Effective Particle/ Turbidity Removal

MCET
environmental, health, and safety training

CSM college of southern maryland
La Plata · Leonardtown · Prince Frederick · Waldorf

Effective Particle / Turbidity Removal
at
Water & Wastewater Facilities

Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD

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Background of Participants

- Before we start, let's introduce ourselves.
  - Name,
  - Water? Wastewater? Both?
  - What is your job there?
  - What do you "need-to-know" about Particle / Turbidity Removal?

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Training Approach

- Presentations & Guided Discussion
- Your input is STRONGLY encouraged
- Ask questions
- Share experiences / observations

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Training Objectives

Understand:

- Water treatment requirements to remove turbidity to satisfy Safe Drinking Water Act (SDWA) requirements
- Wastewater treatment requirements to enhance suspended solids removal
- The fundamentals of coagulation / flocculation / sedimentation and filtration
- The inter-relationships between treatment processes

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Training Objectives

Participants will be able to describe:

- Drinking water treatment requirements:
  - Turbidity removal requirements: ≤ 0.3 NTU; goal : ≤ 0.1 NTU
  - NOM/TOC removal goal: ≤ 2.0 mg/l
- Enhanced suspended solids removal at WWTP
- Fundamentals of:
  - Coagulation/Flocculation
  - Clarification/Sedimentation
  - Filtration
- Inter-relationships between processes
- Pros and Cons of equipment options

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Water Treatment - Overview

Surface Water & GWUDI Treatment Plants:

A. Are subject to Safe Drinking Water Act (SDWA) - Surface Water Treatment Rule (SDWA, Subpart H) requirements for:
   1. Filtration
   2. Disinfection

B. Are dependent on coagulation, flocculation, clarification, and filtration techniques to meet drinking water standards

C. Are subject to Enhanced Surface Water Treatment Rule requirements for Cryptosporidium removals

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Wastewater Treatment - Overview

Wastewater treatment plants:

A. Surface Dischargers subject to Clean Water Act (CWA) – NPDES Program
B. Are subject to stringent effluent TSS and TP discharge standards
C. Are dependent on coagulation, flocculation, clarification, and filtration techniques to meet TSS and TP discharge standards

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Participant Focus

- **What information can you use at your work location?**
  - Water Regulatory Framework
    - Surface Water Treatment Rule
    - Filter Backwash Recycling Rule
  - Wastewater Regulatory Framework
    - Chesapeake Bay Water Quality Standards
- **What information can you contribute to the discussion?**
  - Chemical Addition; Alum, $FeCl_3$, PACl, and polymers

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Course Outline

- **Introduction**
  - Definitions
  - Regulatory Framework
    - SDWA
    - SWTR
    - ESWTRs
  - Contaminants of Concern
    - Turbidity
    - NOM/TOC
    - Pathogens
  - Water Treatment Overview
    - Conventional
    - Direct
- **Coagulation**
  - Role of Coagulation
  - Chemicals
    - Alum and $FeCl_3$
    - Polymers
  - Flash Mix
  - Chemical Feed Pumps
  - Mixers
  - Zeta Potential
- **Flocculation**
  - Floc Formation
  - Detention Times
  - Mixing Requirements
- October 2016
- **Sedimentation/Clarification**
  - Hydraulic Loadings
  - Detention Times
  - DAFs
  - Conventional Clarifiers
  - New Clarification Processes
- **Filtration**
  - Filtration Rates
  - Backwash Rates
  - Filter Backwash Recycling Rule
  - Granular Media Filters
    - Single media
    - Dual media
  - Membranes
    - Microfiltration and Ultrafiltration
    - Nanofiltration and Reverse Osmosis

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Regulations

Safe Drinking Water Act (SDWA)

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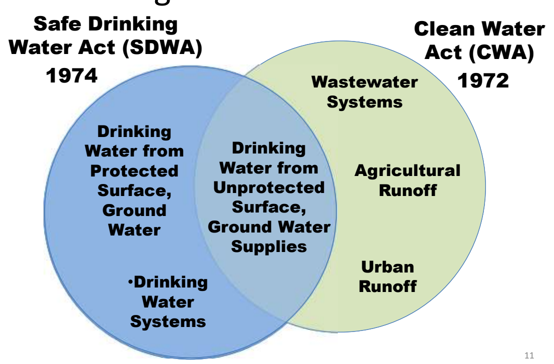
Legislative Mandates



