ENV H 440/ENV H 541

Wastewater treatment processes (II)

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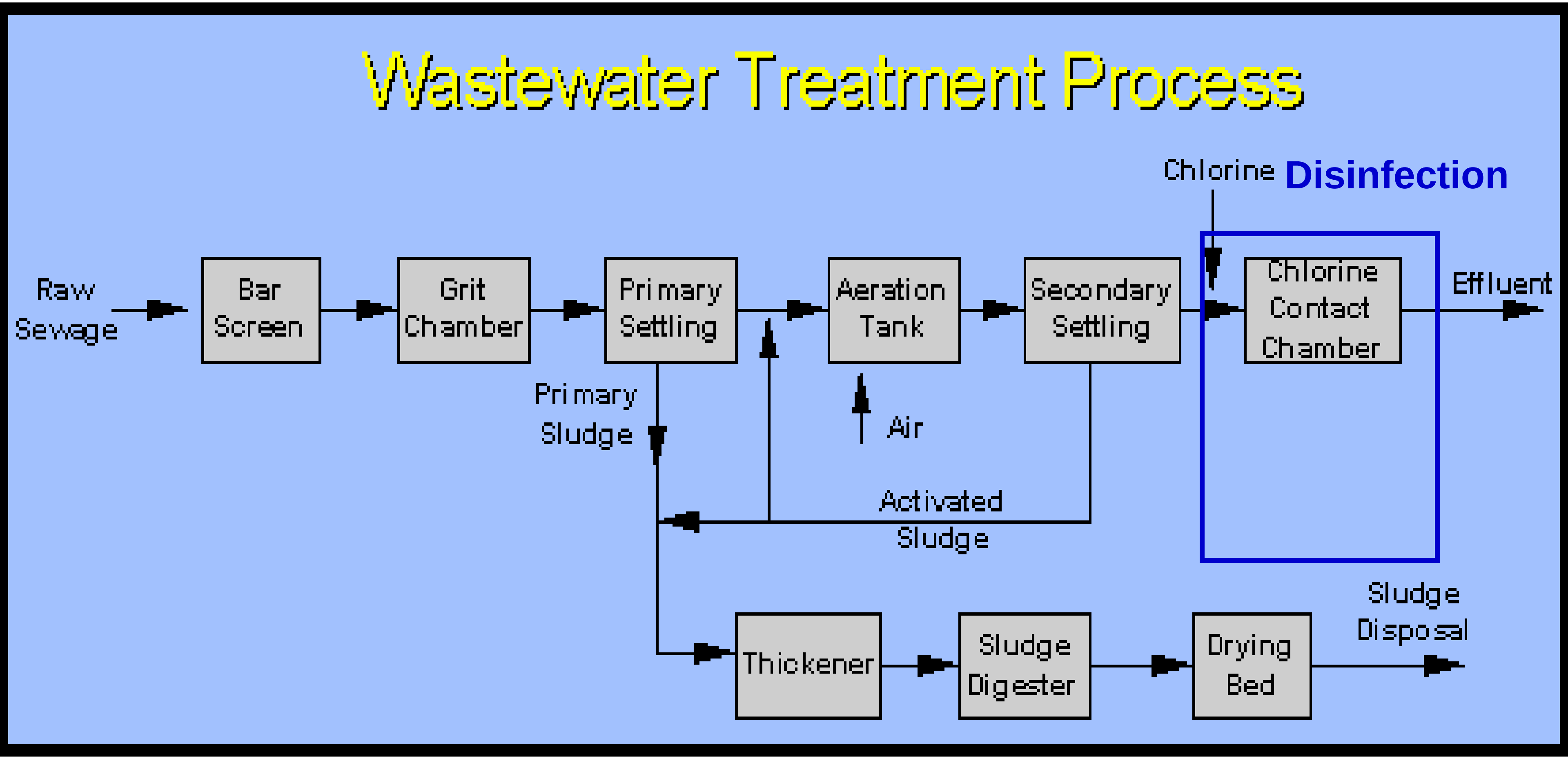
Wastewater Disinfection



Wastewater disinfection

- To inactivate pathogens in wastewater
- Several choices
  - Free chlorine and combined chlorine
  - UV
  - Ozone
  - Chlorine dioxide

Chlorination

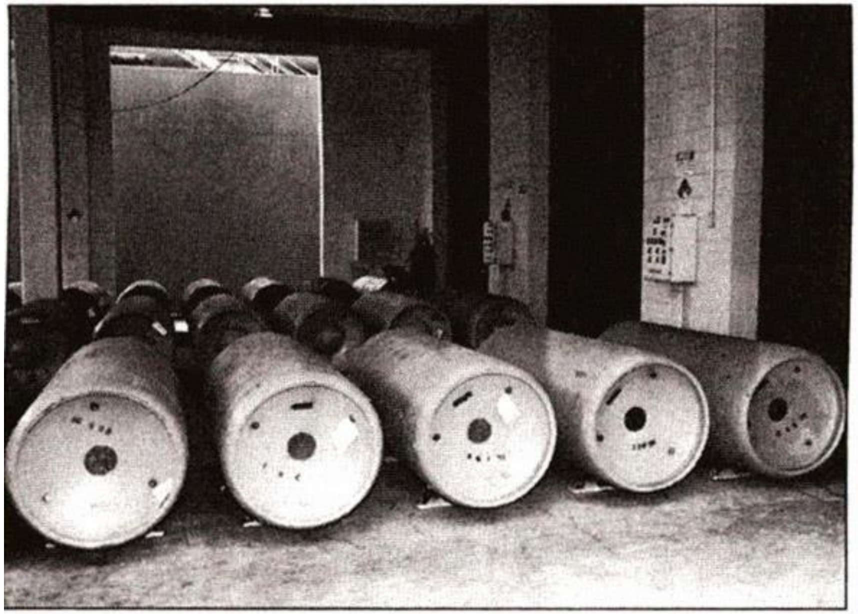
Free chlorine - Chemistry

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

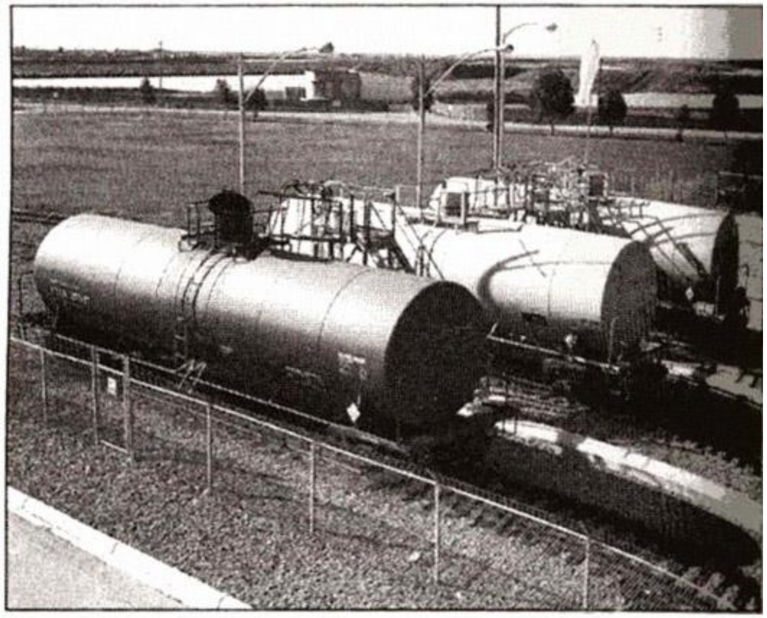
$$Cl_2\ (g) + H_2O <=> HOCl + Cl^- + H^+$$

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

Chlorine application (I)

