Drinking Water Treatment Technologies:
Filtration, Coagulation, Sedimentation, Disinfection

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Objectives

- **To understand**
  - the principles of water treatment
  - the differences between palatable and potable water
  - the regulations that control drinking water quality
  - the differences between ground- and surface water treatment
  - the goals and operation of the most common water treatment processes

Objectives

- **To be able to draw**
  - **the schematics for water treatment**
- **To be able to do basic water treatment calculations**
  - **mass balance on solids**
  - **begin understand the design method: using example of a water treatment plant**
  - **sizing retention time in basins, length and depth of weir filtration rates**

Palatable vs. Potable

- Palatable
  - esthetically pleasing
  - presence of chemicals does not pose a threat to human health
  - includes chloride, color, corrosivity, iron, manganese, taste and odor, total dissolved solids

Potable Water

- Potable
  - safe to drink
  - not necessarily esthetically pleasing
  - potability affected by
    - microbials (e.g. Giardia, Cryptosporidium)
    - organic chemicals (e.g., alachor, chlordane, cis-1,2-dichloroethylene, disinfection by-products)
    - inorganic chemicals (e.g., cadmium, copper, lead, mercury)
    - radionuclides
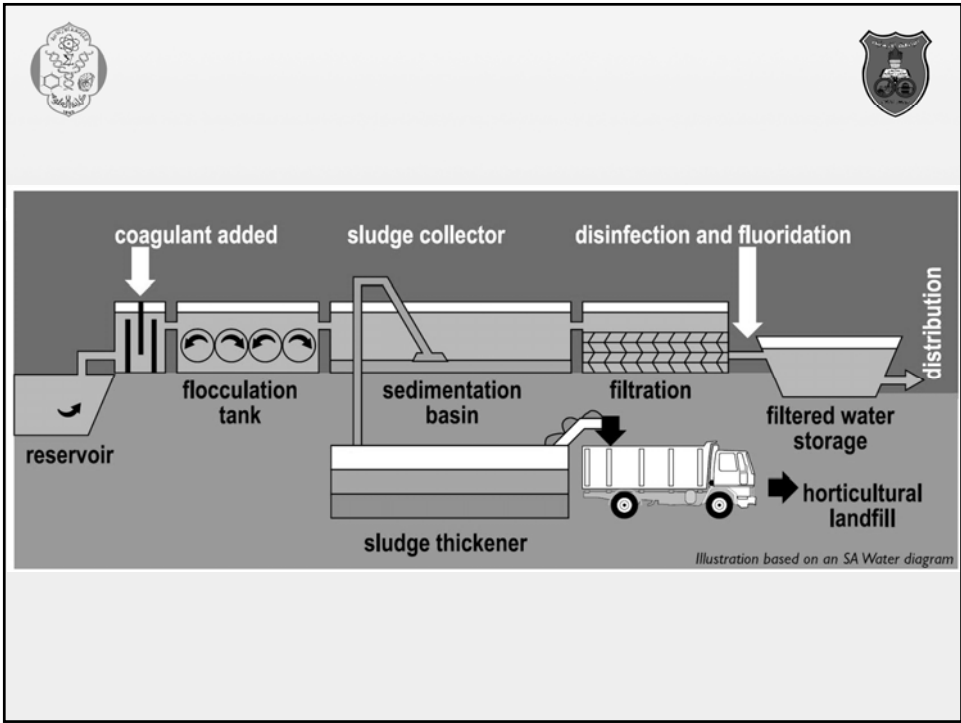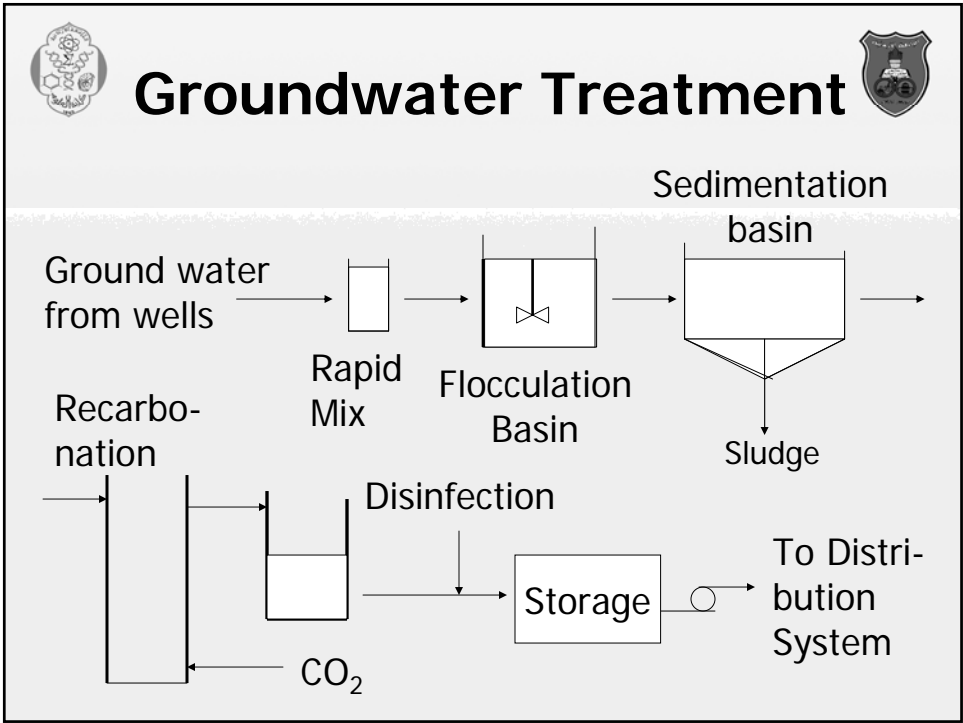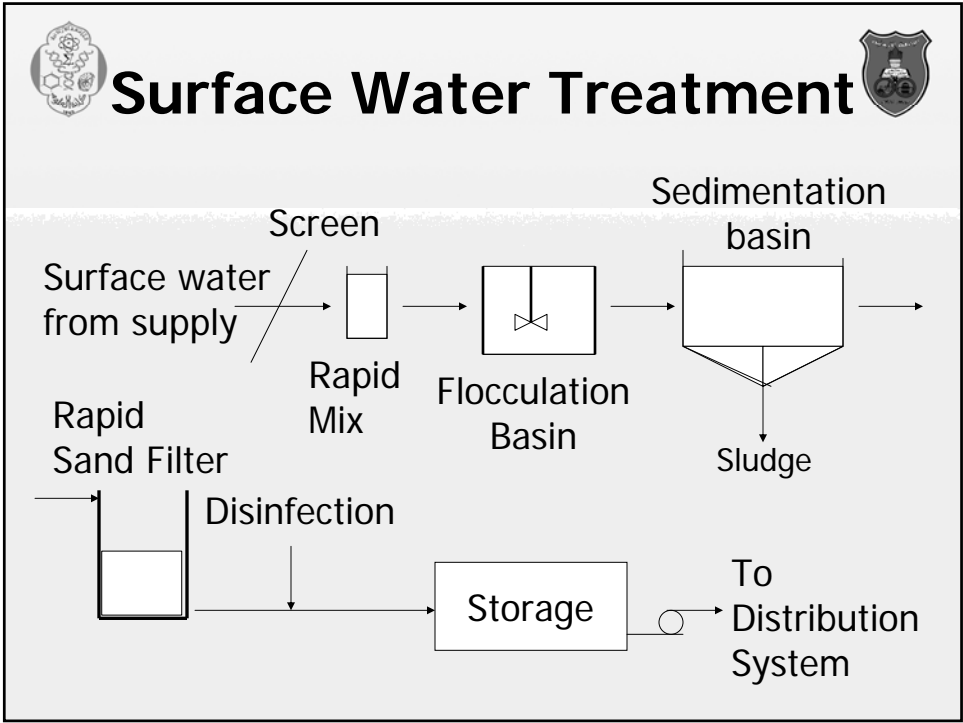
Palatable and Potable

- The goal of municipal water treatment is to provide water that is both palatable and potable
- Palatability and Potability regulated under Safe Drinking Water Act
  - Palatability: Secondary Maximum Contaminant Levels (SMCLs)
  - Potability: Primary Maximum Contaminant Levels (MCLs) - (for systems serving more than 25 persons per day for greater than 60 days per year)

Ground- vs. Surface Water

Groundwater	Surface water
■ constant composition	■ variable composition
■ high mineral content	■ low mineral content
■ low turbidity	■ high turbidity
■ low color	■ colored
■ low or no D.O.	■ D.O. present
■ high hardness	■ low hardness
■ high Fe, Mn	■ taste and odor

coagulant added   sludge collector   disinfection and fluoridation

distribution

flocculation tank   sedimentation basin   filtration   filtered water storage

reservoir

horticultural landfill

sludge thickener

Illustration based on an SA Water diagram

Surface Water Treatment

Groundwater Treatment

Groundwater Treatment

Groundwater Treatment

Aerators

Aeration

This "waterfall" is designed to vent undesirable gases to the atmosphere, primarily carbon dioxide and hydrogen sulfide. Removing carbon dioxide helps to reduce the amount of lime that must be added in the next treatment step.