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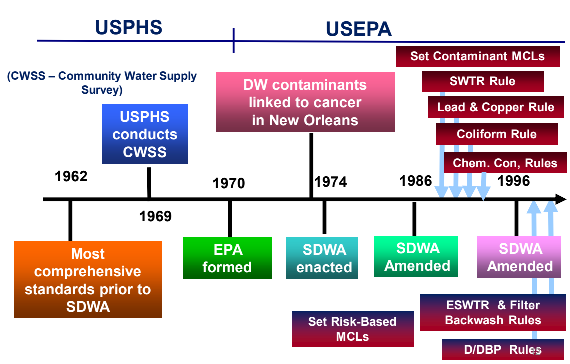
Federal Drinking Water Program



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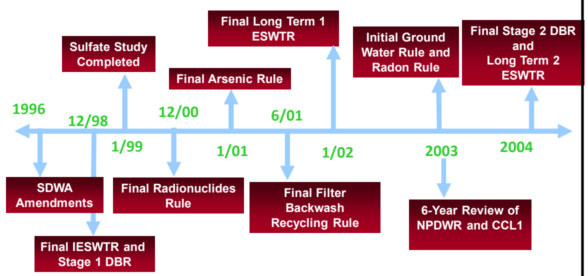
Rule Schedule



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SDWA Contaminants

Microbial Risks
- Turbidity (Water quality indicator)
- Coliform Bacteria (Total, Fecal & E. coli)
- Enteroviruses
- Protozoa (Giardia, Cryptosporidium)
- Bacterial Pathogens (Legionella)

Chemical & Radiological Risks
- Inorganic chemicals (IOCs)
- Volatile organic chemicals (VOCs)
- Synthetic organic compounds (SOCs)
- Disinfectants & Disinfection by products (DBPs)
- Radionuclides (Radium 226/228, Uranium)

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Federal Rules

- Regulations to decrease Microbial Risk
  - SWTR - Surface Water Treatment Rule (1989)
  - ESWTR – Enhanced Surface Water Treatment Rules
    - Long-Term 1 (LT1ESWT - 2002)
    - Long-Term 2 (LT2ESWT - 2006)
  - Filter Backwash Rule (2001)
  - Total Coliform Rule (1989)
  - Ground Water Rule (2006)

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Federal Rules

- Regulations to decrease Chemical and Radiological Risk
  - Lead & Copper Rule (1991)
  - DBPR – Disinfectants/Disinfection Byproducts Rules
    - Stage 1 (Stage 1 DBPR – 1998)
    - Stage 2 (Stage 2 DBPR – 2006)
  - Fluoride Rule (1986)
  - Chemical Contaminant Rules (1987 – 1992)
  - Arsenic Rule (2001)
  - Radionuclides Rule (2000)
  - Radon Rule (Proposed)

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What will the Future Bring?

Regulatory Challenges
- Federal Rules
- State Ordinances
- Local Ordinances

Legal Challenges
- Toxic Tort Claims
- Personal Property
- Public Nuisance Claims

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Regulations

Surface Water Treatment Rules

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Surface Water Treatment Rule

- Promulgated in 1989
- Requires filtration for turbidity removal for all surface water systems
- Requires disinfection with filtration to achieve a total of 3-log Giardia inactivation and 4-log virus inactivation

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Subpart H—Filtration and Disinfection

- General Requirements
  - Establish criteria under which Filtration and Disinfection are required
  - Establish Treatment Techniques (TT) in lieu of MCLs for:
    - *Giardia lamblia*
    - *Legionella*
    - Viruses
    - Heterotrophic plate counts (HPC)
    - Turbidity

