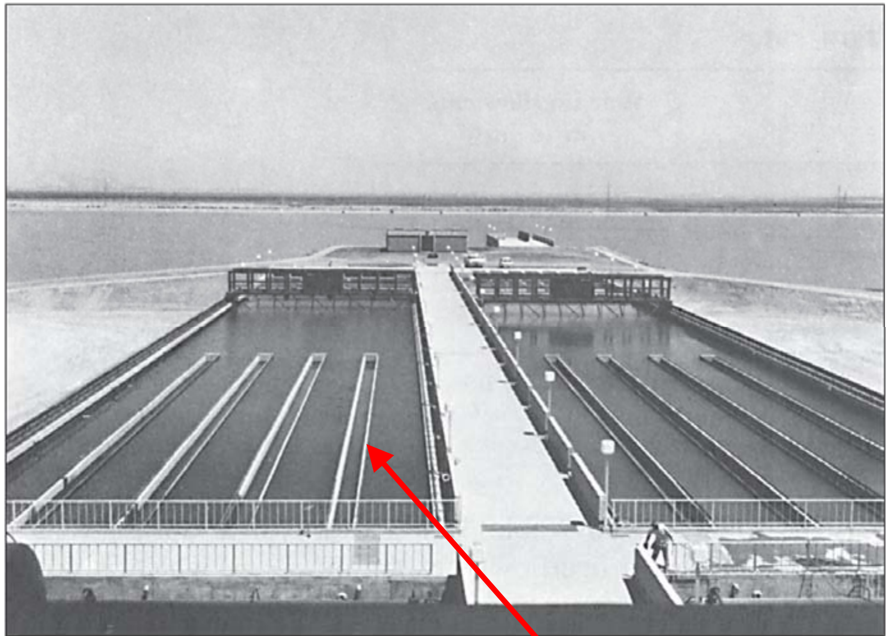
Water treatment II

Water treatment

- Sedimentation
- Filtration
- Disinfection
- Sludge treatment and disposal

Sedimentation

- Sedimentation basins: (a) rectangular (b) circular



(a)

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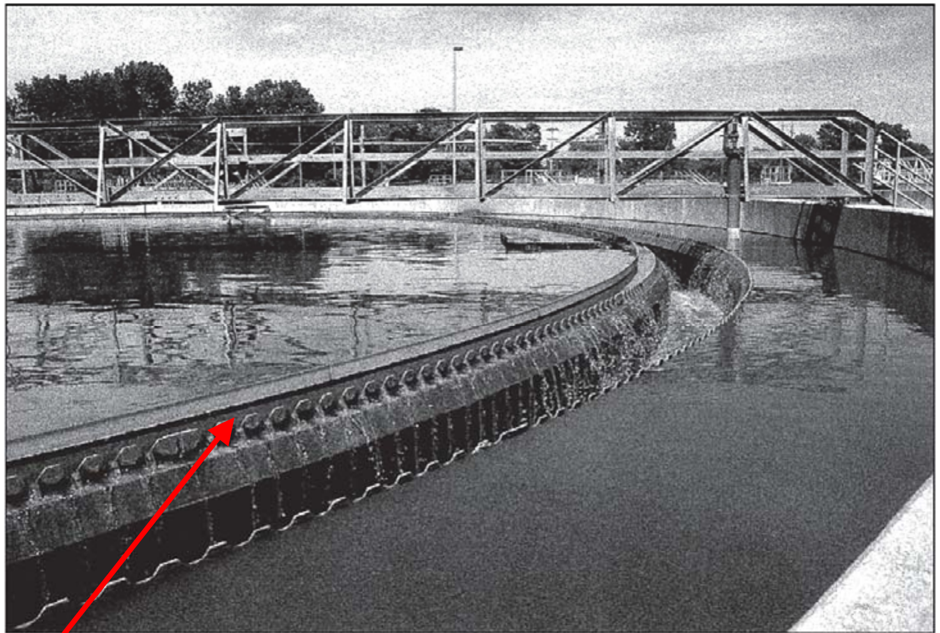


(b)

Weir

Sedimentation – Design parameters

- Retention time, t_0: 2-4 hr

$$t_o = \frac{V}{Q}$$

V = volume of the sedimentation basin (m^3)
Q = water flow rate (m^3/s)

- Overflow rate, v_0
  - More directly related to the removal efficiency

$$v_o = \frac{Q}{A_c}$$

A_c = surface area of the sedimentation basin (m^2)
= W (width) x L (length)