Hydrogen sulfide produces a "rotten egg" odor, and is removed for aesthetic reasons. Another benefit of aeration is that oxygen in the air reacts with dissolved iron to form particles which are removed in later stages of treatment. Iron removal begins here with its conversion from the soluble (ferrous) form to the insoluble (ferric) form.

Groundwater Treatment

Aeration

$$4Fe^{2+} + O_2 + 10H_2O \leftrightarrow 4Fe(OH_3)_{(s)} + 8H^+$$

$$2Mn^{2+} + O_2 + 2H_2O \leftrightarrow 2MnO_{2(s)} + 4H^+$$
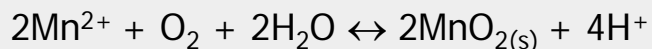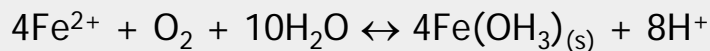
Coagulation

- Surface water must be treated to remove turbidity, color and bacteria.
- The main object of the coagulation is to turn the small particles of color, turbidity and bacteria into larger flocs either as precipitates or suspended particles.

Colloidal Stability

- It is well known that colloid are suspended in solution and can't be removed by sedimentation or filtration
- This is due to the size of the colloids which is too small to settle in a reasonable time period.
- Most of colloid are possess a negative charge that repels other colloidal particles before they collide with one other.
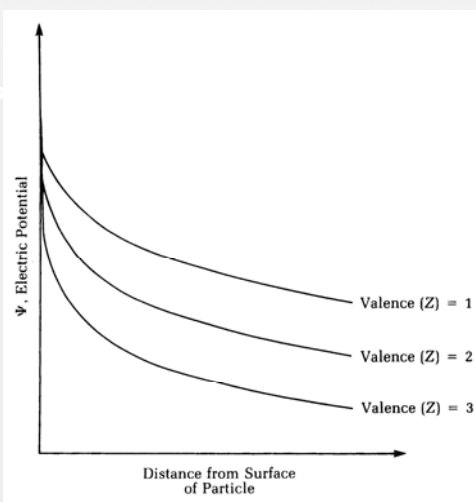
Colloidal Destabilization

- We must neutralize the charges of the colloids.
- Such neutralization can take place by the addition of an ion of opposite charge to the colloid.
- Most colloids found in water are negatively charged, the addition of sodium ions (Na+) should reduce the charge
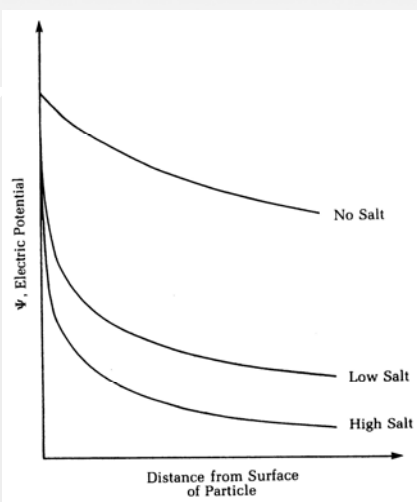
Effect of Salt on electric potential   **Effect of valence on electric potential**

Coagulation

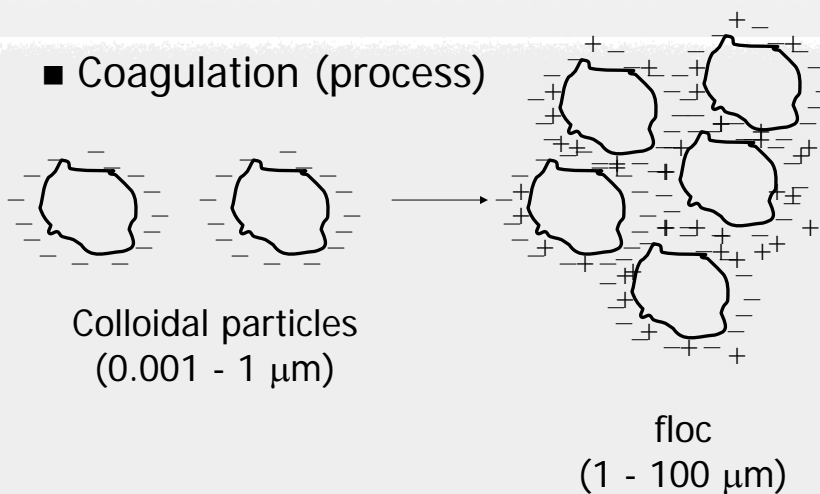- A coagulant is the substance (chemical) that is added to the water to accomplish coagulation.
- Properties of coagulant:
  - Trivalent cation
  - Nontoxic
  - Insoluble in the neutral pH range
- The two most commonly used coagulant are aluminum (Al^{+3}) and ferric iron (Fe^{+3})

Coagulation and Flocculation

- Coagulation (process)

Colloidal particles
(0.001 - 1 μm)

floc
(1 - 100 μm)

Aluminum

- Aluminum can be purchased as either dry or liquid alum $(Al_2(SO_4)_3 \cdot 14H_2O)$
- When alum is added to water containing alkalinity, the following reaction occurs:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \Leftrightarrow 2Al(OH)_{3\,(s)} + 6CO_2 + 14H_2O + 3SO_4^{-2}$$

- Two important factors in coagulant addition are pH and dose.
- The optimum dose and pH must be determined from laboratory tests.

Jar Test

Jar Test II
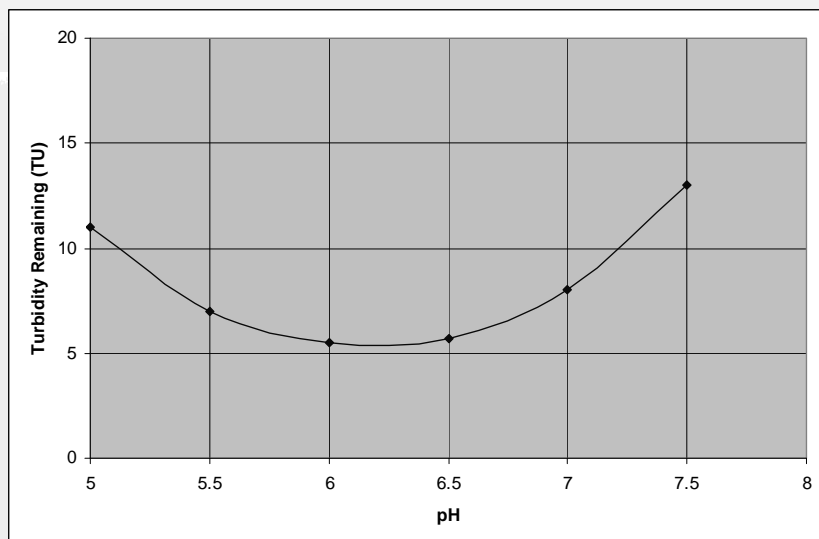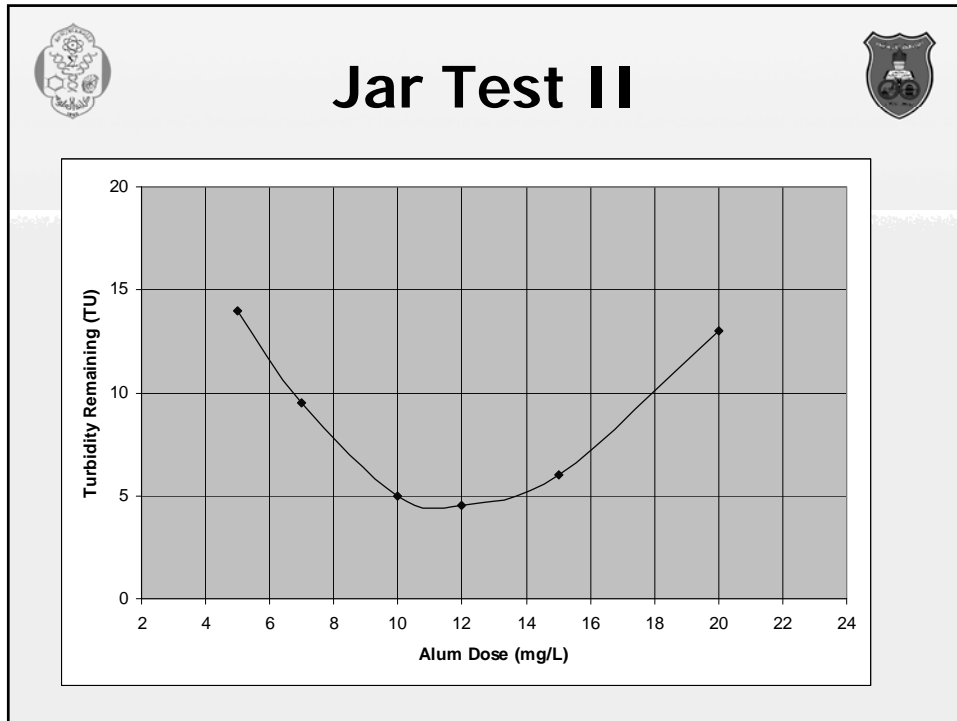
Iron

