Lecture 9: Water treatment processes

(Jan 30th 2015)

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Objective: Understand functioning of different unit processes for water treatment

Courtesy: Dr. Irene Xagoraraki (Michigan State University, East Lansing, USA)

Previous lecture re-cap

- Introduction of water treatment processes

- Discussion on solids removal using sedimentation and coagulation-flocculation processes

PROCESSES

(solid removal)

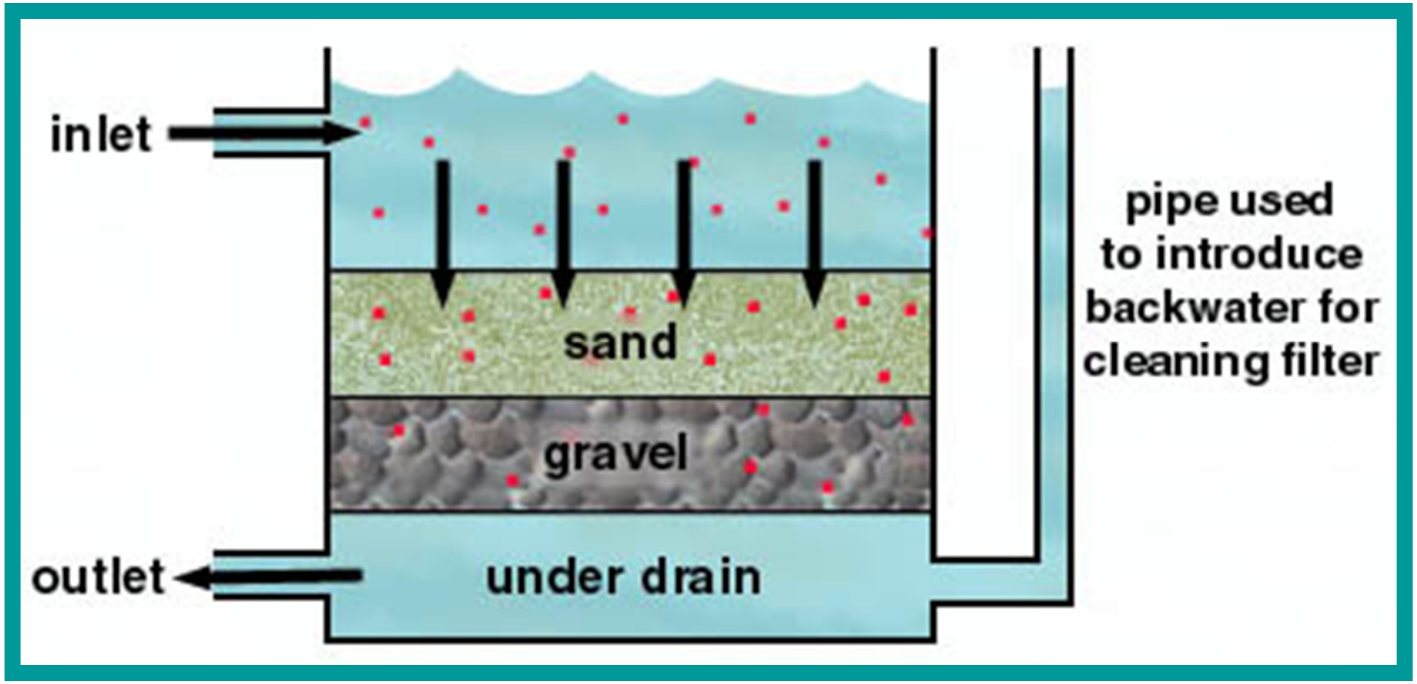
Filtration

Filtration

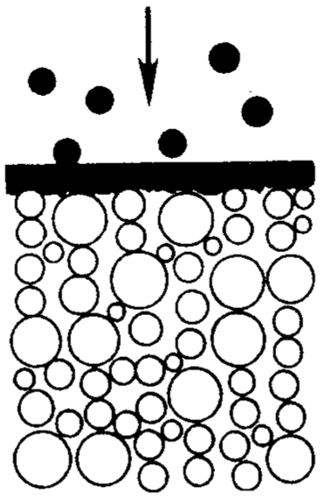
- Many water treatment facilities use filtration to remove particles from water. Those particles include clays and silts, natural organic matter, precipitates from other treatment processes in the facility, iron and manganese, and microorganisms. Filtration clarifies water and enhances the effectiveness of disinfection.

Granular Media Filtration

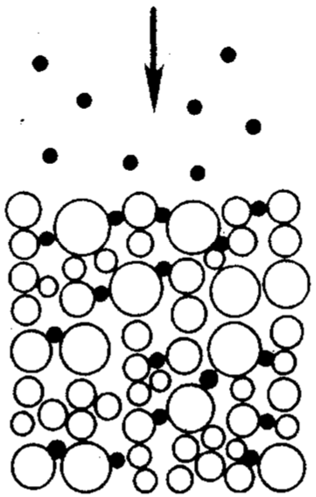
<u>Granular Filter Media:</u>
sand, anthracite coal, garnet



