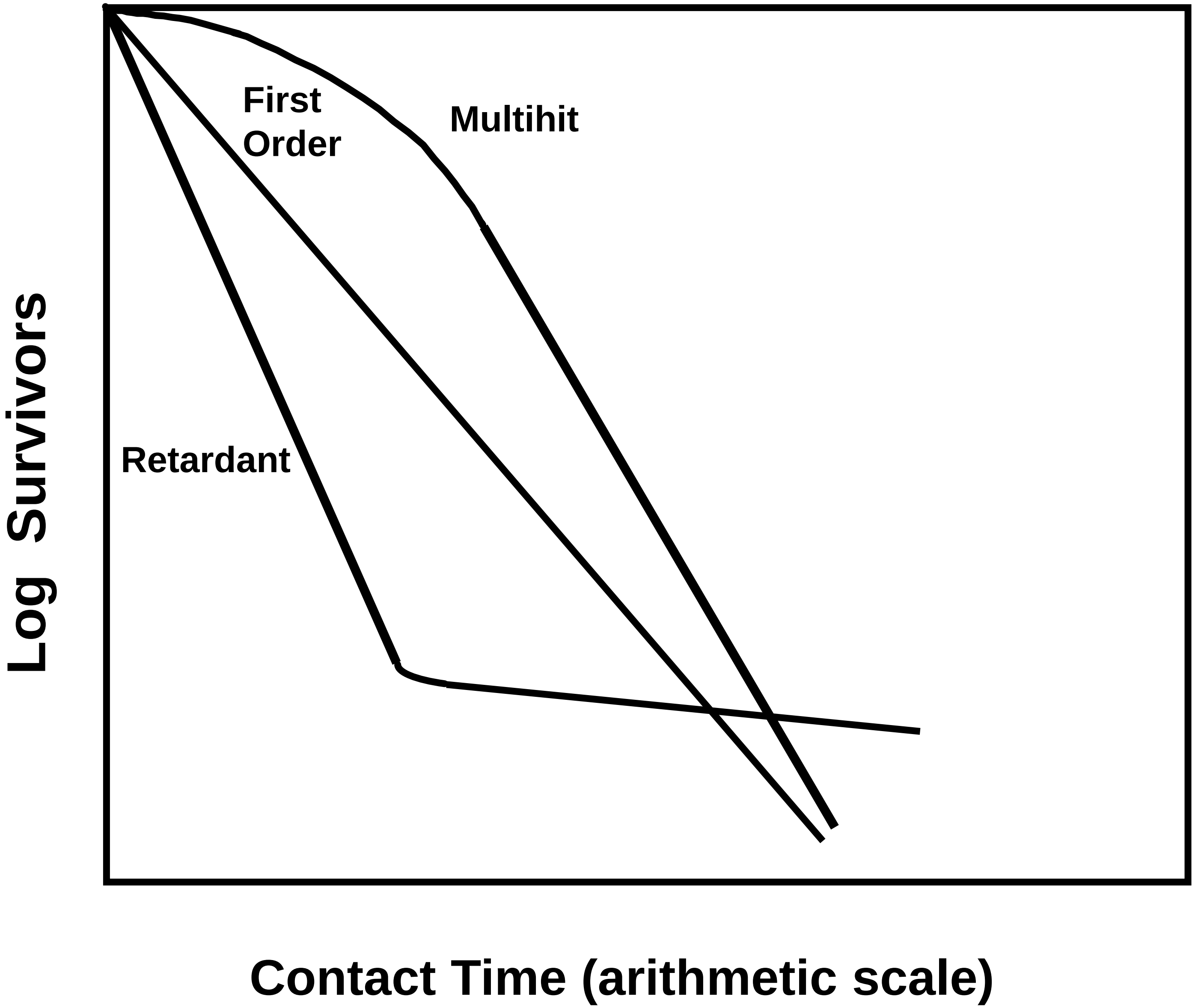
where:
$N_o$ = initial number of organisms
$N_t$ = number of organisms remaining at time = t
k = rate constant of inactivation
C = disinfectant concentration
n = coefficient of dilution
t = (exposure) time

  - Assumptions
    - Constant disinfectant concentration
    - Homogenous microbe population: all microbes are identical
    - "Single-hit" inactivation: one hit is enough for inactivation
  - When k, C, n are constant: first-order kinetics

- Decreased disinfectant concentration over time or heterogeneous population
  - "tailing-off" or concave down kinetics: initial fast rate that decreases over time

- Multi-hit inactivation
  - "shoulder" or concave up kinetics: initial slow rate that increase over time

# Chick-Watson Law and deviations



# CT Concept

- Based on Chick-Watson Law
- “Disinfection activity can be expressed as the product of disinfection concentration (C) and contact time (T)”
- The same CT values will achieve the same amount of inactivation

# Disinfection Activity and the CT Concept

- Example: If CT = 100 mg/l-minutes, then
  - If C = 1 mg/l, then T must = 100 min. to get CT = 100 mg/l-min.
  - If C = 10 mg/l, T must = 10 min. in order to get CT = 100 mg/l-min.
  - If C = 100 mg/l, then T must = 1 min. to get CT = 100 mg/l-min.

# $C*t_{99}$ Values for Some Health-related Microorganisms (5°C, pH 6-7)

| Organism | Disinfectant | | | |
|---|---|---|---|---|
| | Free chlorine | Chloramines | Chlorine dioxide | Ozone |
| *E. coli* | 0.03 – 0.05 | 95 - 180 | 0.4 – 0.75 | 0.03 |
| Poliovirus | 1.1 – 2.5 | 768 - 3740 | 0.2 – 6.7 | 0.1 – 0.2 |
| Rotavirus | 0.01 – 0.05 | 3806 - 6476 | 0.2 – 2.1 | 0.06-0.006 |
| *G. lamblia* | 47 - 150 | 2200 | 26 | 0.5 – 0.6 |
| *C. parvum* | 7200 | 7200 | 78 | 5 - 10 |

# $I*t_{99.99}$ Values for Some Health-Related Microorganisms

| Organism | UV dose (mJ/cm2) | Reference |
|---|---|---|
| *E.coli* | 8 | Sommer et al, 1998 |
| *V. cholera* | 3 | Wilson et al, 1992 |
| Poliovirus | 21 | Meng and Gerba, 1996 |
| Rotavirus-Wa | 50 | Snicer et al, 1998 |
| Adenovirus 40 | 121 | Meng and Gerba, 1996 |
| *C. parvum* | < 3 | Clancy et al, 1998 |
| *G. lamblia* | < 1 | Shin et al, 2001 |