- Iron can be purchased as either the sulfate salt ($Fe_2(SO_4)_3 \cdot \chi H_2O$) or the chloride salt ($FeCl_3 \cdot \chi H_2O$).

$$FeCl_3 + 3HCO_3^- \Leftrightarrow Fe(OH)_{3(s)} + 3CO_2 + 3Cl^-$$

$$FeCl_3 + 3H2O \Leftrightarrow Fe(OH)_{3(s)} + 3HCl$$

Reactors

- The tanks used to perform physical, chemical and biochemical reactions are called reactors
- It is classified based on their flow characteristics and their mixing conditions
- Three type of reactors are used in water treatment
  - Batch Reactors
  - Flow reactors
  - Plug flow reactors

- For time –dependent reactions the time that a fluid particle remains in the reactor obviously affects the degree to which are the reaction goes to completion

$$t_0 = \sqrt{\dfrac{V}{Q}}$$

Where:
t_0= theoretical detention time
V = Volume of fluid in basin
Q = flow rate into basin

Flocculation

- Mixing, or rapid mixing as it called, is the process whereby the chemicals are quickly and uniformly dispersed in the water.
- During the coagulation and softening the chemical reactions that take place in rapid mixing form precipitates.
- Either aluminum hydroxide or iron hydroxide form during coagulation, while calcium carbonate and magnesium hydroxide form during softening
- The precipitates formed in these processes must brought into contact with one other so that they can agglomerate and form larger particles called **flocs**

- This contacting process is called **flocculation** and is accomplished by slow, genteel mixing
- In the treatment of water the degree of mixing is measured by the velocity gradient **G**.

$$G = \sqrt{\frac{P}{\mu v}}$$

Where:
G = velocity gradient
P = Power input
V = Volume of water in mixing Tank
μ = dynamic viscosity

Rapid Mix

- Rapid mixing is probably the most important physical operation affecting coagulant dose efficiency.
- The chemical reaction in coagulation is completed *in less than 0.1s*, therefore it is imperative that mixing be as instantaneous and complete as possible.
- Rapid mixing can be accomplished within a tank utilizing a vertical shaft mixer, within a pipe using an in-line blender, or in a pipe using a static mixer.

- The selection of G and Gt_o values for coagulation is dependent on the mixing device, the chemicals selected and the anticipated reactions.
- Coagulation occurs predominantly by two mechanisms:
  - Adsorption of the hydrolysis species on the colloid (very fast reaction within one second)
  - Destabilization or sweep coagulation where the colloid is trapped in the hydroxide precipitate (slower reaction and occur between 1 to 7 seconds)

Surface Water Treatment

- **Removal of turbidity**
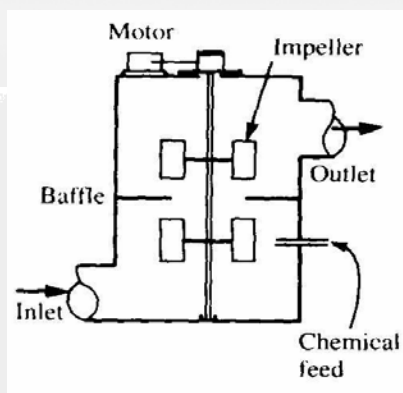 - **rapid mix tank**
  - **flocculation tanks**
  - **settling (sedimentation) tanks**

Rapid Mixing

- Used to blend chemicals and water being treated
- Retention time from 10 - 30 sec.
- Mechanical mixing using vertical-shaft impeller in tank with baffles

(Source: Water Supply and Pollution Control, 5th ed. W. Viessman, Jr. and M.J. Hammer, Harper Collins College Publ. 1993)

- Flocculation is normally accomplished with an axial flow impeller, a paddle flocculater or a baffled chamber
- The axial flow impeller have been recommended over the other types of flocculater because they import a nearly constant G through out the tank
- The flocculater basin should be divided into three compartments
- The velocity decrease from the first to the third compartment

Flocculation

- Paddle units rotate slowly, usually <1 rpm
- Velocity of water: 0.5 - 1.5 ft/sec
- Detention time of at least 20 min
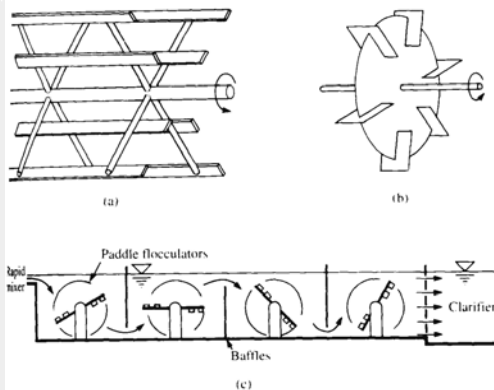
(Source: Water Supply and Pollution Control, 5th ed. W. Viessman, Jr. and M.J. Hammer, Harper Collins College Publ. 1993)

Axial Flow · Propeller · Turbine

Chemical Feed Line · Fixed Wood Baffles · Settling Tank · Flash Mixer · Rotating Baffles · Paddles · Elevation