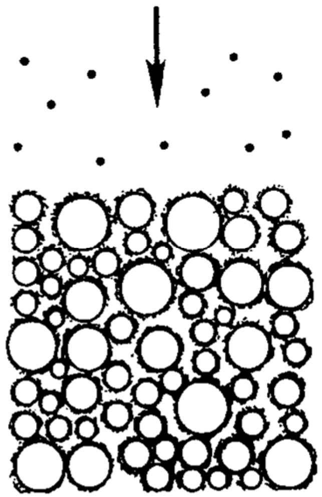
Filtration



Cake Filtration



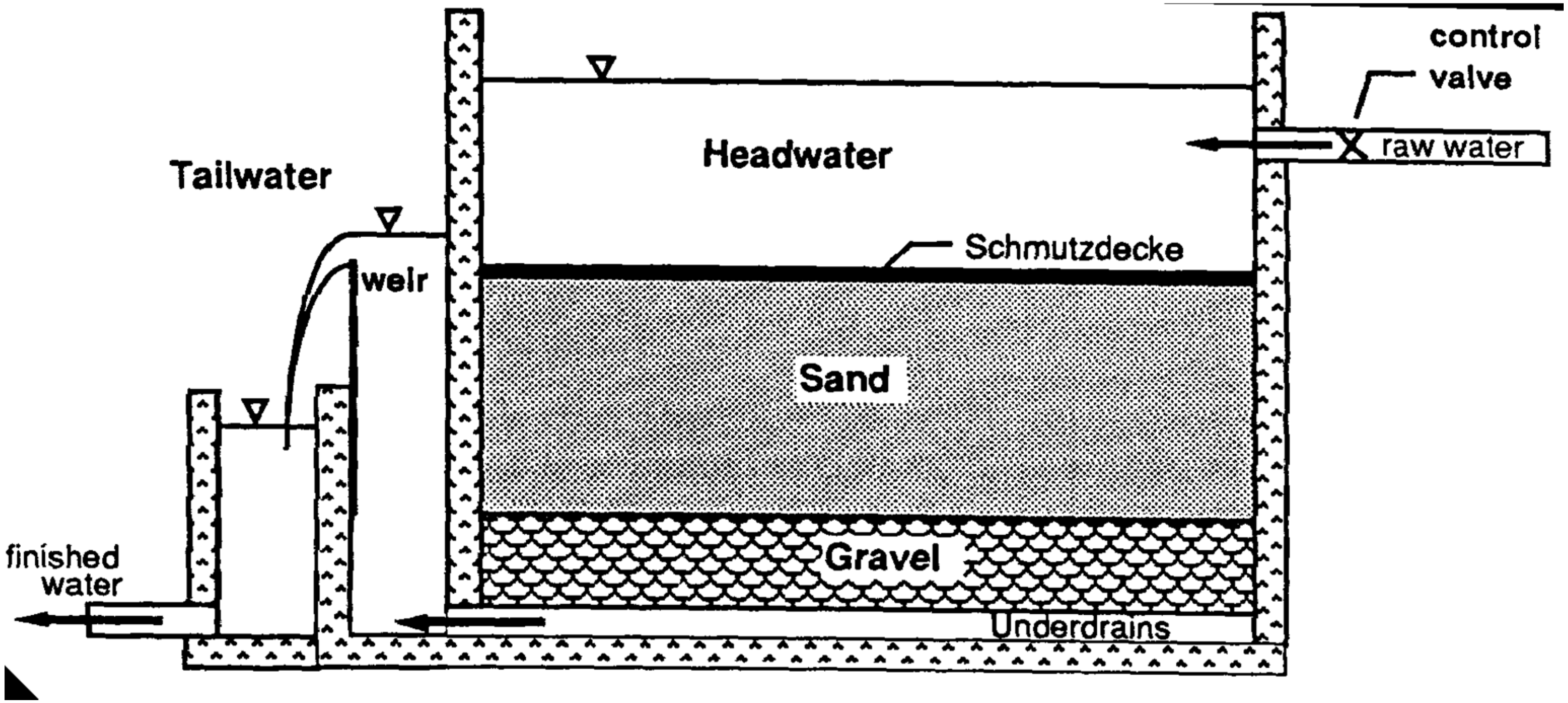
Straining Filtration



Adsorptional Filtration (filters are coated)

Picture source: McDowell-Boyer *et al*, 1986. Reproduced by permission of American Geophysical Union.

