

Water treatment II

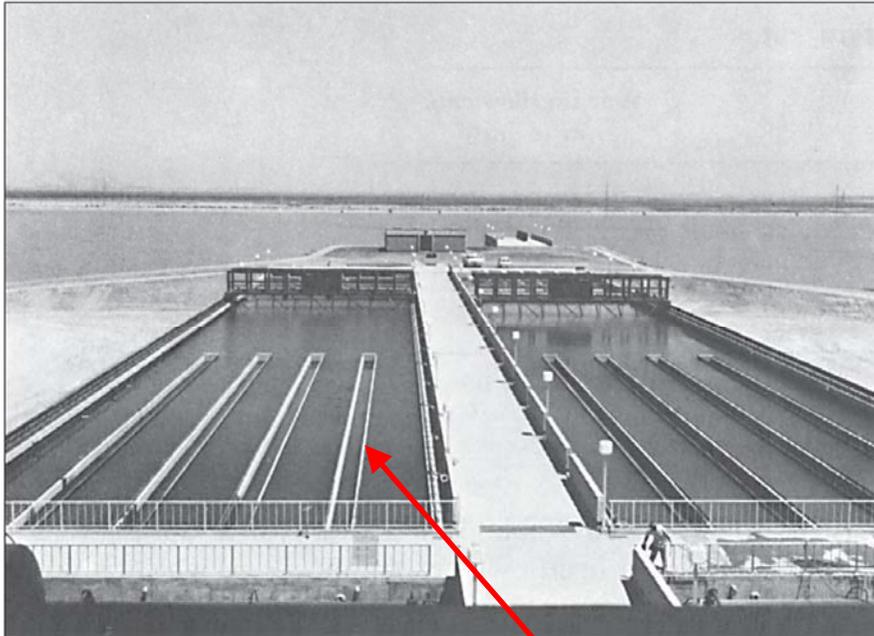
Water treatment

- Sedimentation
- Filtration
- Disinfection
- Sludge treatment and disposal

Sedimentation

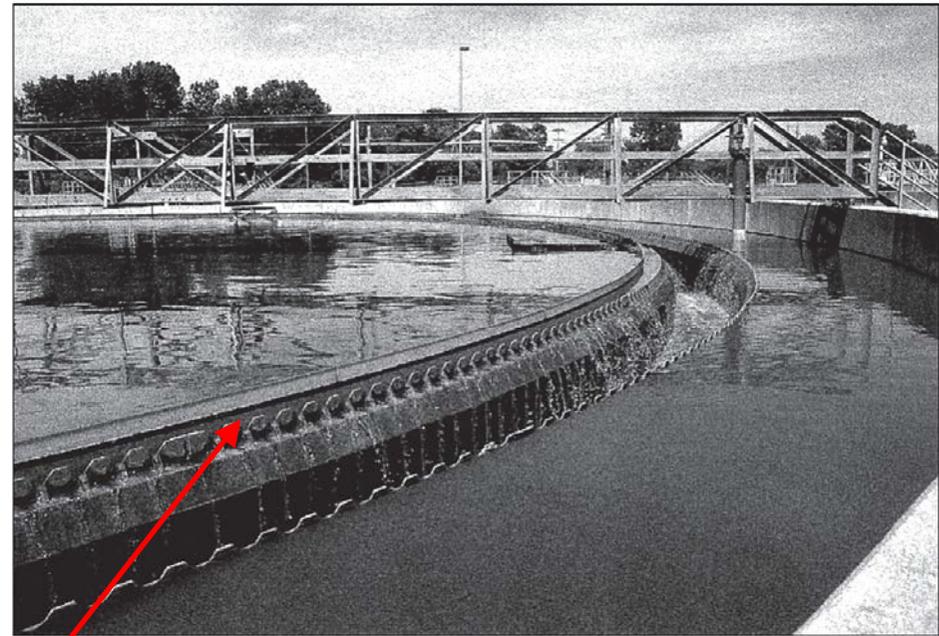
- Sedimentation basins: (a) rectangular (b) circular

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(a)

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(b)

Weir

Sedimentation

- Design parameters
 - Retention time, t_o : 2-4 hr

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

$V = \text{volume of the sedimentation basin (m}^3\text{)}$
 $Q = \text{water flow rate (m}^3\text{/s)}$

- Overflow rate, v_o : directly related to the removal efficiency

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

$A_c = \text{surface area of the sedimentation basin (m}^2\text{)}$
 $= W \text{ (width)} \times L \text{ (length)}$