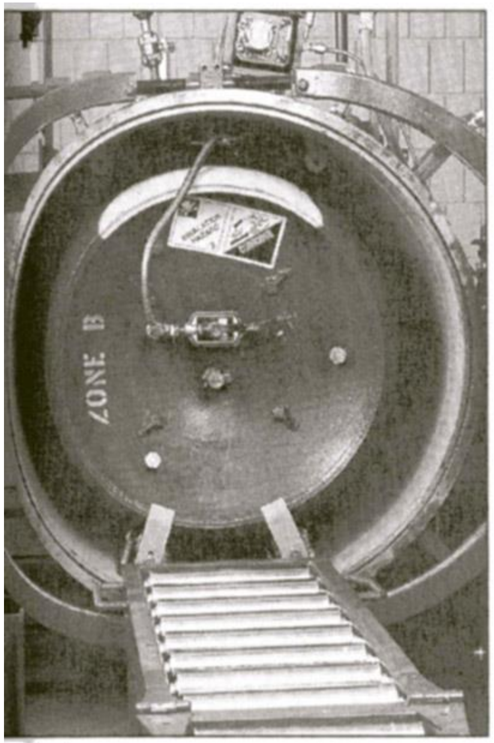


(a)

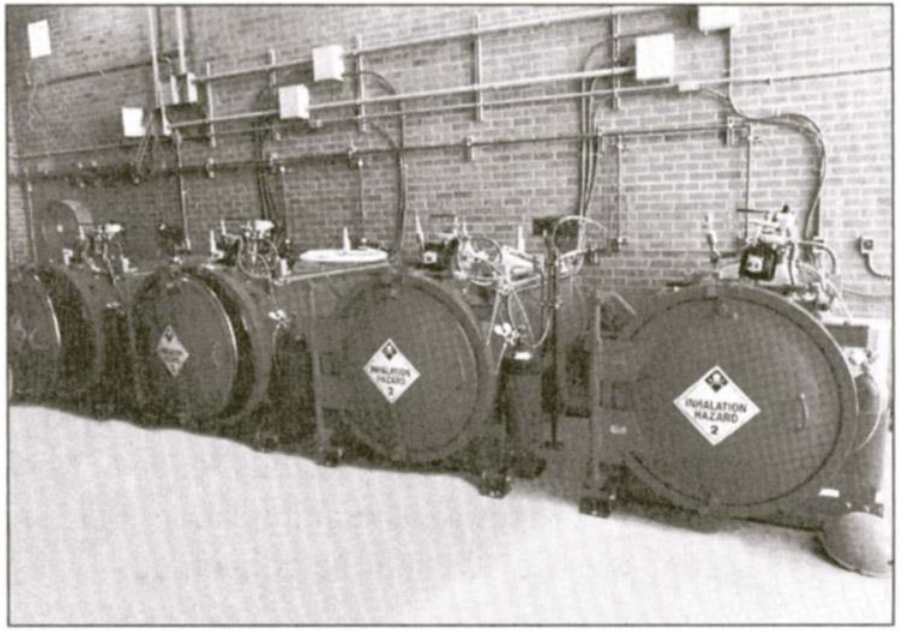


(b)

Chlorine application (II)

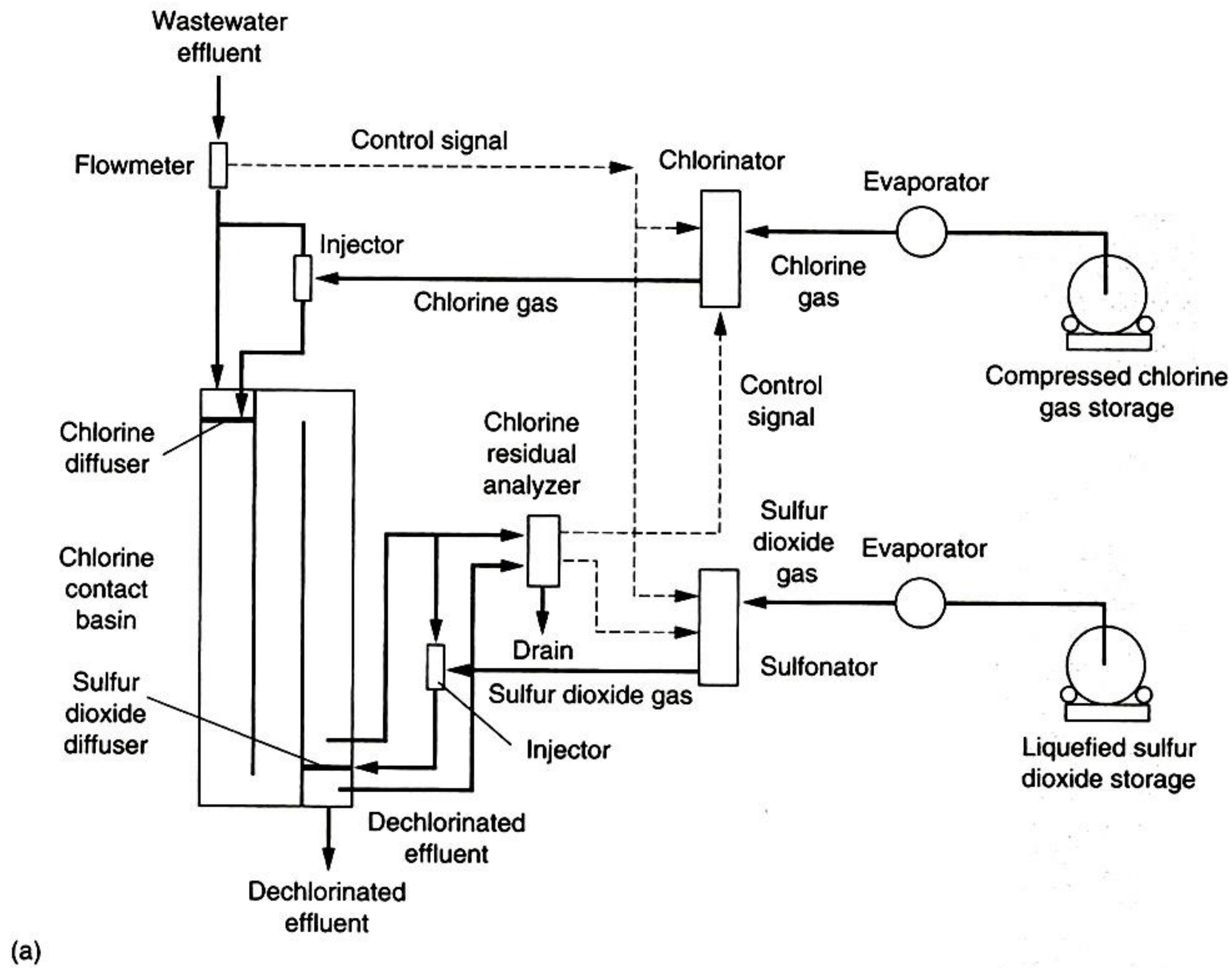


(a)



(b)