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Federal Rules

- Surface Water Treatment Rule (SWTR - 1989)
  - Surface water sources must receive filtration and disinfection
  - Finished water turbidity standard of ≤ 0.5 NTU
  - Concentration and time (C x T) requirements for disinfection
- Enhanced Surface Water Treatment Rules (ESWTR – 1998 - 2006)
  - Finished water turbidity standard of ≤ 0.3 NTU
  - Benchmarking / profiling for Cryptosporidium removal

http://www.epa.gov/safewater/

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Enhanced Surface Water Treatment Rules

- *Cryptosporidium* oocysts
  - Pathogen inactivation
  - Particle removal (0.3 NTU 95% of time)
  - Alternative disinfectants (ozone)
  - Membrane filtration
  - UV disinfection

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Contaminants of Concern

- Particles - Turbidity
- Pathogens:
  - Cryptosporidium
  - Giardia
  - Bacteria and viruses
- Natural organic matter (NOM):
  - Total or dissolved organic carbon (TOC or DOC)
  - Color
  - Precursor to disinfection byproducts (DBPs)
- Manganese and iron
- Other:
  - Algae
  - Tastes and odors
  - Hardness
  - Contamination

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Particles

- Turbidity is a regulated parameter
- Surrogate for Giardia and Cryptosporidium
- Interfere with disinfection
- Residuals production
- Affects coagulant dose (for some waters)
- Impact on water treatment costs:
  - Coagulant demand
  - Filter run length
  - Residuals handling and disposal

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Natural Organic Matter (NOM)

- Increases is NOM concentration cause:
  - Increase in color
  - Increase in disinfection by byproduct (THMs, HAAs) formation
  - Increase in disinfectant (and/or oxidant) demand
  - Increase in particle stability through coating of particle surfaces
  - Increase in coagulant dosing
  - Increase in sludge production
  - Increase in the fouling of membranes
  - Decrease in the adsorption of micro-pollutants by activated carbon
  - Interference with UV disinfection
  - Increase in microbial re-growth in water distribution systems

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Natural Organic Matter (NOM)

Impact on Water Treatment Costs:

- Coagulant dose
- Residuals handling and disposal
- Increased disinfectant dose
- Alternative disinfectants:
  - Ozone
  - Chlorine dioxide
  - Chloramines

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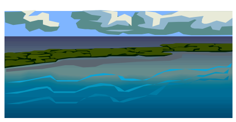
Surface Water Treatment Rule

- Protects against exposure to viruses, Legionella, Cryptosporidium, Giardia and other pathogens by requiring certain types of treatment for surface water sources



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Types of Pathogens

- Viruses (e.g., Norwalk virus, rotaviruses)
- Bacteria (e.g., *Shigella, E.coli*)
- Parasites, protozoa and cysts (e.g., *Giardia lamblia, Cryptosporidium*)

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Bacteria

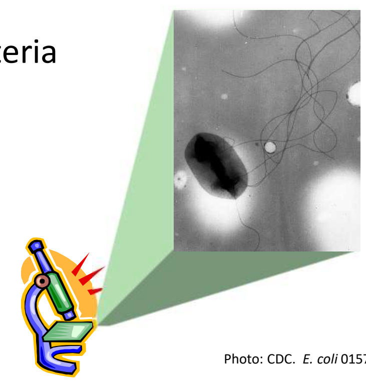

Photo: CDC. *E. coli* 0157:H7

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Viruses

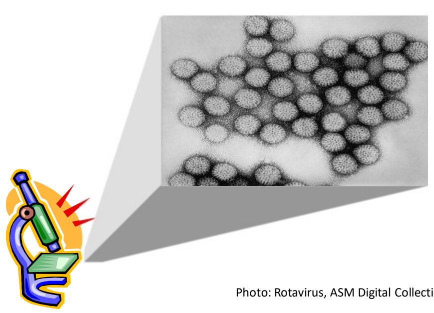

Photo: Rotavirus, ASM Digital Collection

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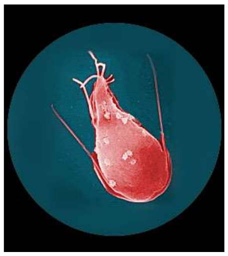
Protozoa