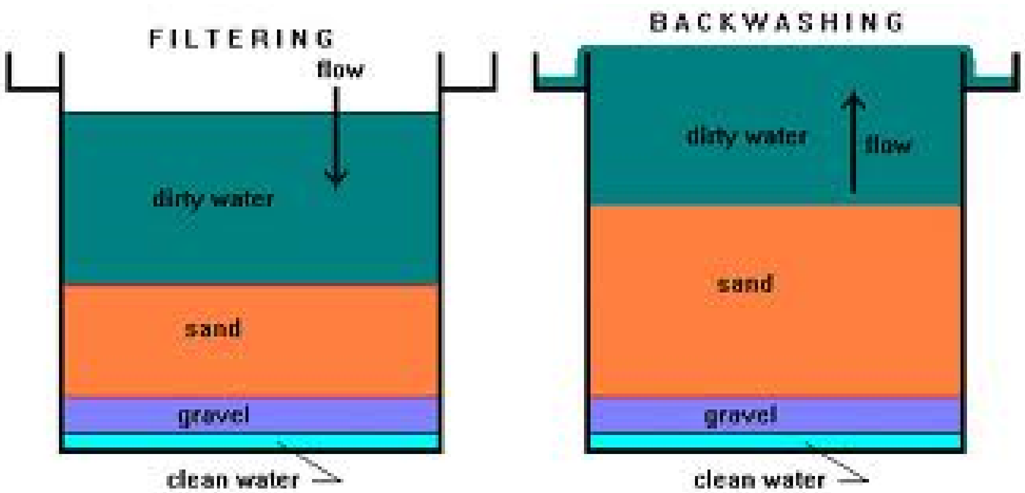
* Large, dense particles → greater settling velocity
→ greater v_0 allowed

Filtration

- The effluent of the sedimentation basin still contains particles that are too small to settle
- Filtration is the final step of particle removal from water
- Goal: additional turbidity and pathogen removal
  - Pathogens are small particles (virus: 5-50 nm, bacteria: 0.5-10 µm, protozoa oocysts: 2-20 µm)
- Water flows downward through a bed of granular media, and particles in water are trapped by the media

Filtration - backwash

- As particles are removed, filter becomes clogged → "head loss" increases → water becomes harder to pass the filter & effluent turbidity increases
- "Backwash" of filter needed (takes about 10-15 min, about once per day)
- Backwash
  - Water flow upward at a high speed to expand the media
  - Particles are washed out and collected



http://www.rpi.edu

Filtration – filter media

- Filter media
  - Single media: sand only
  - Dual media: anthracite coal and sand (most common)
  - Multimedia: anthracite coal, sand, and garnet
- Large, lighter particles on the top and small, heavier particles on the bottom → can use full depth of the filter bed & maintain the layers after backwashing

Material	Grain density (g/cm^3)	Effective size (mm)
Anthracite coal	1.6-1.7	1.5-2.5
Sand	2.4-2.6	0.6-0.95
Garnet	4.5	0.4-0.5

Disinfection

- Goal: to inactivate (kill) pathogens
- Disinfection kinetics
  - Chick's law:

$$\frac{dN}{dt} = -kN \longrightarrow ln\left(\frac{N}{N_0}\right) = -kt$$

N = number of organisms

k = first-order reaction constant

  - Chick-Watson law: consider the concentration of the disinfectant as a variable

$$ln\left(\frac{N}{N_0}\right) = -k'C^n t$$

$k = k'C^n$

C = disinfectant concentration, mg/L

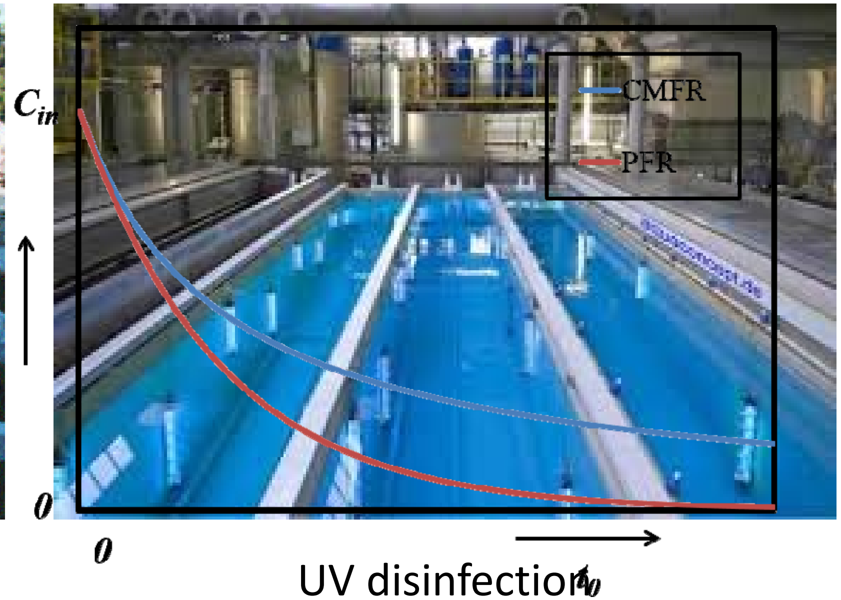
n = coefficient

→ The efficiency of disinfection depends on disinfectant concentration (*C*) and contact time (*t*)