Filtration



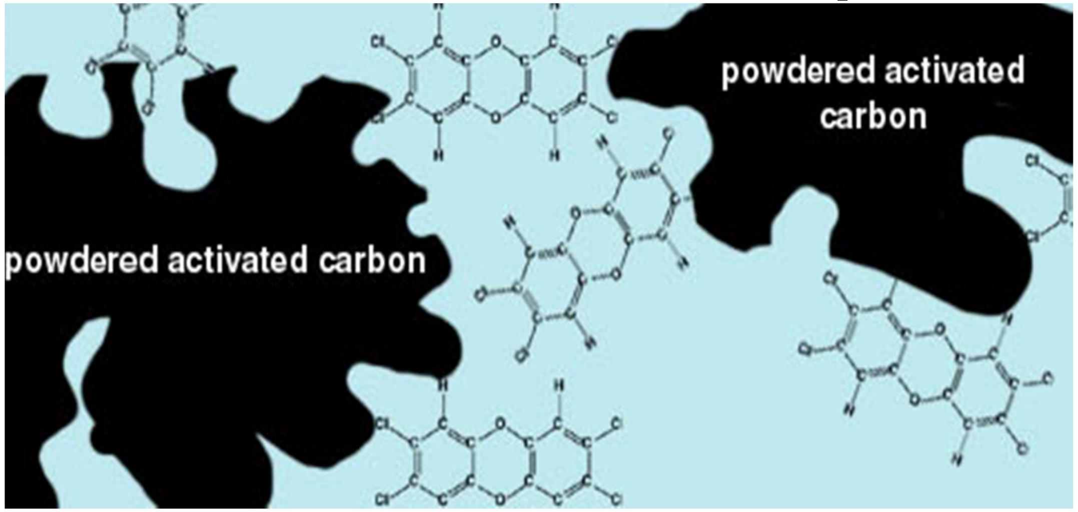
Source: Back to Basics Guide to Surface Water Treatment, American Water Works Association, 1P-2.5M-73026-11/92-MG

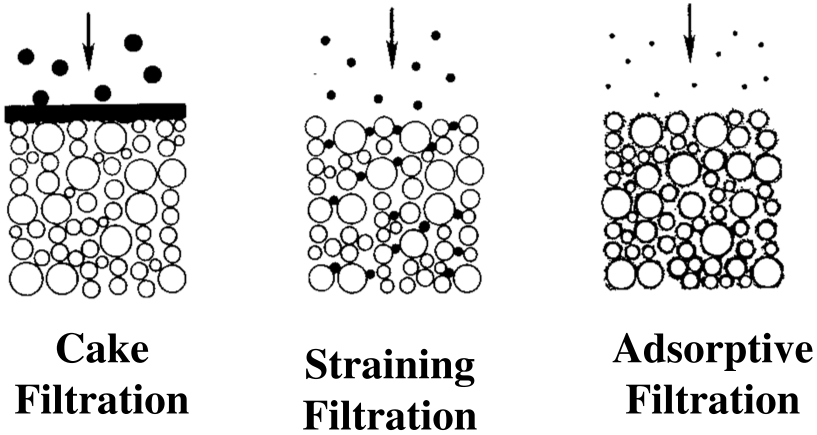
PROCESSES

(removal of ions, organic compounds and microorganisms)

Adsorption

Adsorption





Adsorptive filtration is a technique based on the coating of the filter medium with adsorbents, resulting in modified media that can simultaneously act as a filter and as an adsorbent

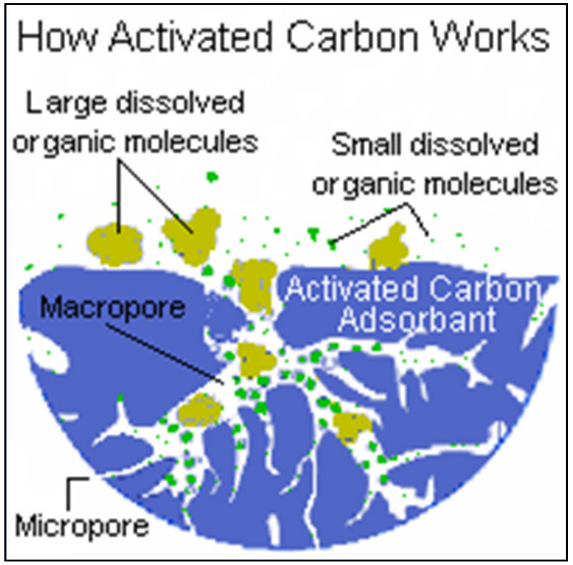
Picture source: McDowell-Boyer *et al*, 1986. Reproduced by permission of American Geophysical Union.

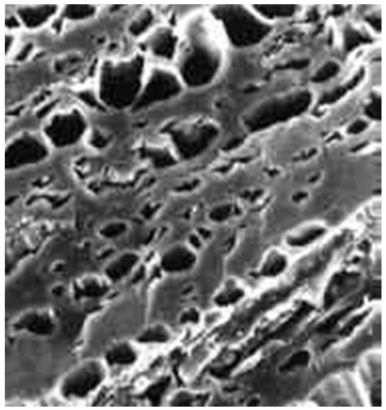
Activated Carbon Adsorption

- Contaminant reduction in AC filters takes place by two processes:
  - physical removal of contaminant particles, blocking any that are too large to pass through the pores (filters with smaller pores are more effective),
  - and a process called adsorption by which a variety of dissolved contaminants are attracted to and held (adsorbed) on the surface of the carbon particles. The characteristics of the carbon material (particle and pore size, surface area, surface chemistry, density, and hardness) influence the efficiency of adsorption.