Settling Basin

Flocculation Basin · Settling Basin · Dual Media Filter · Coal · Sand · Gravel · To Clearwell
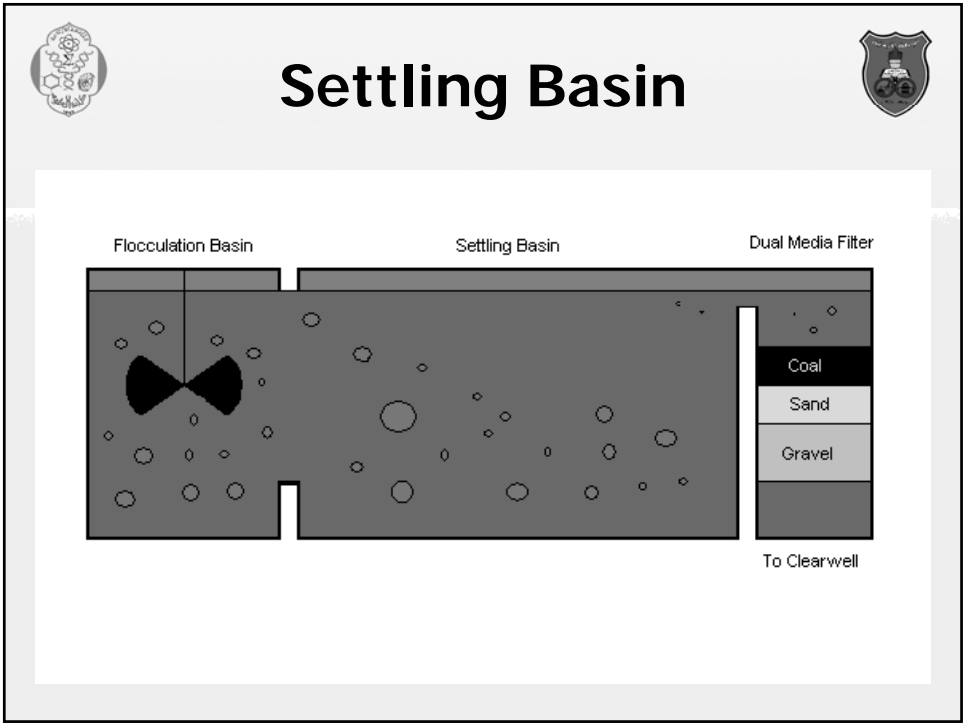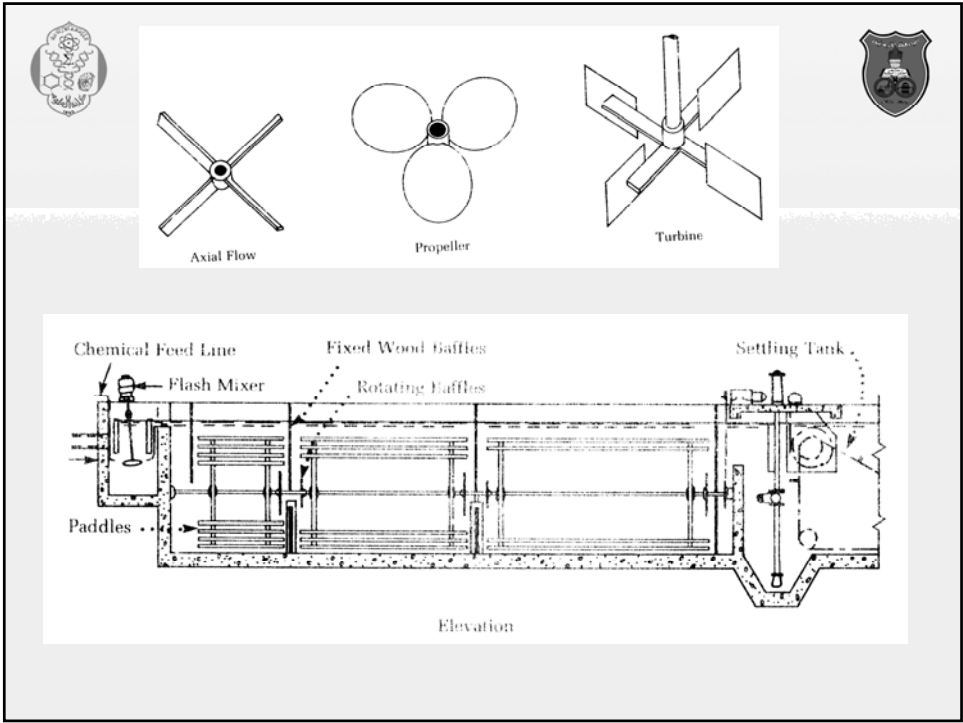
Power Requirements

- In the design of mixing equipment for rapid mix and flocculation tanks the power imparted to the liquid in a baffled tank by an impeller is described by the following equation:

$$P = K_T(n)^3(D_i)^5\rho$$

where

P = Power
K_T = impeller constant
n = rotational speed
D_i = impeller diameter
ρ = density of liquid

Softening: WATER HARDNESS

- Hardness - an undesirable property of water resulting from the presence of primarily Ca^{2+} and Mg^{2+} ions.
- Hardness produces a scummy residue and scale on plumbing and sinks.
- Hardness can be expressed as the sum of the calcium and magnesium concentrations, given in equivalents per liter or the equivalent weight of $CaCO_3$ or ppm as $CaCO_3$.

  Total hardness (eq/L) = Ca^{2+} (eq/L) + Mg^{2+} (eq/L)

Hardness rating	Concentration of $CaCO_3$ (mg/L)
Soft	0 to <75
Medium hard	75 to <150
Hard	150 to <300
Very hard	300 and greater

Hardness

■ A term often used to characterize the ability of a water to:
- cause soap scum
$$Ca^{2+} + (Soap)^- \leftrightarrow Ca(Soap)_{2\ (s)}$$
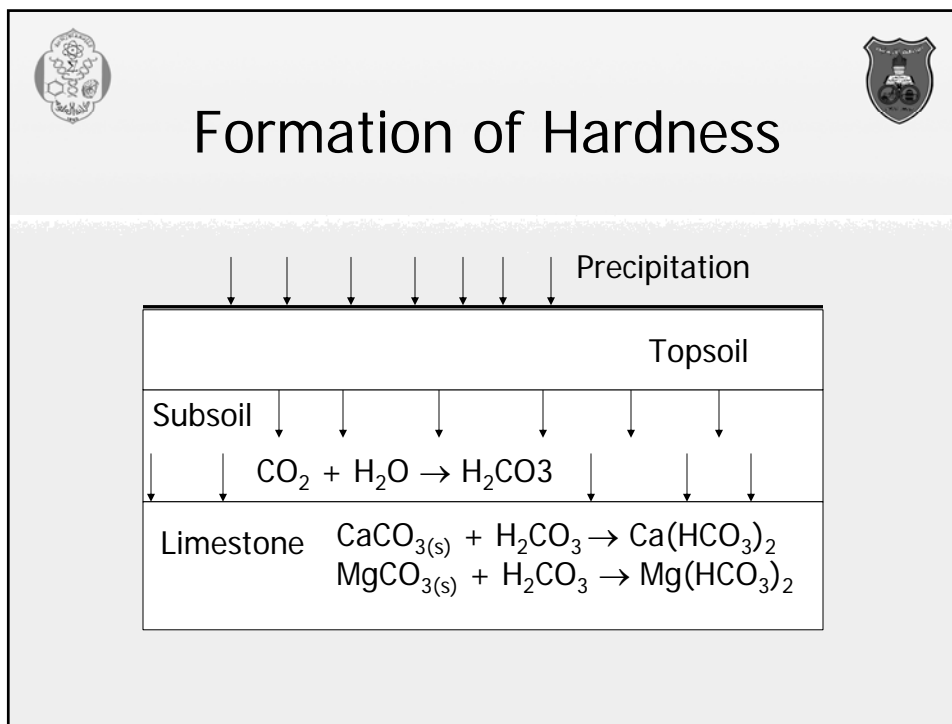- increase the amount of soap needed
- cause scaling on pipes
- cause valves to stick due to the formation of calcium carbonate crystals
- leave stains on plumbing fixtures
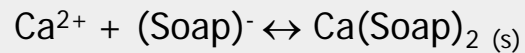
Hardness

■ 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.

Formation of Hardness

Precipitation

Topsoil

Subsoil

$$CO_2 + H_2O \rightarrow H_2CO3$$

Limestone

$$CaCO_{3(s)} + H_2CO_3 \rightarrow Ca(HCO_3)_2$$
$$MgCO_{3(s)} + H_2CO_3 \rightarrow Mg(HCO_3)_2$$

Hardness

■ Carbonate Hardness

- Often called "temporary hardness" because heating the water will remove it. When the water is heated, the insoluble carbonates will precipitate and tend to form bottom deposits in water heaters.
- Ca^{2+}, Mg^{2+} associated with HCO_3^-, CO_3^{2-}
- CH = TH or Total alkalinity, whichever is less

Hardness

- Non-Carbonate Hardness
  - Called permanent hardness because it is not removed when the water is heated. It is much more expensive to remove non-carbonate hardness than carbonate hardness.
  - Ca^{2+}, Mg^{2+} associated with other ions, Cl^-, NO_3^-, SO_4^{2-}
  - NCH = TH - CH
  - If Alkalinity $\geq$ Total hardness, then NCH = 0

Hardness Units

- milligrams per liter (mg/L) as calcium carbonate
- parts per million (ppm) as calcium carbonate
- grains per gallon of hardness (to convert from grains per gallon to mg/L, multiply by 17.1)
- equivalents/liter
  - equivalents
    - acids and bases: number of H^+ transferred
    - redox reactions: number of e^- transferred