Giardia

Cryptosporidium

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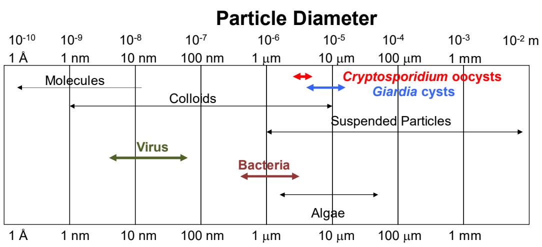
Particle Size



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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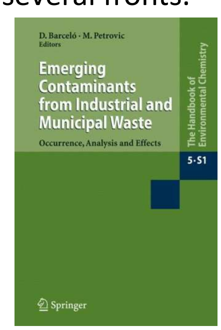
Continuing pressure also exists for regulatory change on several fronts.

Emerging Contaminants

- Endocrine Disruptors
- Pharmaceuticals
- Personal Care Products
- Flame Retardants
- Dioxins



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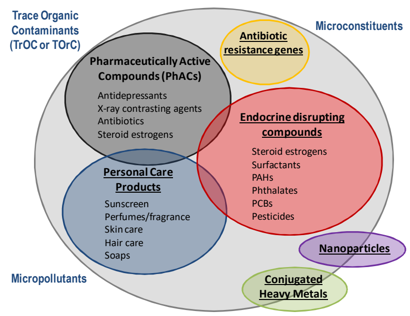
Contaminants of Emerging Concern (CECs)



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WTP and WWTP

Overview

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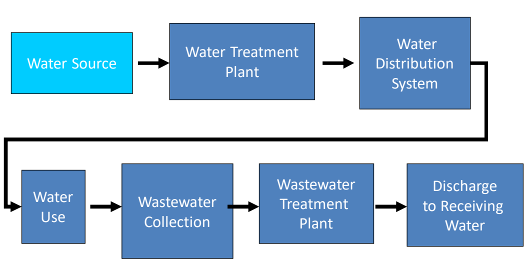
Water Use Cycle



Simmons 36

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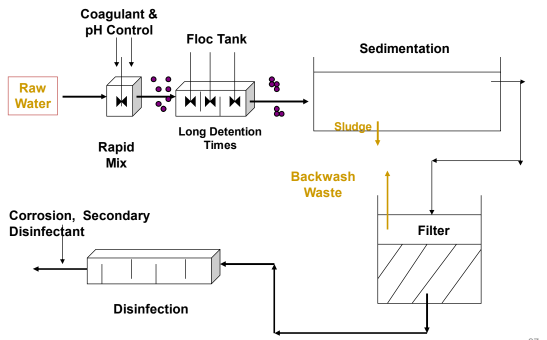
Conventional WTP



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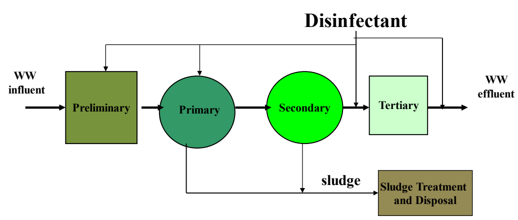
Wastewater Treatment Scheme



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Wastewater treatment Processes

- Preliminary treatment - physical process that removes screenings and grit
- Primary - physical sedimentation of suspended particulates
- Secondary - physical and biological treatment to reduce organic and nutrient loadings
- Tertiary – enhanced solids and nutrient removal

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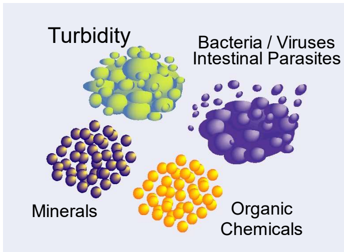
WATER and WASTEWATER TREATMENT

"Treatment plants are the **primary** barrier against unsafe water…any malfunction in the treatment processes could result in water quality problems."