Activated Carbon Adsorption

- Organic contaminants, unwanted coloring, and taste-and-odor-causing compounds can stick to the surface of granular or powder activated carbon and are thus removed from the drinking water.





http://www.cyber-nook.com/water/Solutions.html#carbon

PROCESSES

(cation removal)

Softening

Hardness

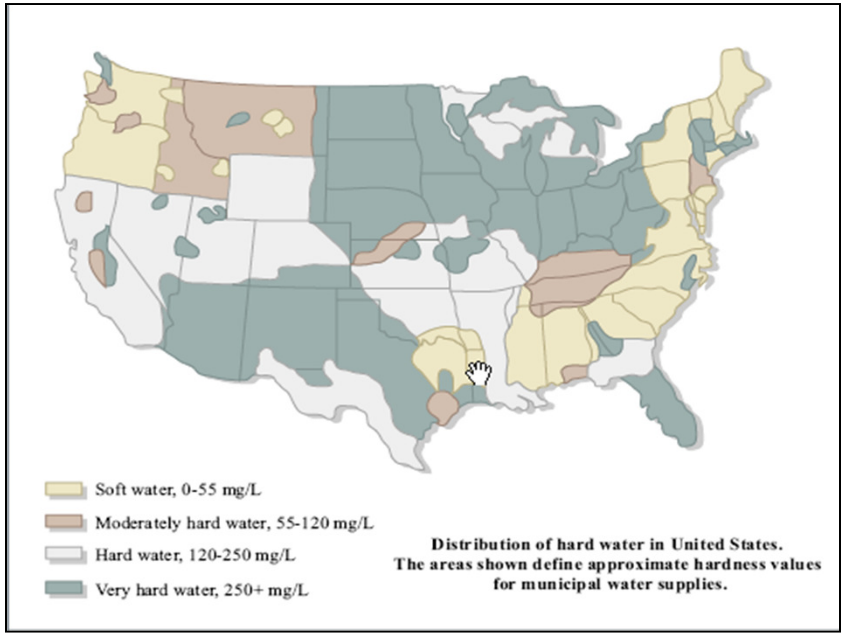
- Total Hardness
  - Technically - the sum of all polyvalent cations
  - Practically - the amount of calcium and magnesium ions (the predominant minerals in natural waters)
  - It is divided into carbonate and noncarbonate hardness.

Description	Hardness range (mg/L as $CaCO_3$)
Soft	0 - 75
Moderately hard	75 - 100
Hard	100 - 300
Very hard	> 300

Hardness

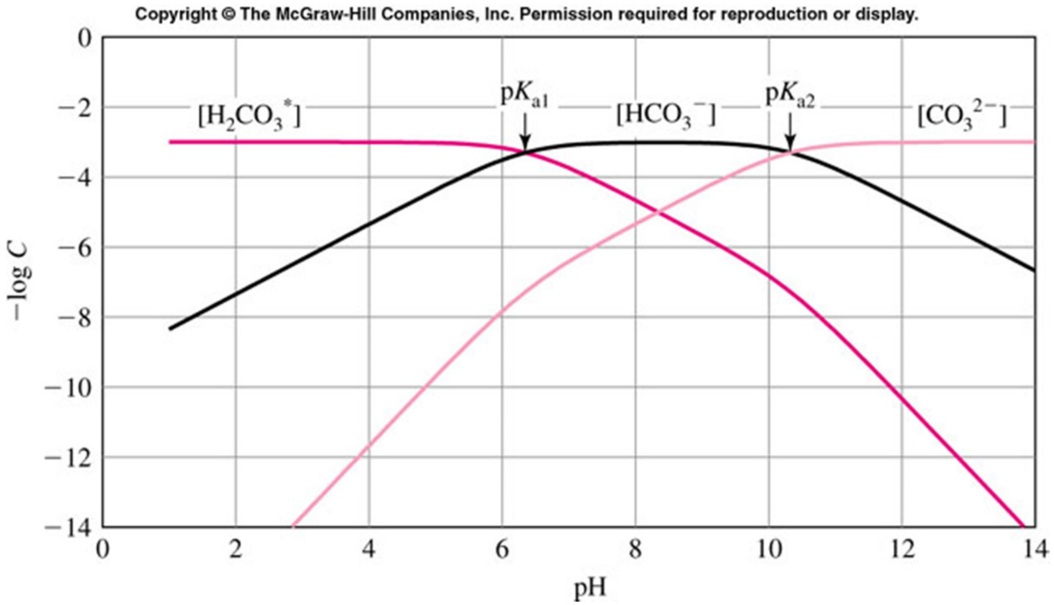
$$Ca^{2+}_{(aq)} + 2HCO_3^-(aq) \longrightarrow CaCO_{3(s)} + H_2O + CO_2$$

$$Mg^{2+}_{(aq)} + 2OH^-_{(aq)} \longrightarrow Mg(OH)_{2(s)}$$



Alkalinity

Alkalinity is often used describe a water's ability to resist pH changes upon the addition of an acid. It could also be called acid-neutralizing capacity.