Disinfection – reactor design

- Goal: to inactivate (kill) pathogens by 99-99.9% (2-3 log removal)
- What is the appropriate reactor design?

Chlorine disinfection



UV disinfection

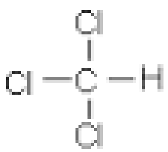
Types of disinfectants

Disinfectant	Advantage	Disadvantage
Chlorine (Cl_2)	• Effective for most microorganisms • leaves residual	• Forms disinfection byproducts • Not effective to some protozoa • Taste and odor problem
Chloramine	• More stable residual than chlorine • Less disinfection byproduct than chlorine	• Less effective than chlorine
Ozone	• Very powerful • Effective for most microorganisms, including protozoa	• Must be produced on-site • Forms disinfection byproducts • No residual
UV	• Effective for bacteria & protozoa • No disinfection byproducts	• Less effective for some viruses • No residual • Effectiveness affected by turbidity

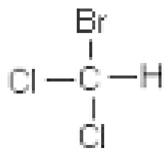
Disinfection byproducts

- Disinfectants may react with Br^- or naturally occurring organic matter to make disinfection byproducts (DBPs)
- Some DBPs are known or possible human carcinogens
- Major DBPs
  - Chlorine disinfection: trihalomethanes (THMs), haloacetic acids (HAAs)

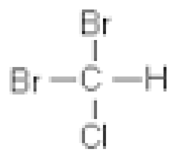
tri halo methanes (THMs)



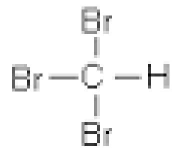
chloroform



bromodichloro methane



chlorodibromo methane

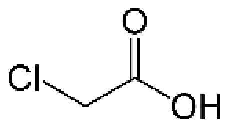


bromoform

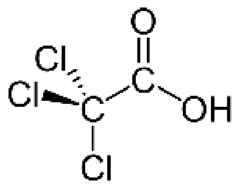
Disinfection byproducts

– Chlorine disinfection: trihalomethanes (THMs), haloacetic acids (HAAs)

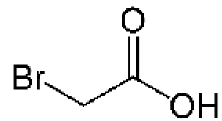
halo acetic acids (HAAs)



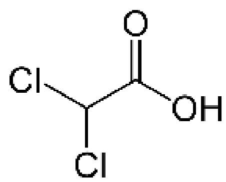
Chloroacetic Acid



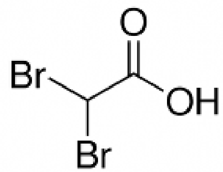
Trichloroacetic Acid



Bromoacetic Acid



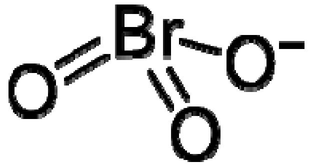
Dichloroacetic Acid



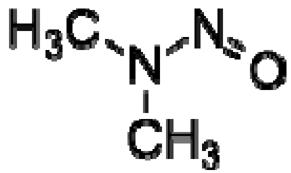
Dibromoacetic Acid

Disinfection byproducts

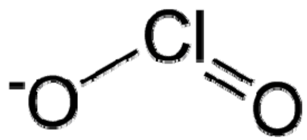
– Ozone disinfection: bromate (BrO_3^-)



– Chloramine (or chlorine) disinfection:
N-nitrosodimethylamine (NDMA)



– Chlorine dioxide disinfection: chlorite (ClO_2^-)



- Balance needed for disinfectant dose!
  – Disinfectant dose ↑, then pathogen kill ↑, but disinfection byproduct ↑

Disinfection byproducts

Does swimming do good or bad for your health??