Chlorine application (III): Gas



Chlorine application (IV): Mixing

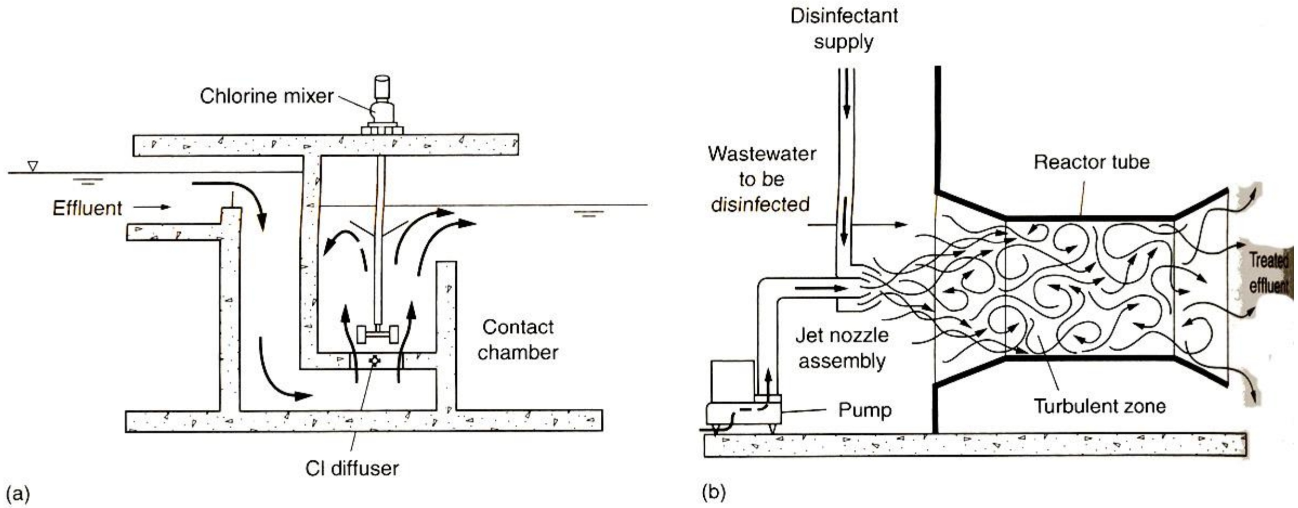


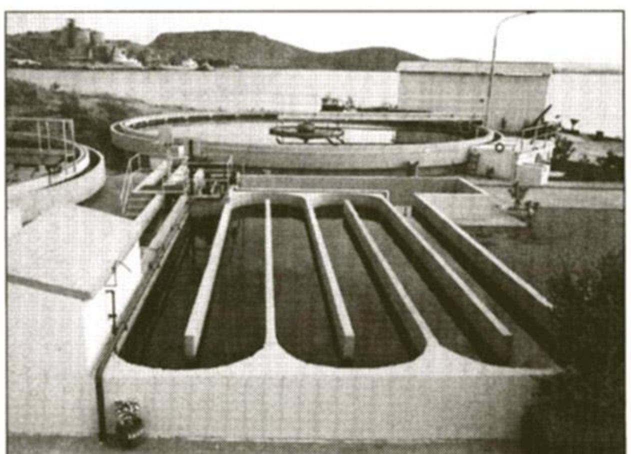
Figure 12–22

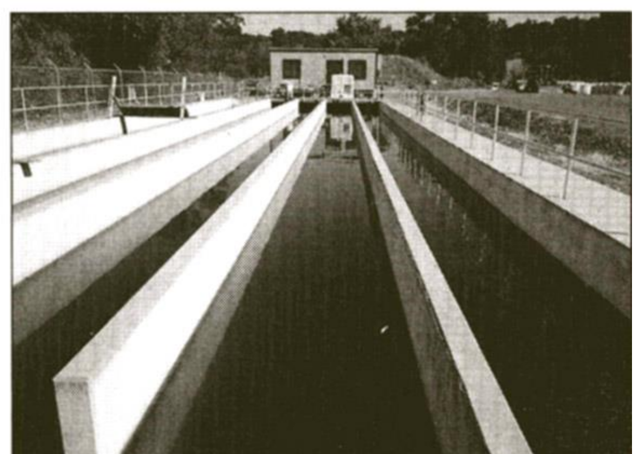
Typical mixers for the addition of chlorine: (*a*) in-line turbine mixer and (*b*) injector pump type. *(From Pentech-Houdaille.)* For additional types of chlorine mixers see Fig. 5–14 in Chap. 5.

Chlorine application (V): Contact chambers (I)

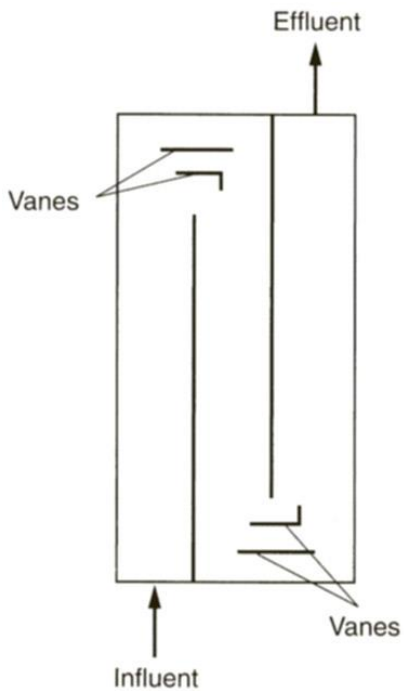

(a)


(b)


(c)

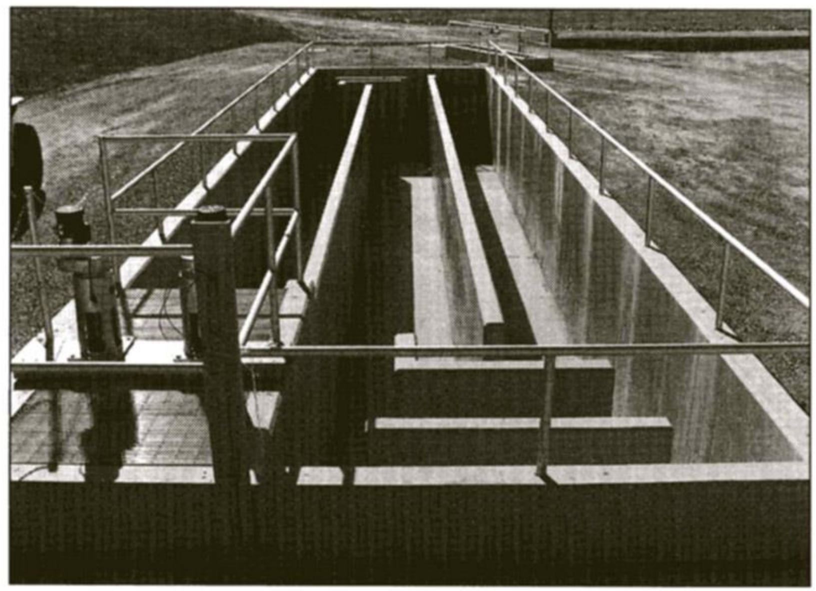

(d)

Chlorine application (VI): Contact chambers (II)



Plan view of
chlorine contact basin

(a)



(b)

Chlorination in drinking water

- Reactions for free chlorine formation:

$$Cl_2\ (g) + H_2O \Leftarrow\Rightarrow HOCl + Cl^- + H^+$$

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

Chlorination in wastewater

- Dynamic chloramination
  - Reaction of free chlorine and ammonia *in situ*
- Chloramine formation
  - $HOCl + NH_3 <=> NH_2Cl + H_2O$
  - $NH_2Cl + HOCl <=> NHCl_2 + H_2O$
  - $NHCl_2 + HOCl <=> NCl_3 + H_2O$