Alkalinity (mol/L) = $[HCO_3^-] + 2\,[CO_3^{2-}] + [OH^-] - [H^+]$

Process: Softening

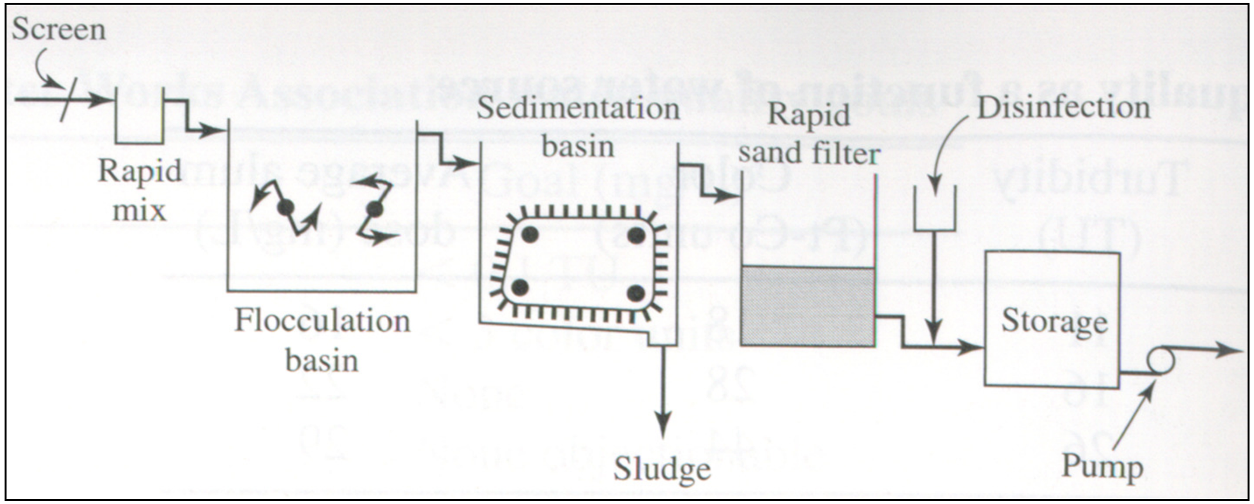
- This process is used to remove bivalent and multivalent cations from water (hardness; for ex: Ca^{2+};
- Cations with carbonate and bicarbonate ions give non-permanent hardness (also known as carbonate hardness). It is a unstable hardness and can easily be removed using boiling (a simplest method).
- Cations with sulfate, chloride, and nitrate give non-carbonate hardness and permanent hardness. This cannot be easily removing using boiling.

Process: Softening

- Cations are removed from using following method:
  - (i)Boiling
  - (ii) reaction with calcium carbonate,
  - (iii) reaction with lime and soda ash

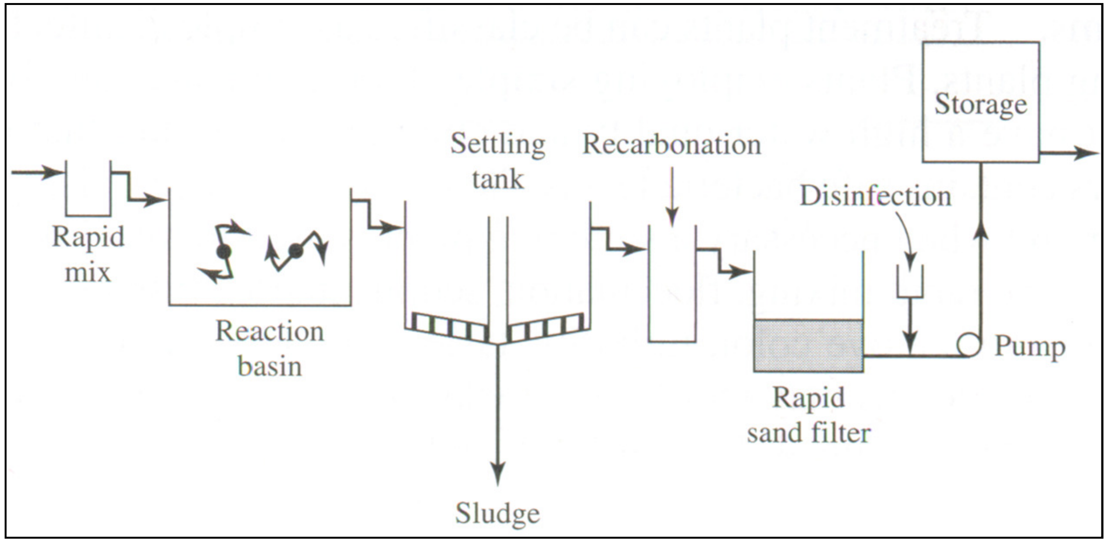
Precipitative Softening

- Add quick lime (CaO) or hydrated lime [$Ca(OH)_2$] in hard water, raise pH higher than 10, convert soluble bicarbonate ions (HCO_3^-) to insoluble carbonate ($CO_3^=$).
- Form calcium carbonate ($CaCO_3$) and magnesium hydroxide [$Mg(OH)_2$] precipitates.
- Add soda ash (Na_2CO_3) if insufficient natural bicarbonate alkalinity.
- Re-carbonated with CO_2, covert carbonate particles into soluble bicarbonates, prevent filter clogging from fine particles that do not settle.