- * Large, dense particles → greater settling velocity
→ greater v_o allowed

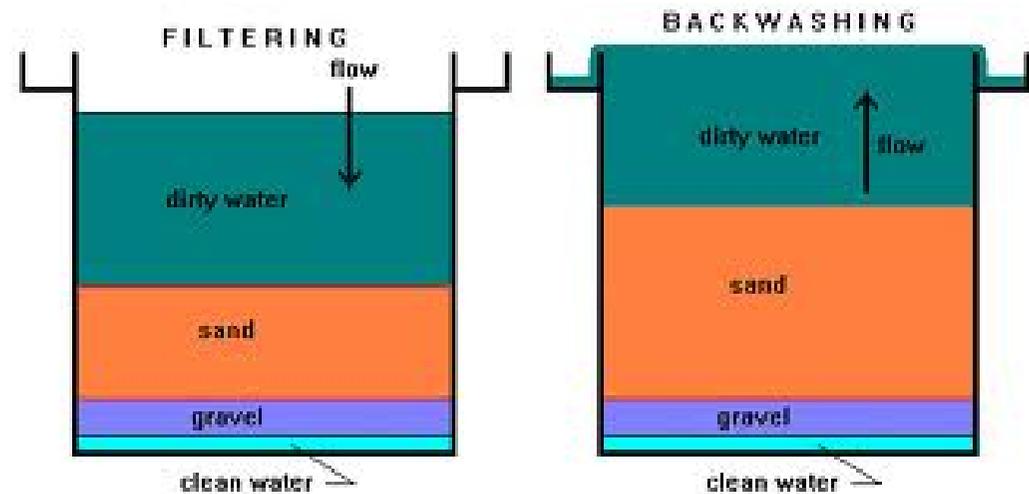
Filtration

- 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

- 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
 - 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

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



Chlorine disinfection



UV disinfection t_0

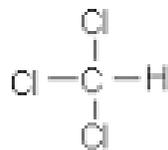
Types of disinfectants

Disinfectant	Advantage	Disadvantage
Chlorine (Cl ₂)	<ul style="list-style-type: none">• Effective for most microorganisms• leaves residual	<ul style="list-style-type: none">• Forms disinfection byproducts• Not effective to some protozoa• Taste and odor problem
Chloramine	<ul style="list-style-type: none">• More stable residual than chlorine• Less disinfection byproduct than chlorine	<ul style="list-style-type: none">• Less effective than chlorine
Ozone	<ul style="list-style-type: none">• Very powerful• Effective for most microorganisms, including protozoa	<ul style="list-style-type: none">• Must be produced on-site• Forms disinfection byproducts• No residual
UV	<ul style="list-style-type: none">• Effective for bacteria & protozoa• No disinfection byproducts	<ul style="list-style-type: none">• Less effective for some viruses• No residual• Effectiveness affected by turbidity

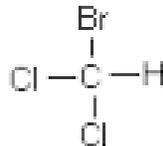
Disinfection byproducts

- 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)

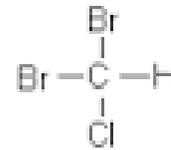
tri halo methanes (THMs)



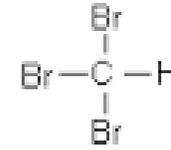
chloroform



bromodichloro
methane



chlorodibromo
methane

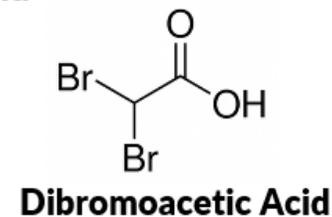
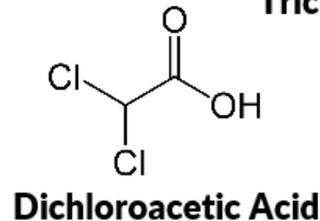
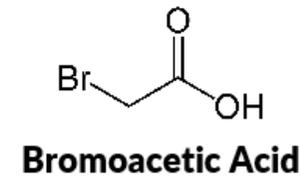
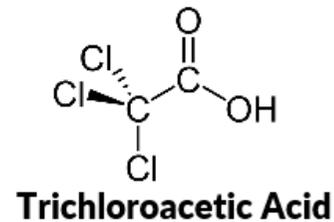
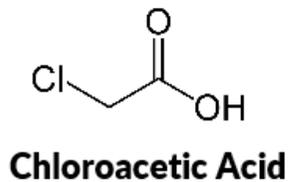


bromoform

Disinfection byproducts

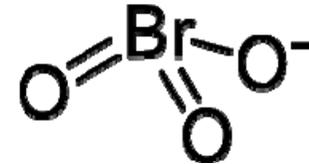
- Chlorine disinfection: trihalomethanes (THMs), haloacetic acids (HAAs)

halo acetic acids (HAAs)