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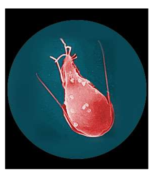
Multiple Barriers

"Barriers" prevent the passage of microorganisms into the distribution system…

Cryptosporidium



Giardia

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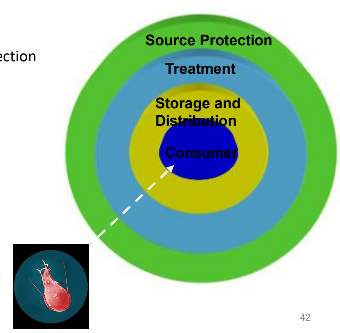
Multiple Barriers
In Water Protection

- Sources
  - Watershed management programs
  - Intake and wellhead protection
- Treatment
  - Coagulation, flocculation, sedimentation
  - Filtration
  - Disinfection
- Storage
  - Disinfectant contact time
  - Screens
- Distribution
  - Pressure
  - Disinfection



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Turbidity Removal

- Conventional treatment
- Direct filtration
- Packaged filtration
- Dissolved Air Flotation (DAF)
- In-line filtration
- Contact adsorption units
- Slow sand filtration
- Diatomaceous earth filtration
- Cartridge filtration
- Membrane filtration

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Water Treatment Processes

- Precipitation
- Rapid Mix
  - Coagulants
  - Flocculant Aids
- Coagulation
- Flocculation
- Sedimentation/Flotation
- Filtration

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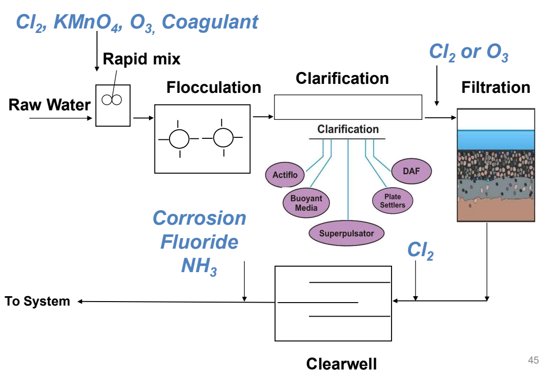
Typical Water Filtration Plant



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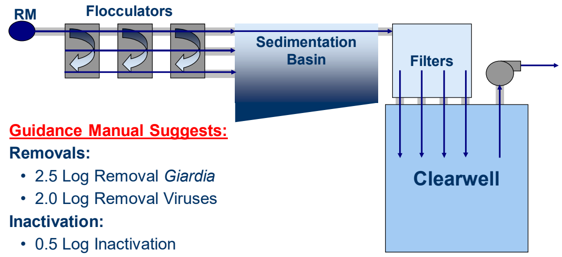
Filtration: Conventional



Guidance Manual Suggests:

Removals:
- 2.5 Log Removal *Giardia*
- 2.0 Log Removal Viruses

Inactivation:
- 0.5 Log Inactivation *Giardia*
- 2.0 Log Inactivation Viruses

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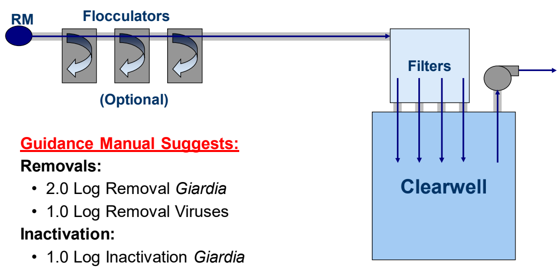
Filtration: Direct



Guidance Manual Suggests:

Removals:
- 2.0 Log Removal *Giardia*
- 1.0 Log Removal Viruses

Inactivation:
- 1.0 Log Inactivation *Giardia*
- 3.0 Log Inactivation Viruses

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Enhanced Solids Removal

Turbidity

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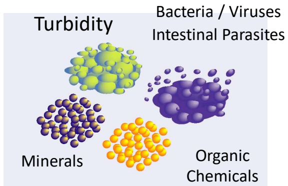
Enhanced Solids Removal

Filtration is the **last** physical barrier preventing solids into the plant discharge. Any malfunction in the treatment process could result in unsafe water for reuse and water quality problems.