Conventional drinking water treatment

Water softening



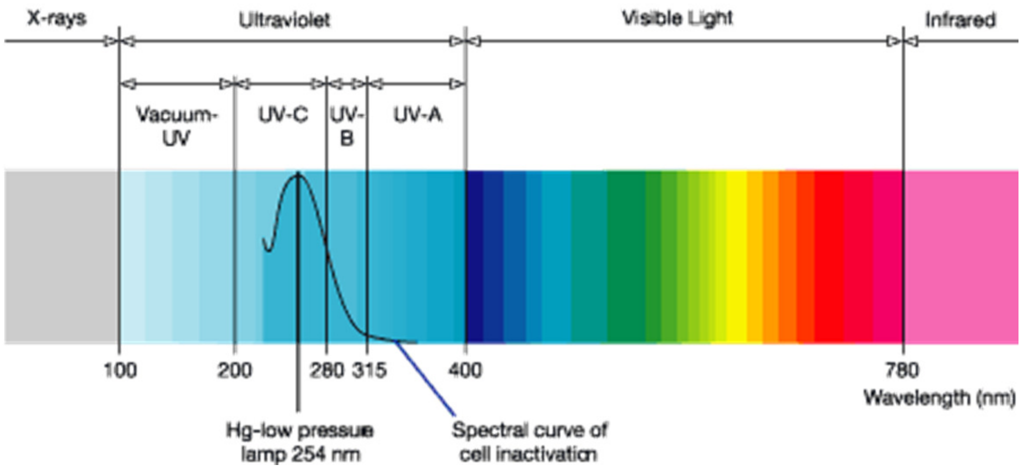
PROCESSES
(microbial removal)

Disinfection

Courtesy: Dr. Irene Xagoraraki (MSU, USA)

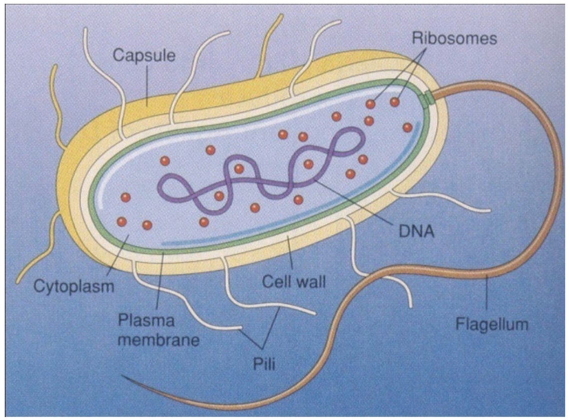
Disinfection

Disinfectants:
NaOCl
$Ca(OCl)_2$
Cl_2 gas
Chloramines
Ozone
UV irradiation



Disinfection

- Any process to destroy or prevent the growth of microbes
- Intended to inactivate the microbes by physical, chemical or biological processes
- Inactivation is achieved by altering or destroying essential structures or functions within the microbe
- Inactivation processes include denaturation of:
  - proteins (structural proteins, transport proteins, enzymes)
  - nucleic acids (genomic DNA or RNA, mRNA, tRNA, etc)
  - lipids (lipid bilayer membranes, other lipids)



Properties of Water Disinfectants

- Free chlorine: HOCl (hypochlorous) acid and OCl^- (hypochlorite ion)
  - HOCl at low pH and OCl^- at high pH; HOCl more potent germicide than OCl^-
  - strong oxidant; relatively stable in water (provides a disinfectant residual)
- Chloramines: mostly NH_2Cl: weak oxidant; provides a stable residual
- Chlorine dioxide, $ClO_{2,}$: strong oxidant; unstable (dissolved gas)

Concerns due to health risks of chemical disinfectants and their by-products (DBPs), especially free chlorine and its DBPs

Properties of Water Disinfectants

- Ozone, O_3: strong oxidant; provides no residual (too volatile, reactive)
- UV radiation
  - low pressure mercury lamp: low intensity; monochromatic at 254 nm
  - medium pressure mercury lamp: higher intensity; polychromatic 220-280 nm)
  - reacts primarily with nucleic acids: pyrimidine dimers and other alterations
- Boiling: efficient kill; no residual protection;
  issues -> fuel/environmental costs

Factors Influencing Disinfection Efficacy and Microbial Inactivation

Microbe type: Resistance to chemical disinfectants:

- Vegetative bacteria: Salmonella, coliforms, etc.: low
- Enteric viruses: coliphages, HAV, Noroviruses: Moderate
- Bacterial Spores
- Fungal Spores
- Protozoan (oo)cysts, spores, helminth ova, etc.
  - *Cryptosporidium parvum* oocysts
  - *Giardia lamblia* cysts
  - *Ascaris lumbricoides* ova
  - Acid-fast bacteria: *Mycobacterium* spp.

High

Resistance:

Least

Most

Factors Influencing Disinfection Efficacy and Microbial Inactivation (Continued)

<u>Type of Disinfectant and Mode of Action</u>

<u>Free chlorine</u>: strong oxidant; oxidizes various protein sulfhydryl groups; alters membrane permeability; also, oxidize/denature nucleic acid components, etc.

<u>Ozone</u>: strong oxidant; ditto free chlorine

<u>Chlorine dioxide</u>: strong oxidant; ditto free chlorine

<u>Electrochemically generated mixed oxidants</u>: strong oxidant; probably ditto free chlorine

<u>Combined chlorine/chloramines</u>: weak oxidant; denatures sulfhydryl groups of proteins

<u>Ultraviolet radiation</u>: nucleic acid damage: thymidine dimer formation, strand breaks, etc.