  - $½\ NHCl_2 + ½\ H_2O <=> ½\ NOH + H^+ + Cl^-$
  - $½\ NHCl_2 + ½\ NOH <=> ½\ N_2 + ½\ HOCl + ½\ H^+ + ½\ Cl^-$

Breakpoint Reaction for Chlorine

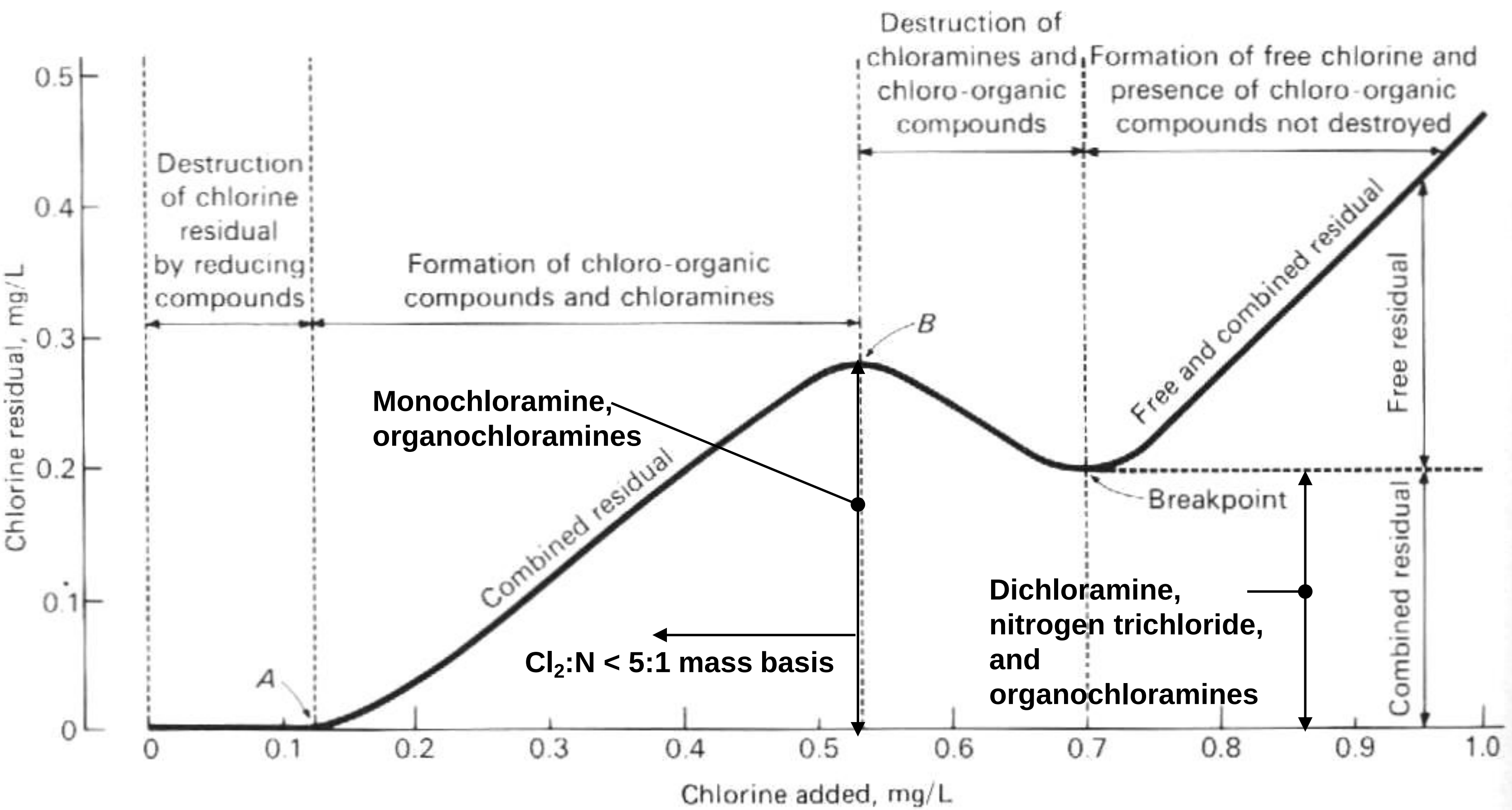


Figure 7-14 Generalized curve obtained during breakpoint chlorination. Note: mg/L = g/m^3.

Ref: Metcalf & Eddy, Inc., 1979. Wastewater Engineering, Treatment and Disposal. McGraw-Hill, New York.

Total and combined chlorine

- Total chlorine = free chlorine + combined chlorine
- Combined chlorine = inorganic chloramines (monochloramine, dichloramine, nitrogen trichloride) + organic chloramines

Wastewater chlorination

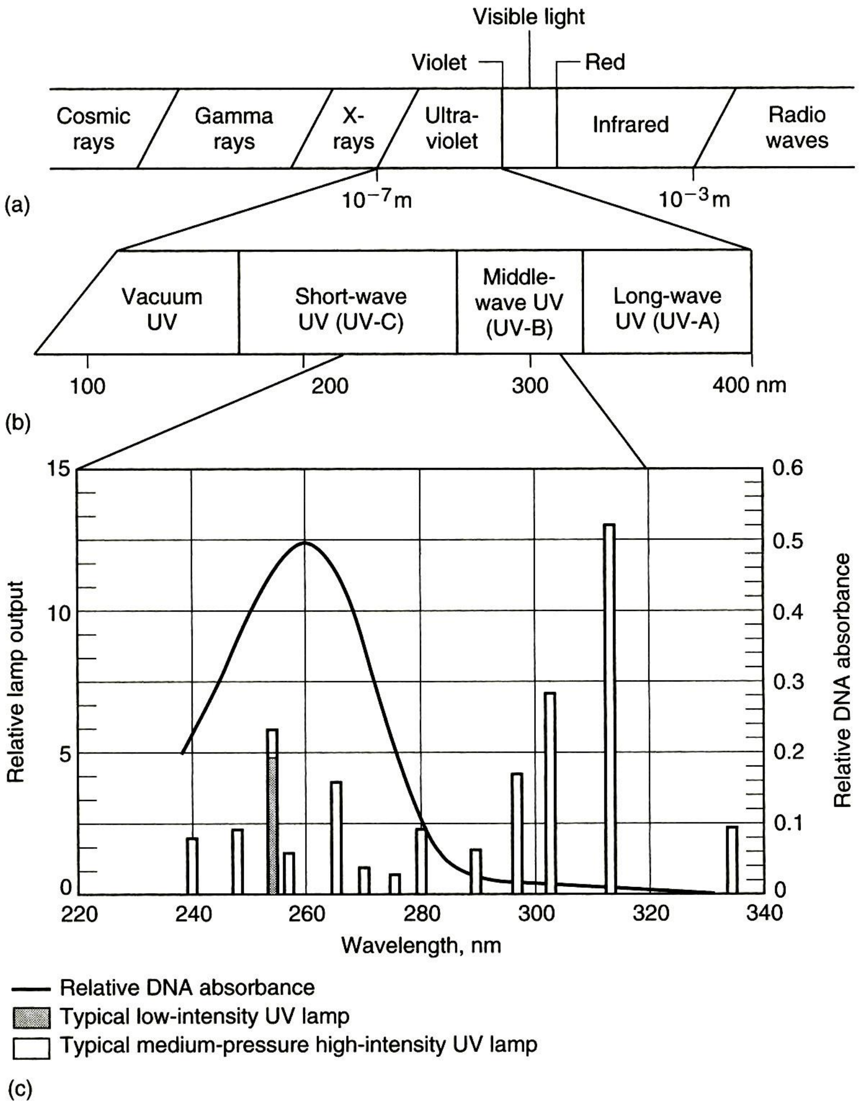
- To inactivate pathogens in wastewater
- Dynamic chloramination and breakpoint chlorination
- 5 - 20 mg/L for 30 minutes
- > 99.99 % reduction of total and fecal coliforms, ~90 % reduction of enteric viruses, ~50% reduction of *Giardia lamblia* cysts, but <10 % reduction of *Cryptosporidium parvum* oocysts

Dechlorination

- Chlorine and monochloramine are very toxic to aquatic life in the receiving stream.
- Neutralization of chlorine
  - Sulfur dioxide (gas)
  - Sodium metabisulfite (liquid)
  - UV irradiation