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Turbidity

- Turbid or cloudy water is caused by suspended particles scattering or absorbing light
- Turbidity is an indirect measurement of the amount of suspended matter in the water
- However, since solids of different sizes, shapes, and surfaces reflect light differently, turbidity and suspended solids do not correlate well

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Turbidity

- Turbidity is normally gauged with an instrument that measures the amount of light scattered at an angle of 90° from a source beam
- The units of turbidity are usually in Nephelometric Turbidity Units (NTU).

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Bench-top Turbidimeter

- Measurement of "cloudiness" in the water
- Expressed in NTU (Nephelometric Turbidity Units)
- Basis for regulatory compliance and process control
- Turbidimeters must be calibrated to maintain accuracy

Bench-top Turbidimeter & Primary Standards

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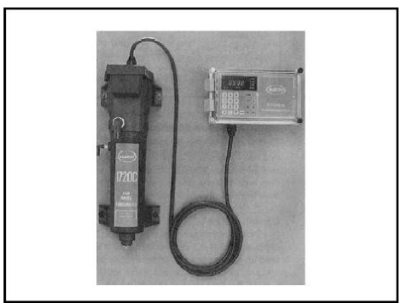
ON-LINE TURBIDIMETERS



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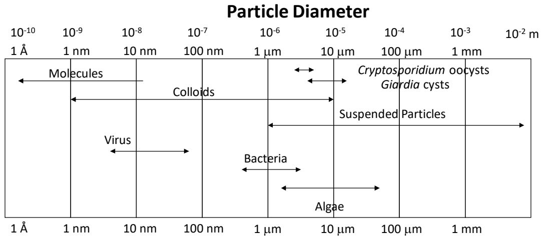
Particle Size

Particle Diameter



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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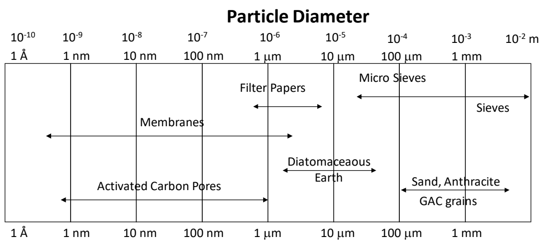
Size Spectrum of Granular Filter Media



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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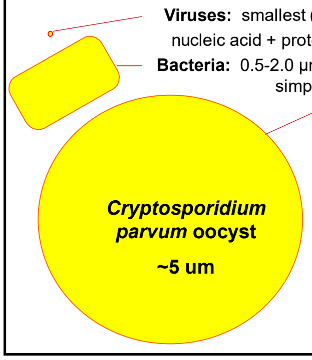
Classes of Microorganisms: The Microbial World

Viruses: smallest (0.02-0.3 µm diameter); simplest: nucleic acid + protein coat (+ lipoprotein envelope)

Bacteria: 0.5-2.0 µm diameter; prokaryotes; cellular; simple internal org.; binary fission.

Protozoa: most >2 µm - 2 mm; eucaryotic; uni-cellular; non-photosynthetic; flexible cell membrane.; wide sizes and shapes; hardy cysts and oocysts; flagellates amoebae, ciliates, sporozoans (*Cryptosporidium* sp.) and microsporidia.



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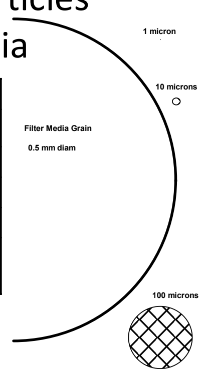
Relative Size of Particles and Filter Media

Soil	1-100 µm
Cryptosporidium oocysts	5 µm
Bacteria	0.3 – 3 µm
Viruses	0.005 – 0.1 µm
Floc particles	100 - 2000 µm
Visible particle w/ 20:20 vision	37 µm

Filter media pores range from 50 to 400 µm depending on media size



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Common Contaminants of Concern

- Particles - Turbidity
- Pathogens:
  - Cryptosporidium
  - Giardia
  - Bacteria and viruses
- Organic matter:
  - Total or dissolved organic carbon (TOC or DOC)
  - Color
  - Precursor to disinfection byproducts (DBPs), if using chemicals for disinfection