Factors Influencing Disinfection Efficacy and Microbial Inactivation, Contd…

Microbial strain differences and microbial selection:

- Disinfectant exposure may select for resistant strains

Physical protection:

- Aggregation
- particle-association
- protection within membranes and other solids

Chemical factors:

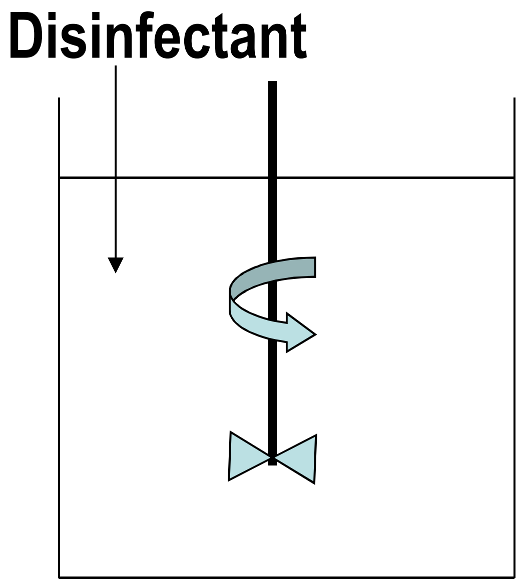
- pH
- Salts and ions
- Soluble organic matter
- Other chemical (depends on the disinfectant)

Factors Influencing Disinfection Efficacy and Microbial Inactivation - Water Quality

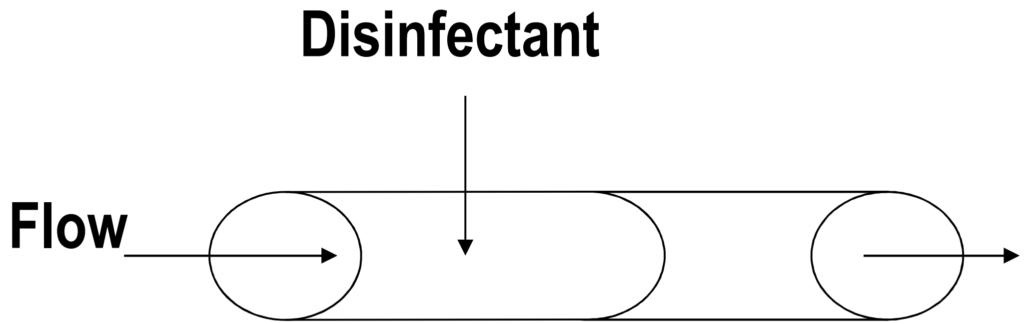
- Particulates: protect microbes from inactivation; consume disinfectant
- Dissolved organics: protect microbes from inactivation; consumes or absorbs (for UV radiation) disinfectant; Coat microbe (deposit on surface)
- pH: influences microbe inactivation by some agents
  - free chlorine more effective at low pH where HOCl predominates
    - neutral HOCl species more easily reaches microbe surface and penetrates)
    - negative charged OCl^- has a harder time reaching negatively charged microbe surface
  - chlorine dioxide is more effective at high pH

Factors Influencing Disinfection Efficacy and Microbial Inactivation - Reactor Design, Mixing & Hydraulic Conditions

Disinfection kinetics are better in plug-flow (pipe) reactors than in batch (back-mixed) reactors



Batch or Back-mixed Reactor



Plug-flow or Pipe Reactor

Courtesy: Dr. Irene Xagoraraki (MSU, USA)

Disinfection (chlorination)