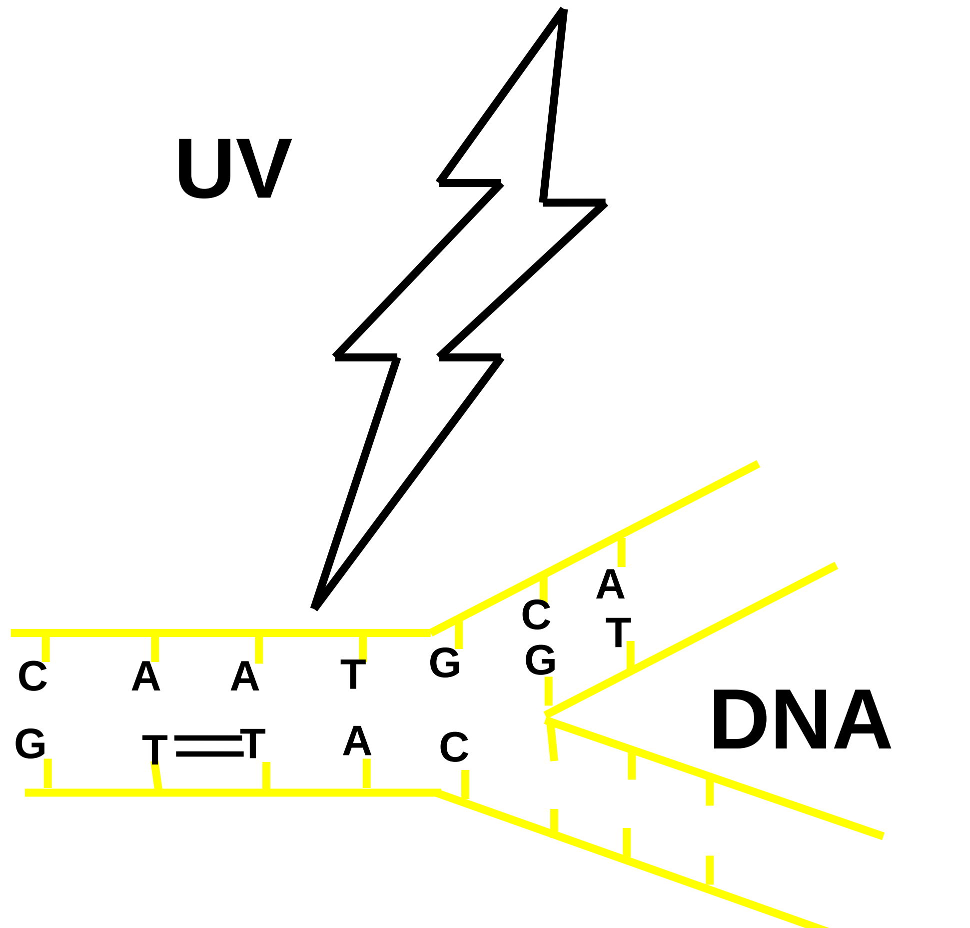
UV irradiation

Spectrum of radiations



Ultraviolet irradiation

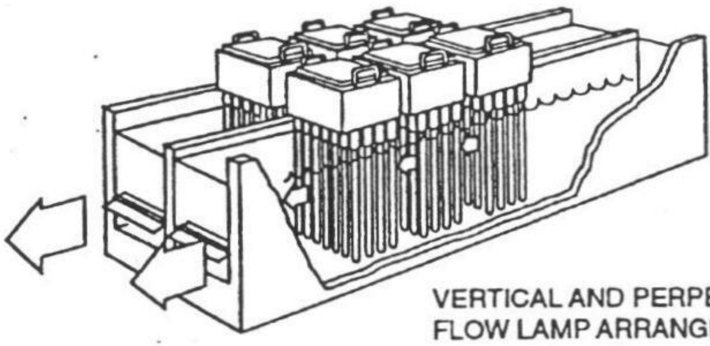
- Physical process
- Energy absorbed by DNA
  - pyrimidine dimers, strand breaks, other damages
  - inhibits replication



UV disinfection – UV lamps

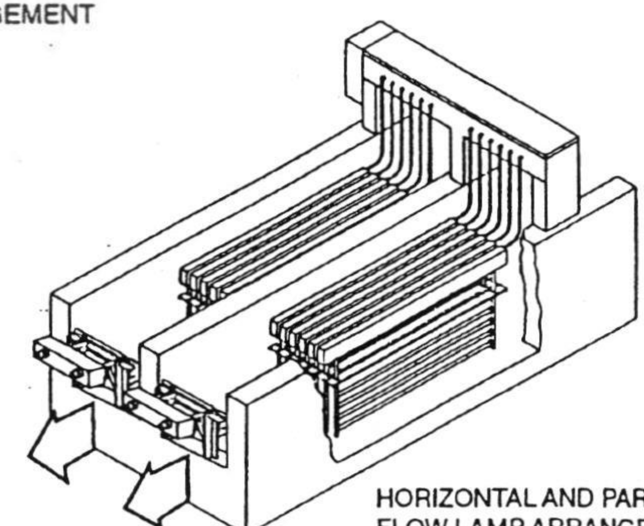
- Low pressure (LP) UV lamps
  - Wavelength at 254 nm
  - Low intensity
- Medium pressure (MP) UV lamps
  - Wavelengths between 100-1000 nm
  - High intensity
- Pulsed UV lamps
  - Intermittent emission
  - High intensity

UV application (I): configuration

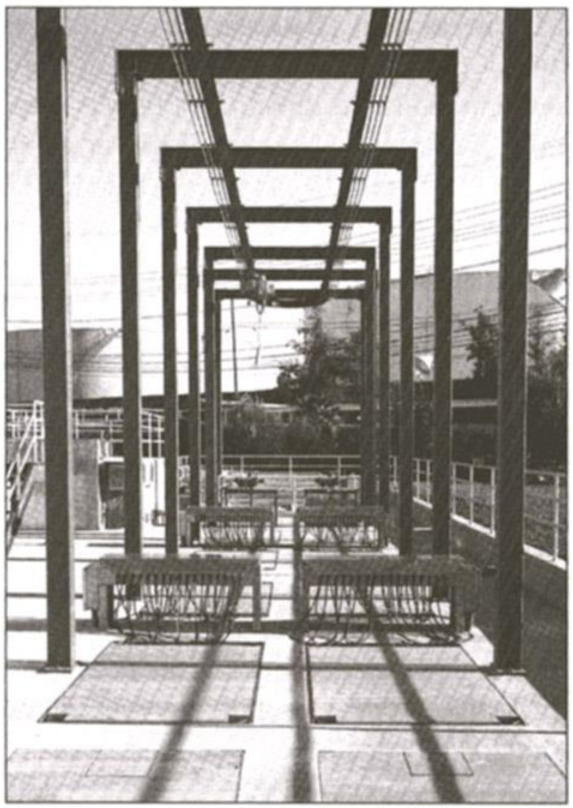


Typical Contactor Configurations

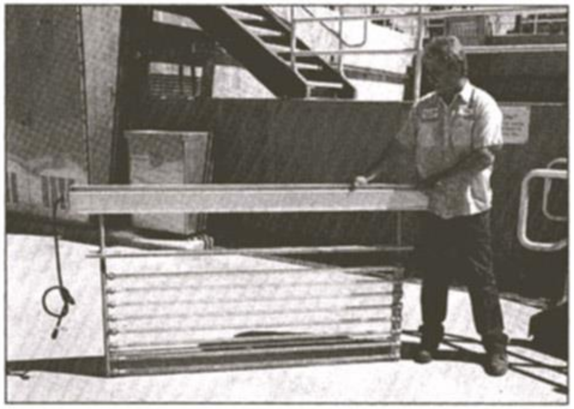
See next few slides for pictures of UV units



UV application (II):
LP UV with vertical arrangement

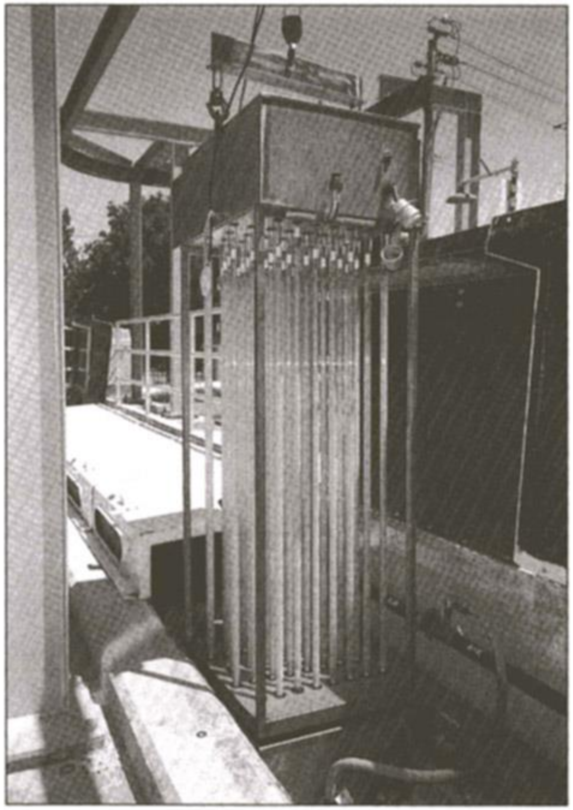


(a)