Chlorine disinfection chemistry

- Chlorine may be added to water as Cl_2, NaOCl, or $Ca(OCl)_2$
- Large plants mostly use Cl_2
- Cl_2 rapidly reacts with water to form HOCl:

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

- HOCl is a weak acid that dissociates to form OCl^- with a pK_a of 7.54 at 25°C:

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

- Both HOCl and OCl^- can kill pathogens, but HOCl is much stronger

Chlorine disinfection chemistry

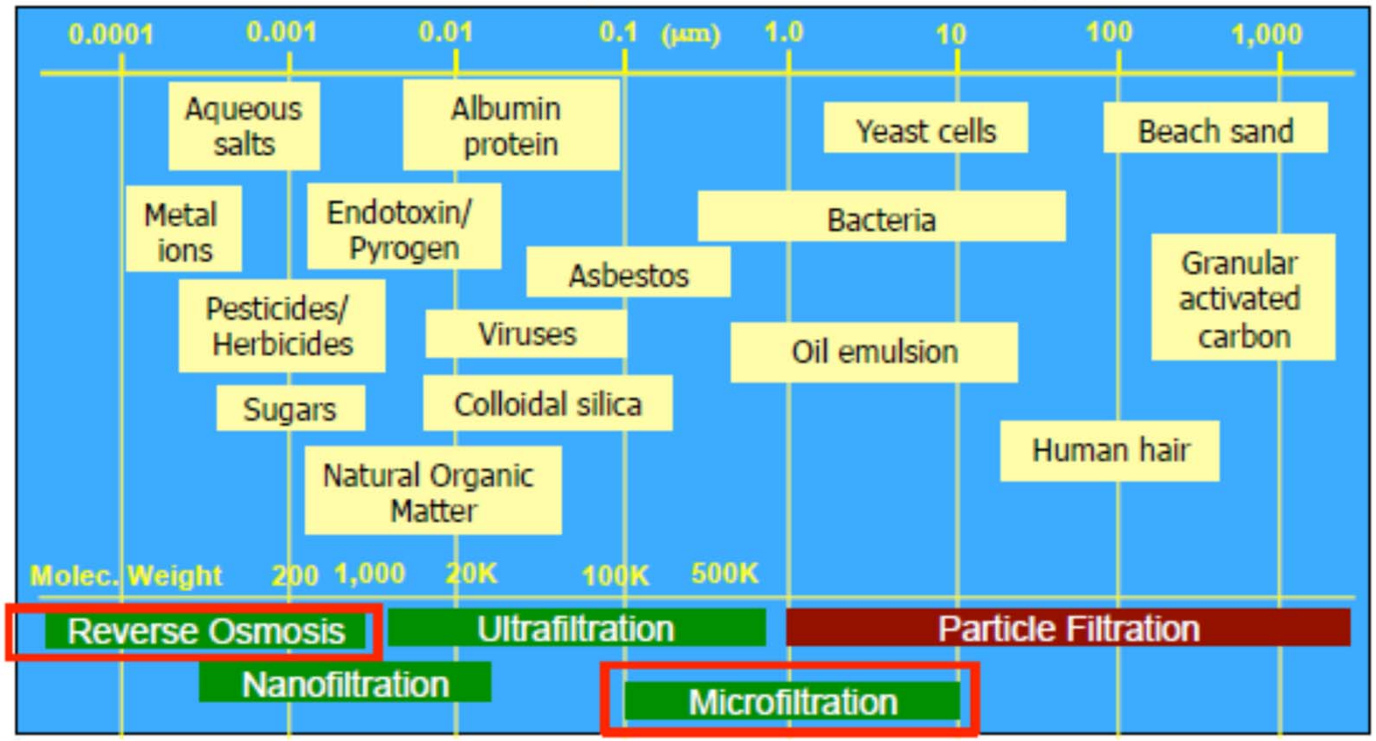
Q: So, for chlorine disinfection, would you prefer high pH (pH>7.54) or low pH (pH<7.54)?

Factors affecting chlorine disinfection

- Dosage
- Contact time
- Turbidity: the presence of particles (turbidity) hides the pathogen from disinfectant – this is one of the reason why we remove particles!
- Other reactive species: some substances in water can consume chlorine (ex: ammonia)
- pH: effective at pH<7.5
- Water temperature: temperature ↑, then pathogen kill rate ↑, but chlorine stability ↓

Membrane filtration

- Getting more and more popular
- Opening size: microfiltration > ultrafiltration > nanofiltration > reverse osmosis



Sludge treatment & disposal

- Large amount of sludge (=mass of settled solids) is produced during the water treatment because of the addition of coagulants or lime
- Major goal of sludge treatment: removing as much water as possible
- When appropriate sludge treatment is accomplished, the sludge is disposed in the landfill

Sludge in the sedimentation basin
http://www.norfolk.gov

Reading assignment

Textbook Ch 10 p. 481-507