Hardness Units

■ Most common expression of hardness

$$mg/L \text{ of } X \text{ as } CaCO_3 =$$

■ Total hardness $= [Ca^{2+}] + [Mg^{2+}] + ...$

- can use: M, mM, eq/L, meq/L, mg/L as $CaCO_3$
- cannot use: mg/L

Example 6: Calculations

■ A sample of water having a pH of 7.2 has the following concentrations of ions

Ca^{2+}	40 mg/L
Mg^{2+}	10 mg/L
Na^+	11.8 mg/L
K^+	7.0 mg/L
HCO_3^-	110 mg/L
SO_4^{2-}	67.2 mg/L
Cl^-	11 mg/L

■ Calculate the TH, CH, NCH, Alkalinity

Example 6: Calculations

Ion	Conc. mg/L	M.W. mg/mmol	$\lvert n \rvert$	Eq. Wt. mg/meq	Conc. meq/L	Conc. mg/L as $CaCO_3$
Ca^{2+}	40.0	40.1				
Mg^{2+}	10.0	24.3				
Na^+	11.8	23.0				
K^+	7.0	39.1				
HCO_3^-	110.0	61.0				
SO_4^{2-}	67.2	96.1				
Cl^-	11.0	35.5				

Example 6: Calculations

Ion	Conc. mg/L	M.W. mg/mmol	$\lvert n \rvert$	Eq. Wt. mg/meq	Conc. meq/L	Conc. mg/L as $CaCO_3$
Ca^{2+}	40.0	40.1	2	20.05		
Mg^{2+}	10.0	24.3	2	12.15		
Na^+	11.8	23.0	1	23.0		
K^+	7.0	39.1	1	39.1		
HCO_3^-	110.0	61.0	1	61.0		
SO_4^{2-}	67.2	96.1	2	48.05		
Cl^-	11.0	35.5	1	35.5		

Sample Calculation: Equivalent Weight of Ca^{2+} = M.W. / $\lvert n \rvert$

$$= 40.1/2 = 20.05$$

Example 6: Calculations

Ion	Conc. mg/L	M.W. mg/mmol	$\lvert n \rvert$	Eq. Wt. mg/meq	Conc. meq/L	Conc. mg/L as $CaCO_3$
Ca^{2+}	40.0	40.1	2	20.05	1.995	
Mg^{2+}	10.0	24.3	2	12.15	0.823	
Na^+	11.8	23.0	1	23.0	0.51	
K^+	7.0	39.1	1	39.1	0.179	
HCO_3^-	110.0	61.0	1	61.0	1.80	
SO_4^{2-}	67.2	96.1	2	48.05	1.40	
Cl^-	11.0	35.5	1	35.5	0.031	

Sample Calculation: Concentration of Ca^{2+} =
(Concentration in mg/L) / (Equivalent Weight in mg/meq) =
(40.0 mg/L) / (20.05 mg/meq) = 1.995 meq/L

Example 6: Calculations

Ion	Conc. mg/L	M.W. mg/mmol	$\lvert n \rvert$	Eq. Wt. mg/meq	Conc. meq/L	Conc. mg/L as $CaCO_3$
Ca^{2+}	40.0	40.1	2	20.05	1.995	99.8
Mg^{2+}	10.0	24.3	2	12.15	.823	41.2
Na^+	11.8	23.0	1	23.0	.51	25.7
K^+	7.0	39.1	1	39.1	.179	8.95
HCO_3^-	110.0	61.0	1	61.0	1.80	90.2
SO_4^{2-}	67.2	96.1	2	48.05	1.40	69.9
Cl^-	11.0	35.5	1	35.5	.031	15.5

Sample Calculation: Concentration of Ca^{2+} in mg/L as $CaCO_3$ =
(Concentration in meq/L) * (Equivalent Weight of $CaCO_3$) =
(1.995 meq/L) / (50 mg/meq) = 99.8 mg/L as $CaCO_3$

Example 6: Calculations

- Check Solution

$$\Sigma(\text{cations}) = \Sigma(\text{anions}) \quad \text{to within} \pm 10\%$$
$$175.6 \quad = \quad 175.6 \quad \text{mg/L as CaCO}_3$$

(Can check using concentrations in meq/L or mg/L as $CaCO_3$)

- Total Hardness = Σ of multivalent cations

$$= (Ca^{2+}) + (Mg^{2+}) = 99.8 + 41.2 =$$
$$141 \text{ mg/L as CaCO}_3$$

Example 6: Calculations

- **Carbonate Hardness** (the portion of the hardness associated with carbonate or bicarbonate)

    Alkalinity = 90.1 mg/L as $CaCO_3$

    TH = 141 mg/L as $CaCO_3$

    CH = 90.1 mg/L as $CaCO_3$

    (Note: if TH < Alk then CH = Alkalinity; and NCH = 0)

- **Non-carbonate Hardness**

    NCH = TH - CH = 141 - 90.1 =

    50.9 mg/L as $CaCO_3$

Lime – Soda Softening

- In lime soda softening it is possible to calculate the chemical doses necessary to remove hardness.

$$Ca^{+2} + CO_3^{-2} \Leftrightarrow CaCO_{3(s)}$$
$$Mg^{+2} + 2OH^- \Leftrightarrow Mg(OH)_{2(s)}$$
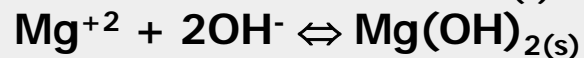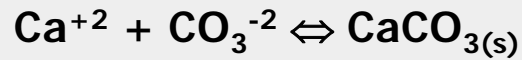
- The objective is to precipitate the calcium as $CaCO_3$ and the magnesium as $Mg(OH)_2$.
- In order to achieve this the pH of the water must be raised to about 10.3 and 11 respectively

Lime addition
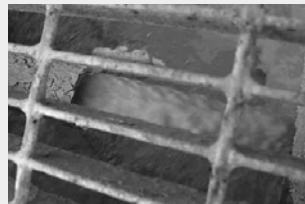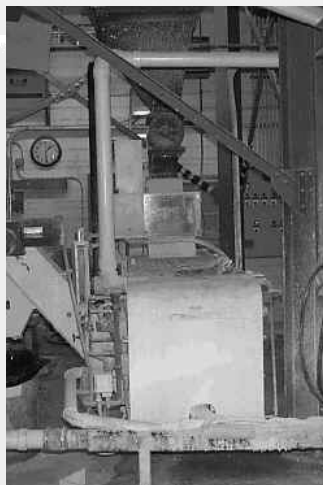
Softening Chemistry

- The chemical processes used to soften water are a direct application of the law of mass action.
- We increase the concentration of CO32- and /or OH- by the addition of chemicals.
- Many water treatment plants find it more economical to buy quicklime (CaO) than hydrated lime. The quicklime converted to hydrated lime by mixed with water to produce a slurry of Ca(OH)2 .
- The conversion process is called slaking

$$CaO + H2O \Leftrightarrow Ca(OH)2 + Heat$$

Softening Reactions

- The softening reactions are regulated by controlling the pH
- Six important softening reactions are present below:
- Neutralization of carbonic acid

$CO_2 + Ca(OH)_2 \leftrightarrow CaCO_{3(s)} + H_2O$

- Precipitation of CH due to calcium

$Ca^{2+} + 2HCO_3^- + Ca(OH)_2 \leftrightarrow 2CaCO_{3(s)} + 2H_2O$

- Precipitation of CH due to magnesium

$Mg^{2+} + 2HCO_3^- + Ca(OH)_2 \leftrightarrow Mg^{2+} + CO_3^{2-} + CaCO_{3(s)} + 2H_2O$

$Mg^{2+} + CO_3^{2-} + Ca(OH)_2 \leftrightarrow MgOH_{2(s)} + CaCO_{3(s)}$

- ■ Removal of NCH due to calcium

$$Ca^{2+} + NaCO_3 \leftrightarrow CaCO_{3(s)} + 2Na^+$$
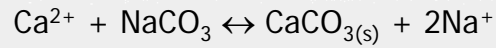
- ■ Removal of NCH due to magnesium
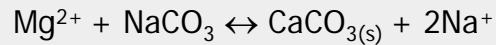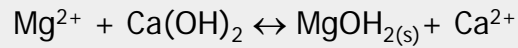
$$Mg^{2+} + Ca(OH)_2 \leftrightarrow MgOH_{2(s)} + Ca^{2+}$$

$$Mg^{2+} + NaCO_3 \leftrightarrow CaCO_{3(s)} + 2Na^+$$

Softening Reactions

- ■ The softening reactions are regulated by controlling the pH
- ■ Six important softening reactions are present below:
  - • Neutrilization of Carbonic acid (H2CO3)
  - • Precipitation of carbonate hardness due to calcium
  - • Precipitation of carbonate hardness due to magnesium
  - • Removal of noncarbonate hardness due to calcium
  - • Removal of noncarbonate hardness due to magnesium