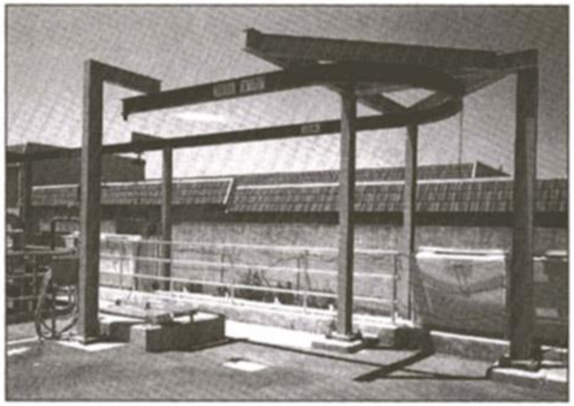


(b)

UV application (III): LP UV with horizontal arrangement



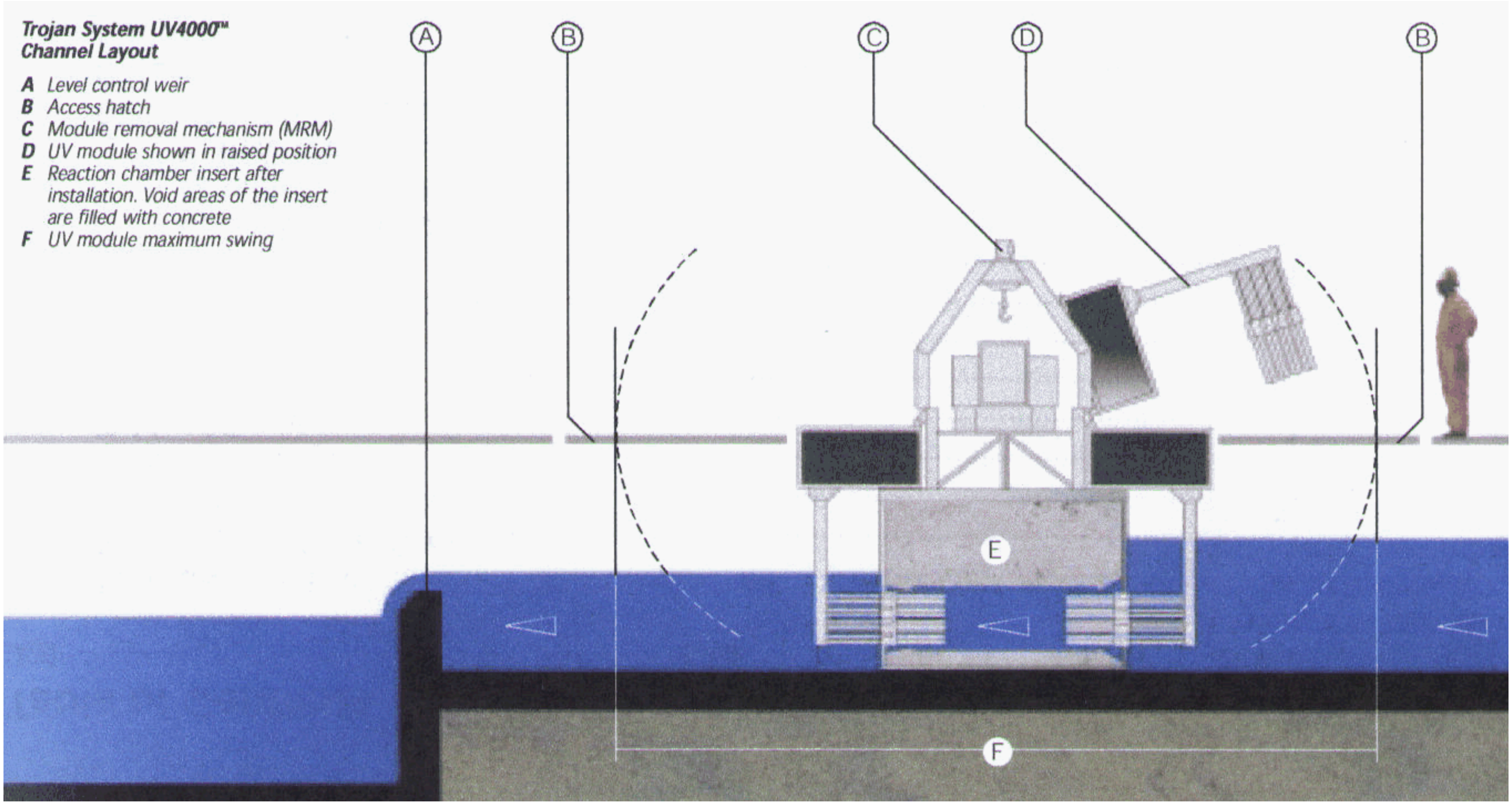
(a)



(b)

UV application (IV): MP UV (I)

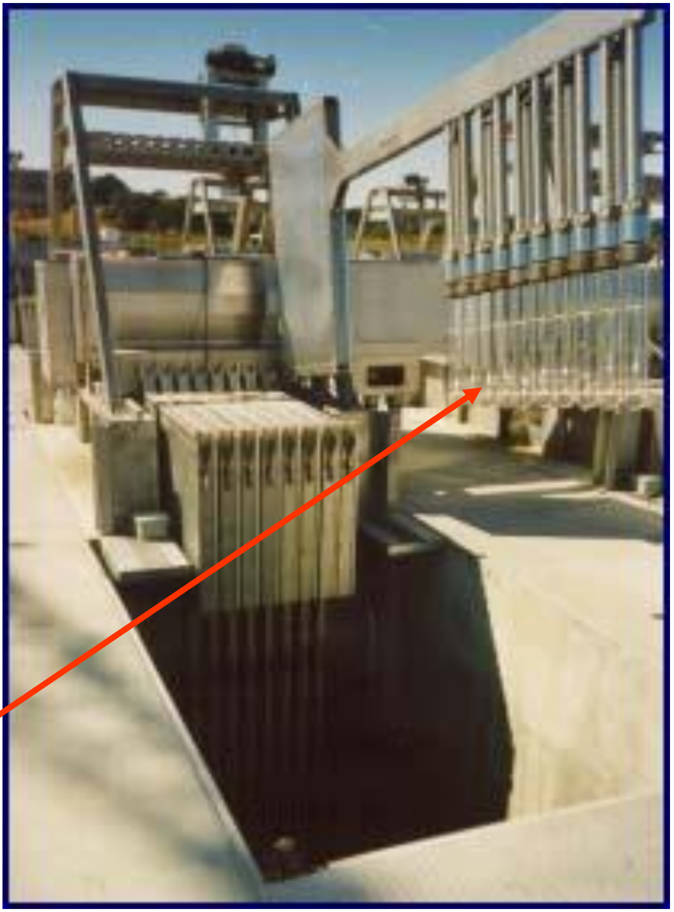
Closed-channel, horizontal, parallel to flow
Medium pressure, high-intensity lamps
Automatic cleaning



UV application (V): MP UV(II)

Closed-channel, horizontal, parallel to flow (Trojan)

Raised UV Lamp Unit



UV disinfection in wastewater

- To inactivate pathogens in wastewater
- LP, LPHO, or MP UV lamps
- 40 mJ/cm^2
- Similar level of reduction for total and fecal coliforms, and enteric viruses, but a lot higher level of reduction for *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts

Advanced treatment

(Minimum) Goals of wastewater treatment processes

- <30 mg/L of BOD_5
- <30 mg/L of suspended solids
- <200 CFU/100ml of fecal coliforms