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Particles

- Turbidity is a regulated parameter
- Surrogate for Giardia and Cryptosporidium
- Interfere with disinfection
- Affects coagulant dose (for some waters)
- Impact on water treatment costs:
  - Coagulant demand
  - Filter run length
  - Residuals handling and disposal

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Colloids

- Small particles
  – No definite size range
  – Generally 1 nm - 10 μm
  – Can be smaller or larger
- In water they are also called "aqua sols"
- Particles can be either organic or inorganic

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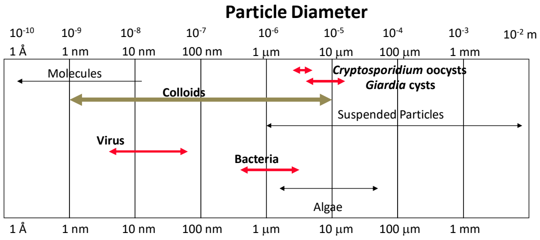
Particle Size



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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Types of particles

- Inorganic
  - Clays
  - Metal oxides and hydroxides
    - $Al(OH)_3$ floc in coagulation
    - $Fe(OH)_3$ floc from oxidation of FeII & coagulation
    - MnO_2 from oxidation of MnII
    - SiO_2 (silica)
  - Carbonates
    - $CaCO_3$ and $CaMgCO_3$

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Types of particles

- Organic particles:
  - Microoganisms
    - Virus
    - Bacteria
    - Algae
    - Protozoa (*Giardia* & *Cryptosporidium*)
  - Organic debris
  - Humic substances

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Particle Charge

- In natural aquatic systems, most particles have a negative charge
- Since water has no electrical charge, the charge on the particles must be balanced by an equivalent number of counter charges (ions) in the water
- Results in "stabilized" particles that repel each other
- Particles tend not to release water

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Particles in raw water resist settling due to…………

1) Particle Size

- Suspended Solids
  - non-settleable solids
  - settleable solids
- Colloidal Solids
- Dissolved Solids

2) Natural Forces

- Zeta Potential
- Van der Waals Force

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Water Treatment

Coagulation

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ROLE OF COAGULATION

- WATER TREATMENT PLANTS - do not work without good coagulation!!!
  - Coagulation affects:
    - Flocculation, Sedimentation, Flotation, and Filtration Performance
    - Affects bubble attachment to flocs and removal by DAFs
    - Affects Granular Media Filtration Performance
- TREATMENT GOALS
  - Turbidity: ≤ 0.1 NTU
  - NOM/TOC: ≤ 2.0 mg/L

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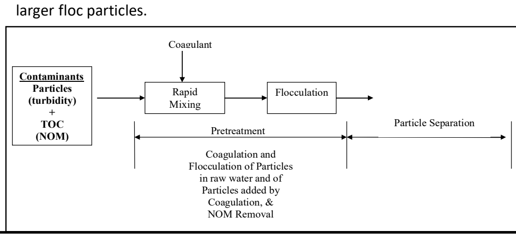
COAGULATION AND FLOCCULATION PROCESSES

•COAGULATION – chemical step involving addition of coagulants. Chemical reactions occur with these particles and chemical reactions involving phase changes may also occur with water (OH-) and Natural Organic Material (NOM) or Total Organic Carbon (TOC) .

•FLOCCULATION – physical step in which the sizes of particles are increased by collisions and attachment of smaller particles leading to larger floc particles.



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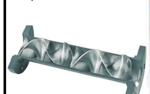
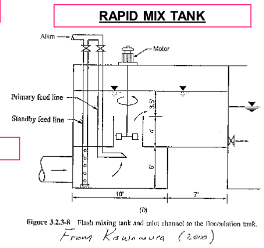
COAGULANT ADDITION IN RAPID MIXING

PIPE STATIC MIXERS
(www.chemineer.com)




CHANNEL STATIC MIXER (www.statiflo.net)

RAPID MIX TANK



- **Initial coagulant chemical reactions are rapid occurring in seconds or less. Thus, processes have short detention times of ~ 1 min or less.**
- **For some coagulants, precipitation reactions occur that take minutes. These begin in Rapid Mixing and continue in Flocculation**

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Objectives of Coagulation

- To destabilize particles
- To convert "dissolved" substances to particulate substances

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Coagulation – Process Description

- Adding and rapid mixing of chemical coagulants into the raw water.
- The process of adding a chemical or combination of chemicals to neutralize the electrostatic charges on suspended particles in raw water so that they will attract to form larger particles.