Ion-Exchange Softening

- Ion exchange can be defined as the reversible interchange of ions between a solid and a liquid phase in which there is no permanent change in the structure of the solid
- Typically, in water softening by ion exchange, the water containing the hardness is passed through a column containing the ion-exchange material
- Generally, the ion exchanged with the hardness is sodium as the following:

$$Ca(HCO_3)_2 + 2NaR \Leftrightarrow CaR_2 + 2NaHCO_3$$

- Where R represents the solid ion-exchange material

Sedimentation

- Particles that can settle within a reasonable period of time can be removed in a sedimentation basins
- These basins are rectangular or circular with either a radial or upward water flow pattern
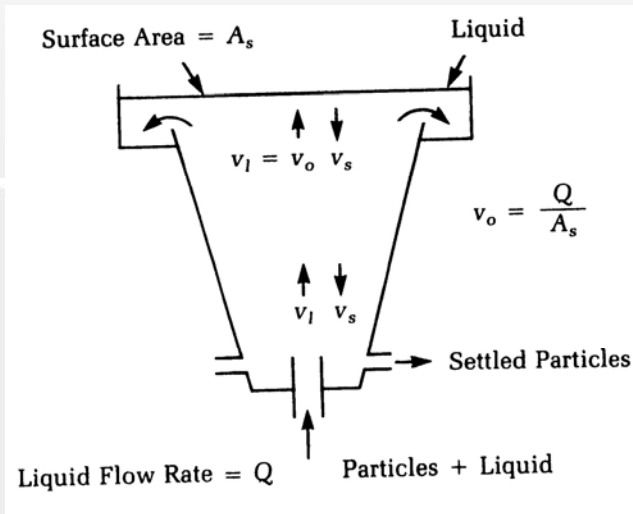- The basin design can be divided into four zones: inlet, settling, outlet and sludge stoarge

Clarifiers
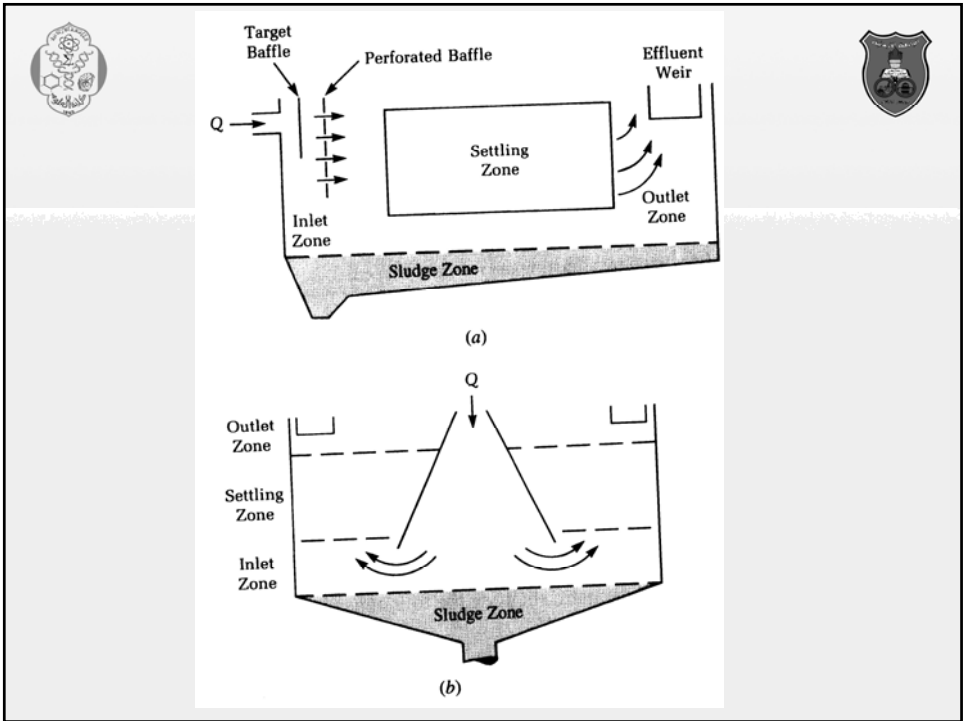
Sedimentation Concepts

- There are two important terms to understand in sedimentation zone design
- **Firstly: the particle (floc) settling velocity V_s**
- **Secondly: the velocity at which the tank is designed to operate, called overflow rate V_o**

**Settling in an upflow clarifier**
V1= velocity of liquid
Vs =terminal settling velocity of particle

- The particle removal in a horizontal sedimentation tank is like wise dependent only upon the overflow rate.
- An ideal horizontal sedimentation tank is based on three assumptions:
  - Particles and velocity vectors are evenly distributed across the tank cross section
  - The liquid moves as an ideal slug down the length of the tank
  - Any particle hitting the bottom of the tank is removed
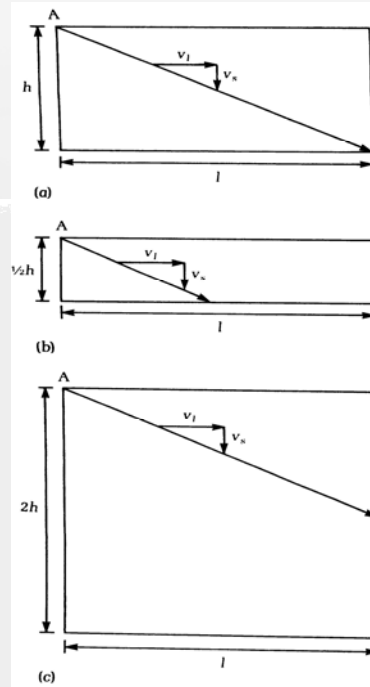
Ideal horizontal sedimentation tank
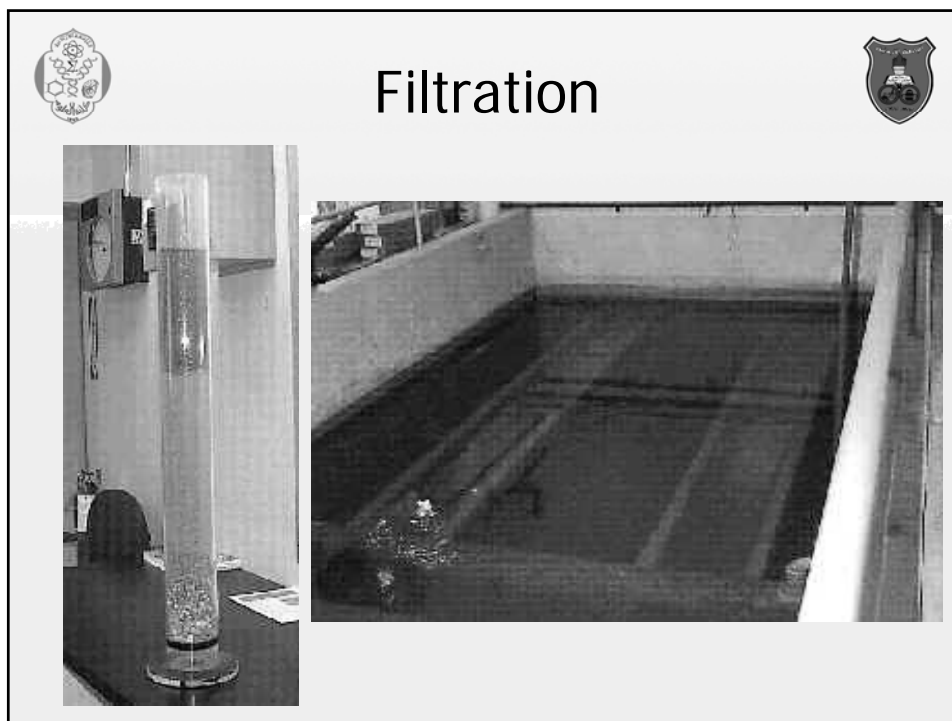
Filtration