Limitation of conventional wastewater treatment

- Low reduction of phosphorus and nitrogen (ammonia)
- No removal of soluble nonbiodegradable chemicals
- Variable removal rate of heavy metals, and toxins

The effect of contaminants

- Phosphorus and nitrogen: eutrophication
  - Excessive growth of algae
  - Depletion of dissolved oxygen
  - Release of foul smell
  - Death of fish species
- Soluble organic and inorganic chemicals
  - Aesthetic problems (foam and colors)
  - Harmful to aquatic life and human (bioaccumulation)

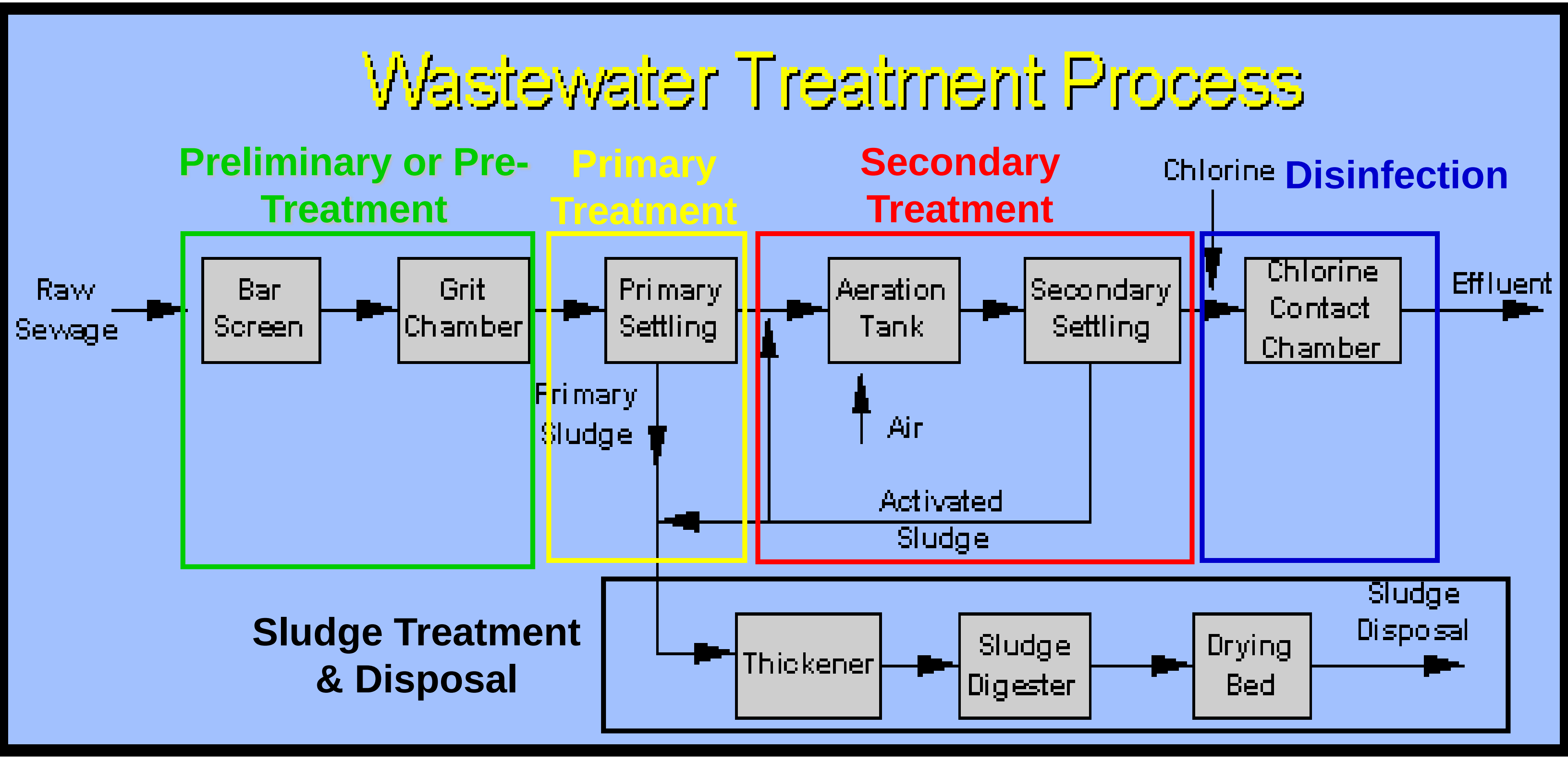
Removal of phosphorus

- The common forms of phosphorus in wastewater
  - Orthophosphates (PO_4^{3-})
  - Polyphosphates
  - Organically bound phosphates
- Phosphorus removal in conventional wastewater treatment
  - Incorporation into the biomass for bacterial growth
  - Overall 20-40% removal of influent phosphorus

Chemical-biological phosphorus removal

- Chemical precipitation (w/ aluminum and iron coagulants)
  - Orthophosphates (PO_4^{3-})
    - $Al_2(SO_4)_3 14.3H_2O + 2\ PO_4^{3-} = 2\ AlPO_4 \downarrow + 3\ SO_4^{2-} + 14.3H_2O$
    - $FeCl_3\ 6H_2O + PO_4^{3-} = FePO_4 \downarrow + 3\ Cl^- + 6\ H_2\ O_3$
  - Polyphosphates and organically bound phosphates (entrapped or adsorbed in flocs)
- Variable reduction of phosphorus depending on the alum-phosphorus weight ratio
  - 13: 1 (75%), 16: 1 (85%), and 22:1 (95%)
- Point of application
  - Prior to primary clarification
  - Directly to biological process
  - Prior to final clarification

Typical Municipal Wastewater Treatment System



Removal of nitrogen

- The common forms of nitrogen in wastewater
  - Ammonia
  - Nitrate
  - Nitrite
  - Gaseous nitrogen
  - Organic nitrogen
- Nitrogen removal in conventional wastewater treatment
  - Sedimentation: 15%
  - Uptake in subsequent biological process: 10%
  - Overall 25% removal of influent nitrogen

Biological nitrification and denitrification

- Organic nitrogen compound → NH_3 (in sewer)
- $NH_3 + O_2 \rightarrow NO_3^-$: aerobic nitrification
- $NO_3^- + AH_2 \rightarrow A + H_2O + N_2$: denitrification

Nitrification Process

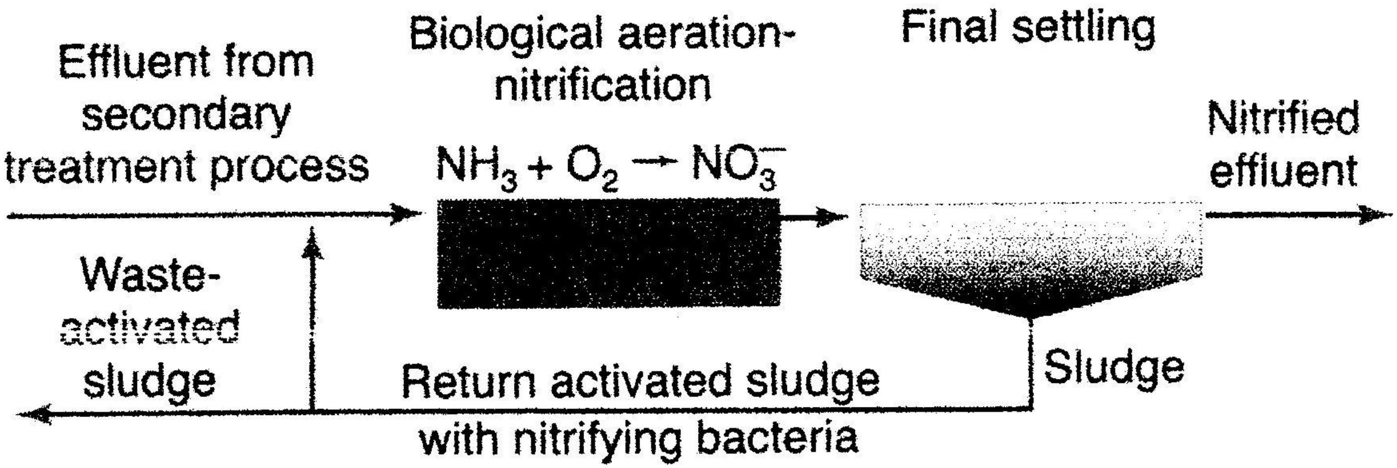


Figure 13–14

Flow diagram for nitrification by suspended-growth aeration following conventional biological treatment.