Full-scale

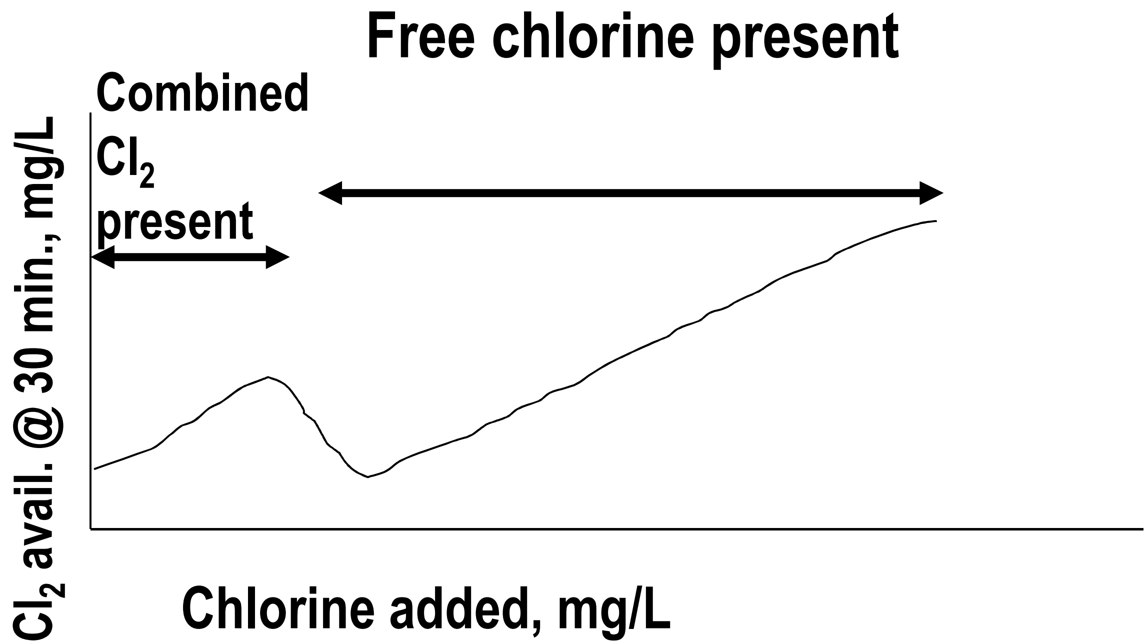
Bench-scale

Chlorination

- Reactions in water
- Reactions with ammonia
- Breakpoint reaction

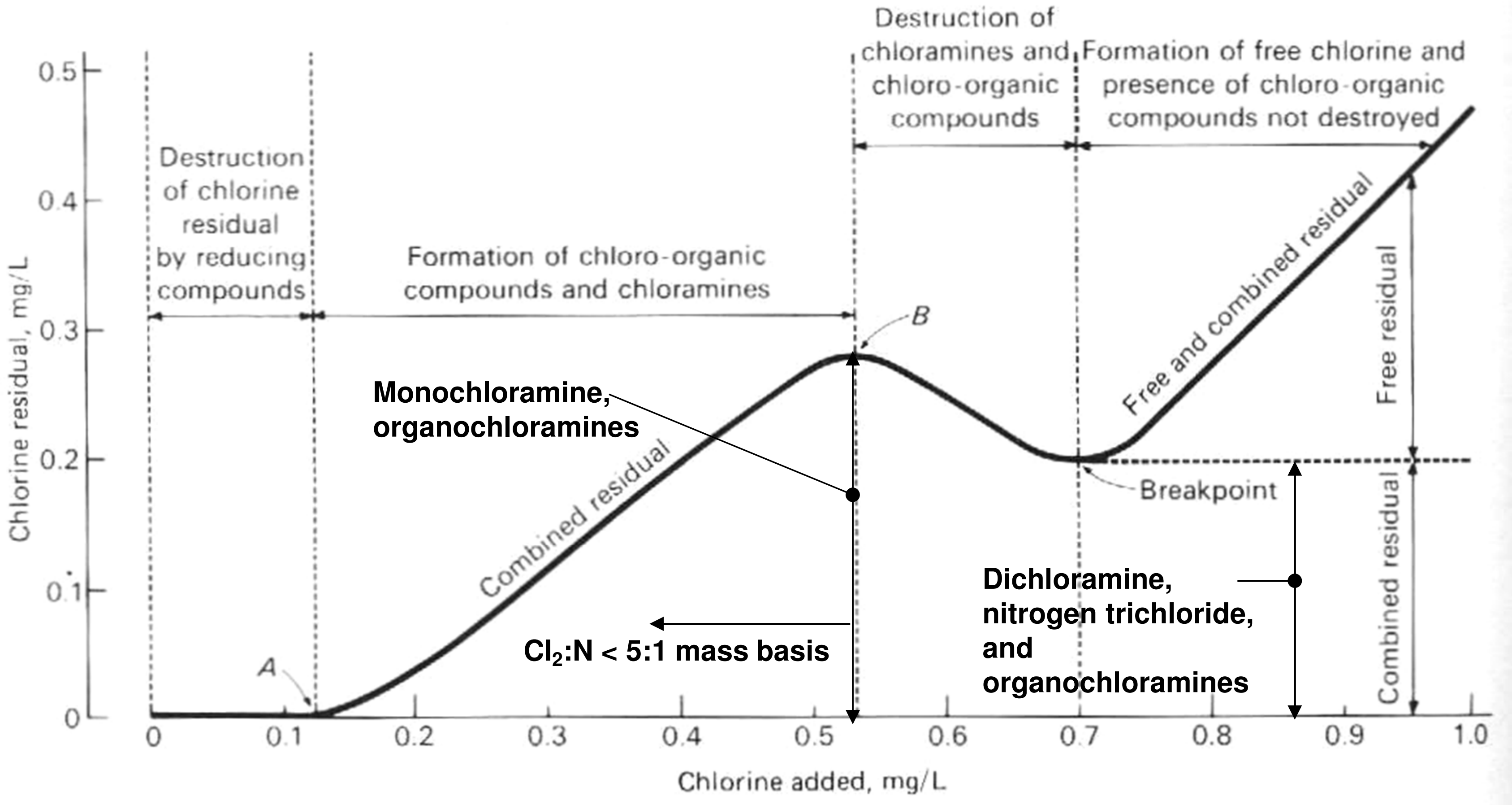
Reaction of Ammonia with Chlorine: Breakpoint Chlorination

- **Presence of ammonia in water or wastewater and the addition of free chlorine results in an available chlorine curve with a "hump"**



- **At chlorine doses between the hump and the dip, chloramines are being oxidatively destroyed and nitrogen is lost (between pH 6.5-8.5).**

Breakpoint Reaction for Chlorine



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

PROCESSES
(gas removal)

Aeration

Aeration

- Used for removing gas
- Depends on water temperature, gas type, its solubility in water; Henry's constant; water-air interfacial area
- Odor causing gas is exchanged from water-air surface
- Physical method (use of steps; example of turbulent river in hills) and mechanical method (use of aerator; spraying in a fountain)

Next class: Tuesday

- Arun Kumar’s last class
- Feb 6th onwards: Prof. B.J. Alappat will teach.