- The water leaving the sedimentation tank still contains floc particles
- The settled water turbidity is generally in the range from 1 to 10 TU with a typical value of 3 TU
- In order to reduce this turbidity to 0.3 TU a filtration process is normally used
- ***Water filtration* is a process for separating suspended or colloidal impurities from water by passage through a porous medium usually a bed of sand or other medium**
- Water fill the pores between sand particles and the impurities are left behind either clogged in the open spaces or attached to the sand itself

- There are several methods of classifing filters and they can be classified according to:
  - Type of medium used (sand , coal, mixed)
  - Allowable loading rate
    - Slow sand filters
    - Rapid sand filters
    - High rate sand filters

- **The water then flows into the settling basins, where the flow is almost devoid of turbulence.**
- **Here the water resides for at least 3 hours and the flocs settle out and collect at the bottom.**
- **The floc may flow into a hopper or be mechanically**
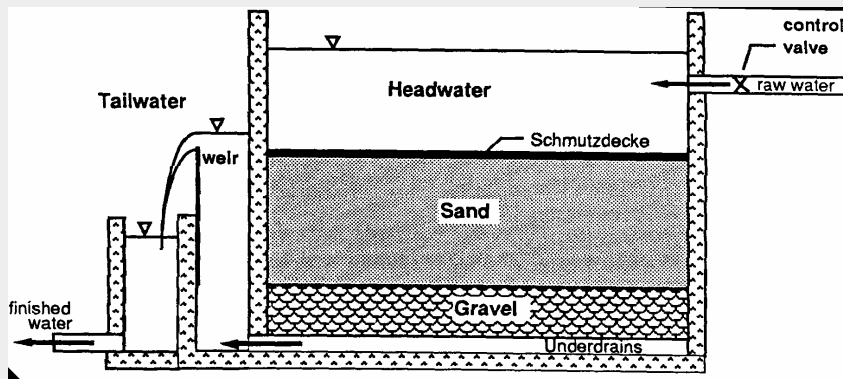- **removed periodically, as is done here.**

- The final step in removing particles is filtration.
- Removal of those particles that are too small to be effectively removed during sedimentation
- Sedimentation effluent: 1 - 10 JTU
- Desired effluent level: <0.3 JTU

- Single media: sand
- Dual media: anthracite coal and sand
- Multimedia: anthracite coal, sand and garnet

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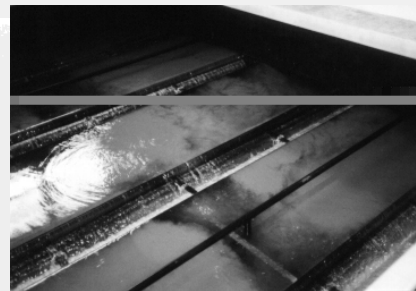
Rapid Sand Filtration

- As particles are removed - filter becomes clogged - headloss increases, turbidity increases
- Must backwash (takes about 10-15 min) done about once per day
- Must design to handle flow with one filter out of service

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- **Backwashing is accomplished by forcing water (and sometimes air) up from the clearwell back through the filter.**
- **The particles in the filter become suspended, releasing the trapped particles.**

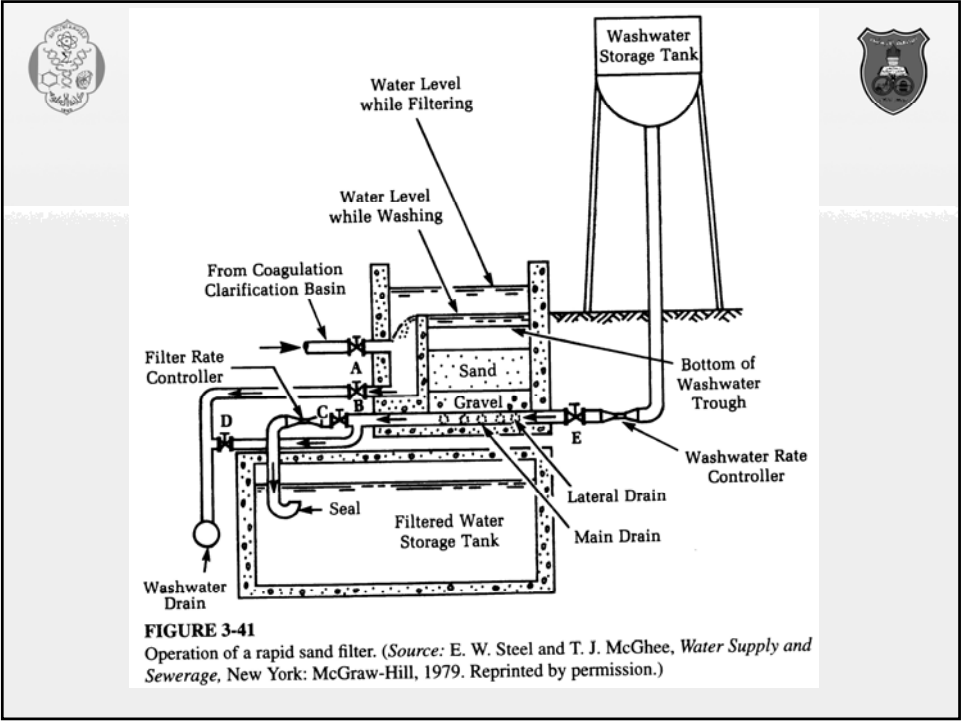- The backwash water then is pumped to settling ponds.
- Here the solids settle out and the supernatant water is pumped back to the New River.
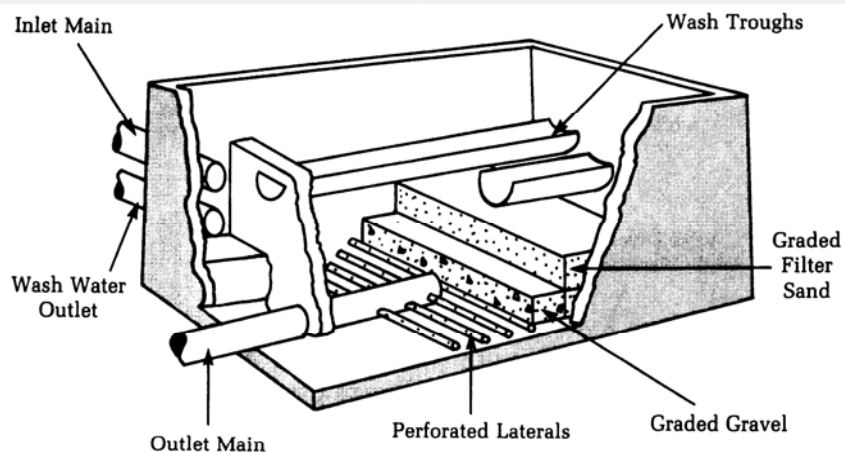
FIGURE 3-40
Typical cross section of a rapid sand filter. (*Source:* American Water Works Association, *Water Treatment Plant Design,* 1969.)

Inlet Main

Wash Troughs

Wash Water Outlet

Graded Filter Sand

Outlet Main

Perforated Laterals

Graded Gravel

FIGURE 3-41
Operation of a rapid sand filter. (*Source:* E. W. Steel and T. J. McGhee, *Water Supply and Sewerage,* New York: McGraw-Hill, 1979. Reprinted by permission.)

U.S. Standard Sieve Series

| Sieve designation number	Size of opening (mm)	Sieve designation number	Size of opening (mm)
200	0.074	20	0.84
140	0.105	(18)	(1.00)
100	0.149	16	1.19
70	0.210	12	1.68
50	0.297	8	2.38
40	0.42	6	3.36
30	0.59	4	4.76

Source: Excerpted from G. A. Fair and J. C. Geyer, *Water Supply and Wastewater Disposal,* New York: Wiley, pp. 664-670, 1954.