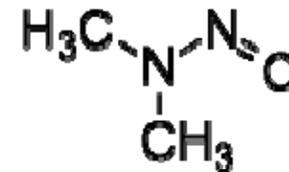


Disinfection byproducts

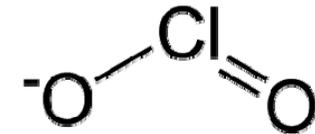
– Ozone disinfection: bromate (BrO_3^-)



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



– Chlorine dioxide disinfection: chlorite (ClO_2^-)



- Balance needed for disinfectant dose!
 - Disinfectant dose \uparrow , then pathogen kill \uparrow , but disinfection byproduct \uparrow

Disinfection byproducts



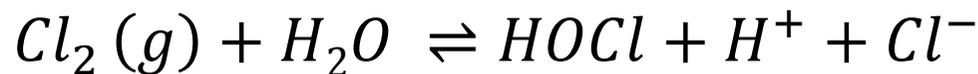
Does swimming do **good** or **bad** for your health??

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:



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



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

Chlorine disinfection chemistry

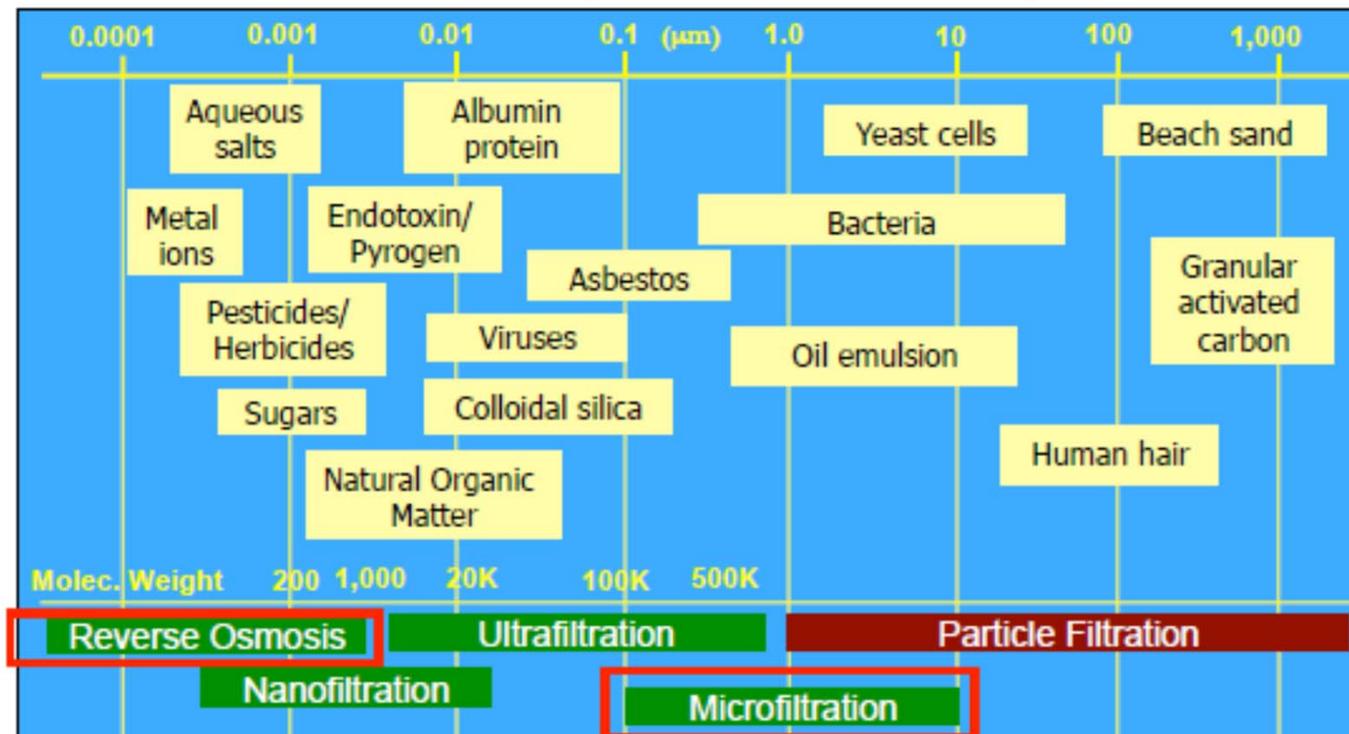
Q: So, for chlorine disinfection, would you prefer high pH ($\text{pH} > 7.54$) or low pH ($\text{pH} < 7.54$)?

Chlorine disinfection

- 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 $\text{pH} < 7.5$
 - Water temperature: temperature \uparrow , then pathogen kill rate \uparrow , but chlorine stability \downarrow

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