Operating conditions for nitrification

- Temperature: > 8^oC
- Optimum pH: 8.4
- Dissolved oxygen level: >1.0 mg/L
- Ammonia nitrogen loading: 160-320 g/m^3/day
- Aeration period: 4-6 hours

Nitrification plant

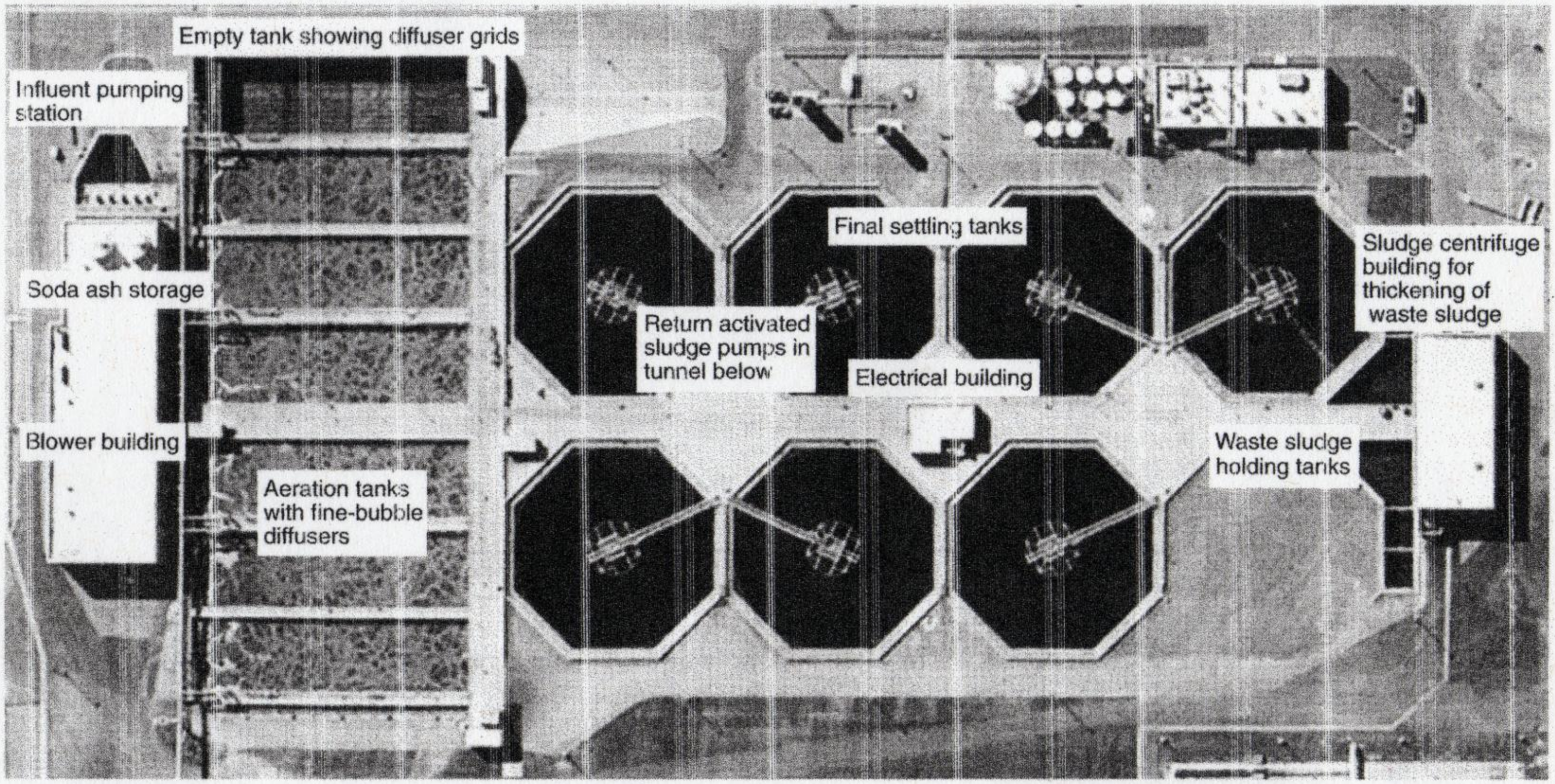


Figure 13–15
Processing arrangement for nitrification by suspended-growth aeration. City of Las Vegas Water Pollution Control Facility, Nevada.
(Courtesy of the City of Las Vegas, NV.)

Denitrification reaction

- Methanol is used as a carbon source
- $5CH_3OH + 6NO_3^- = 3\ N_2\uparrow + 5\ CO_2\uparrow + 7H_2O + 6OH^-$
- Mechanically mixed anoxic chambers
- Nitrogen stripping in the last chamber
- Detention time 2-4 hours

Denitrification process

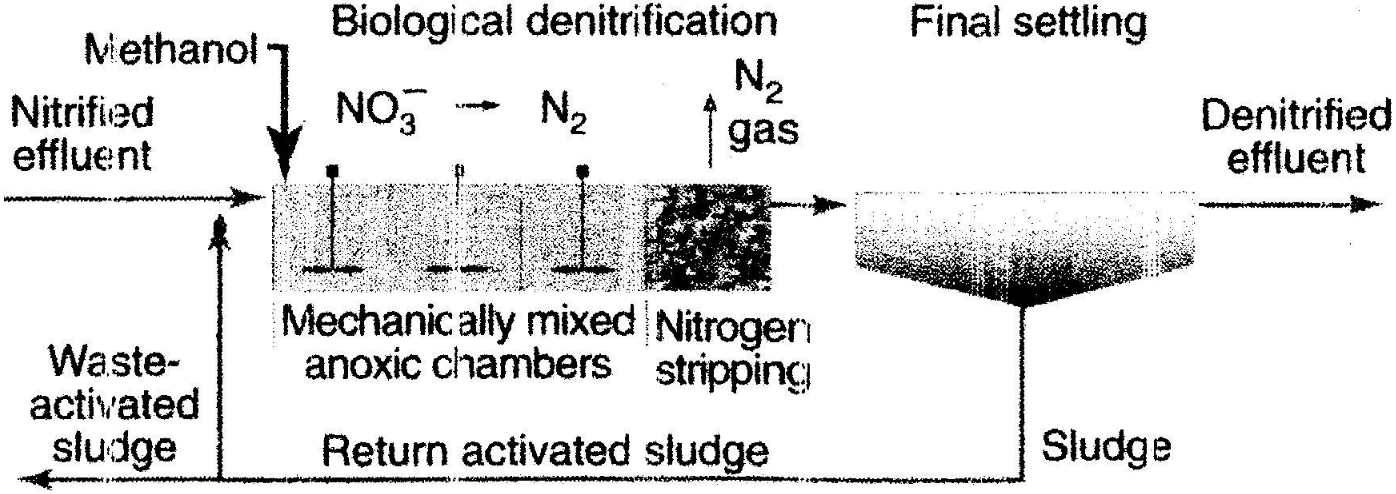


Figure 13–17

Flow diagram for denitrification by anoxic suspended growth following nitrification.

Soluble organic and inorganic chemicals

- Best removed at the source of origin
- Partially removed by entrapment and adsorption onto settable solids and biological flocs
- In water reclamation plants, these materials are removed by highly advanced processes such as membrane filtration and advanced oxygenic processes (O_3, UV and so on)