Sediment Classification

- **Sediments are classified on basis of size of individual grains**
- **Grain size distribution curve**
- **Uniformity coefficient $C_u = d_{60}/d_{10}$**
- **d_{60} = grain size that is 60% finer by weight.**
- **d_{10} = grain size that is 10% finer by weight.**
- **$C_u = 4 =>$ well sorted; $C_u > 6 =>$ poorly sorted.**
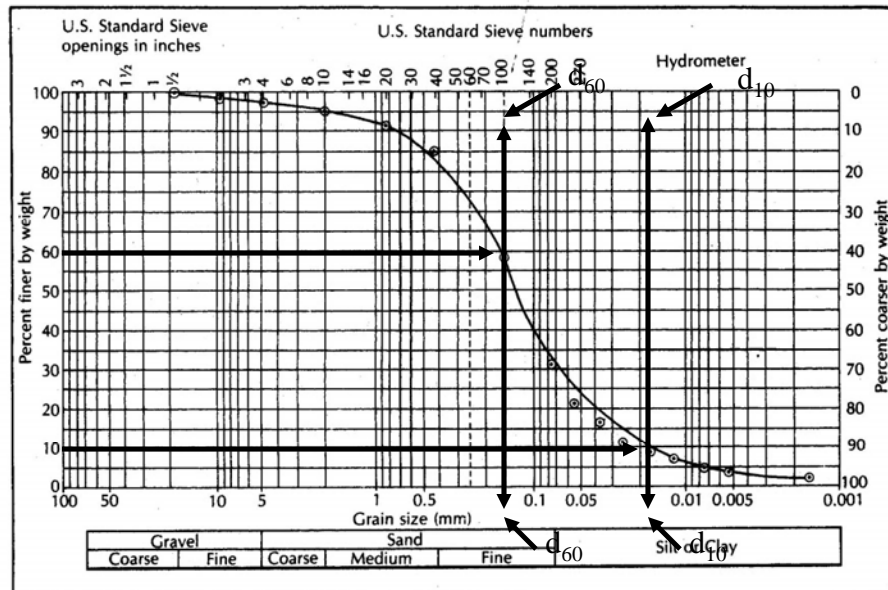
▲ FIGURE 3.4
Grain-size distribution curve of a silty fine to medium sand.

▲ FIGURE 3.5
Grain-size distribution curve of a fine sand.
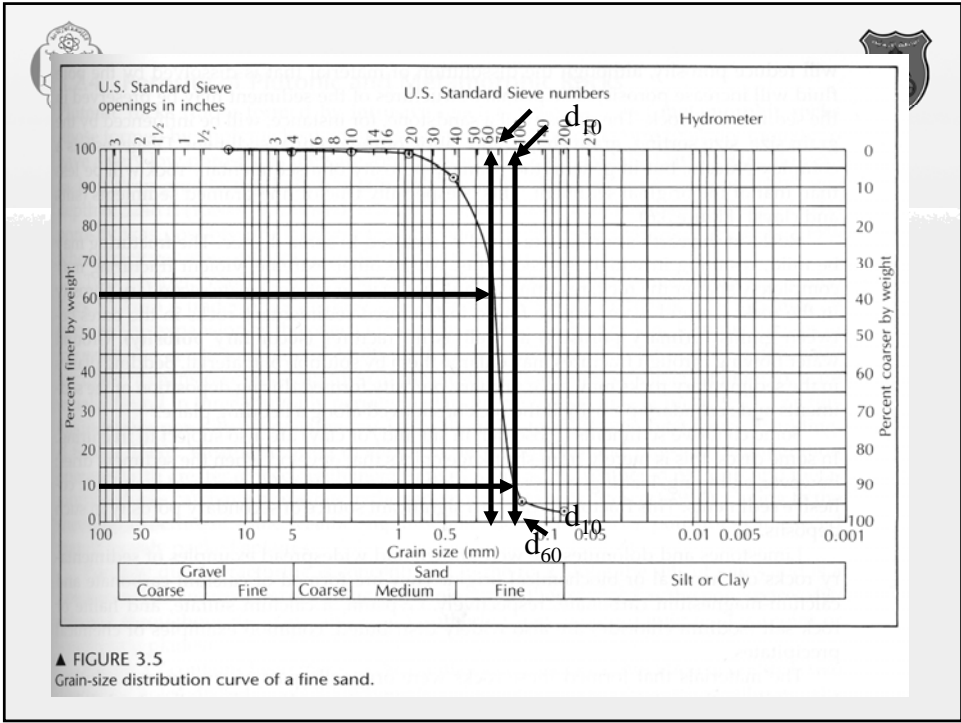
Surface Water Treatment

- Prior to distribution, chlorine gas is added.
- This ensures residual chlorine so that pathogens cannot survive throughout the distribution system.
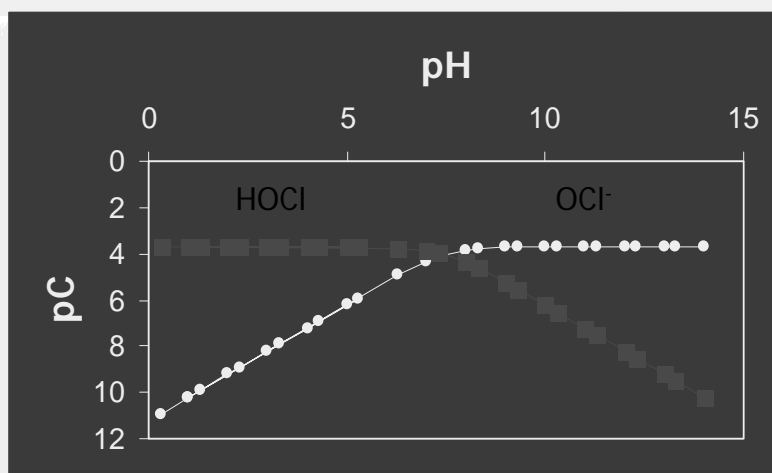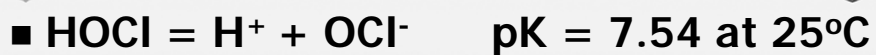
Chlorine Reactions in Water

- $Cl_{2\,(g)} + H_2O = HOCl + H^+ + Cl^-$
  - pH dependent
  - essentially complete within a few milliseconds
- $HOCl = H^+ + OCl^-$
  - HOCl is about 80 - 100 times more effective than is OCl^- for E. Coli
  - $[HOCl] + [OCl^-]$ = free available chlorine

Chlorine Reactions in Water

- $HOCl = H^+ + OCl^-$ pK = 7.54 at 25°C

Other Forms of Chlorine

- **Hypochlorite salts**
  - **NaOCl**
  - **Ca(OCl)$_2$**
- **Advantages/Disadvantages**
  - **chlorine gas: cheaper, tends to decrease pH, reduces alkalinity**
  - **hypochlorite salts: more expensive, saver, always contain alkali to enhance stability, tend to raise pH**

Alternative Disinfectants

- Chloramines (NH$_2$Cl, NHCl$_2$, NCl$_3$)
  - longer lifetimes in water
  - less effective oxidant
  - usually used in combination with other disinfectants
- Chlorine dioxide (ClO$_2$)
  - potent bactericide and viricide
  - may produce toxic chlorate and chlorite
  - provides residual disinfection

Alternative Disinfectants

- Ozone (O_3)
  - very powerful oxidant
  - potent bactericide and viricide, kills cysts
  - no taste and odor problems
  - widely used in Europe
  - no residual
  - more expensive than chlorine (more economical when chlorine must be used with activated carbon)

Alternative Disinfectants

- Ultraviolet radiation
  - effective bactericide and viricide
  - water must be free of turbidity and lamps free of slime and precipitates
  - no residual protection

Disinfection Kinetics

- Chick's Law:

$$-\frac{dN}{dt} = kN$$

Disinfectant Ability

- Current regulations use the CT concept, which require a specific log reduction in the numbers of Giardia and viruses
- C = concentration of disinfectant in contactor
- T = contact time (actually T-10)
- CT = $0.9847C^{0.1758}pH^{2.7519}temp^{-0.1467}$

Groundwater Treatment

Polyphosphate addition

Fluoride addition

Groundwater Treatment

- Polyphosphate addition
  - Added for corrosion control as it forms a protective film on pipes
  - Also helps to control lead levels in tap water as it complexes with lead
- Fluoride addition
  - Added either as NaF, Na_2SiF_6, H_2SiF_6
  - React in water to yield fluoride ion (F^-)

Major Features of Karst Topography

Fig. 12.20

Groundwater Contamination

Fig. 12.22

Contamination of water well by Septic System

Karst