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Settling Rate for Small Particles

TABLE 4-1 Natural settling rates for small particles

Particle Diameter, *mm*	Representative Particle	Time Required to Settle in 1-ft (0.3-m) Depth
		Settleable
10	Gravel	0.3 seconds
1	Coarse sand	3 seconds
0.1	Fine sand	38 seconds
0.01	Silt	33 minutes
		Considered Nonsettleable
0.001	Bacteria	55 hours
0.0001	Color	230 days
0.00001	Colloidal particles	6.3 years
0.000001	Colloidal particles	63-year minimum

Source: Water Quality and Treatment. *3rd ed. 1971.*

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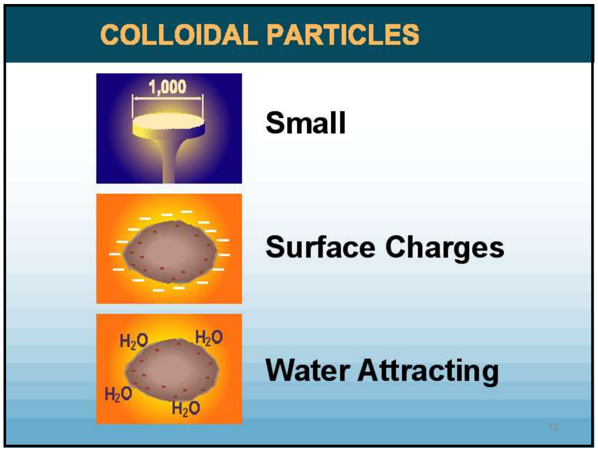
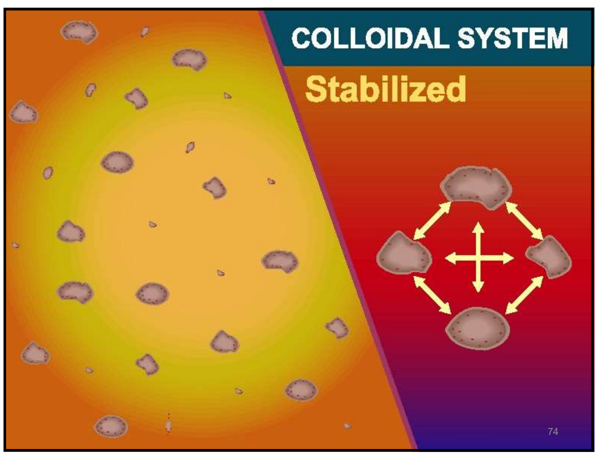
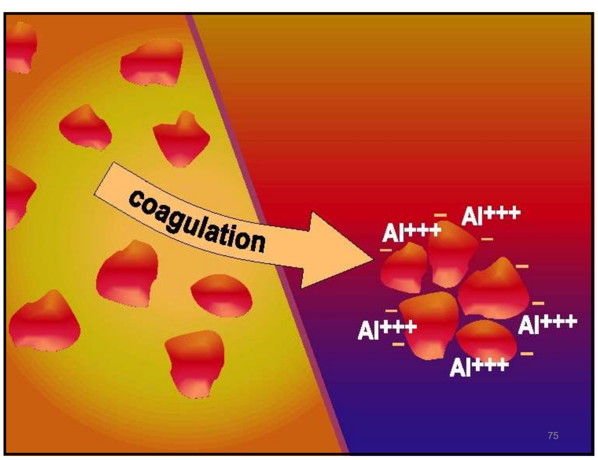

COLLOIDAL PARTICLES
1,000
Small
Surface Charges
H_2O
Water Attracting

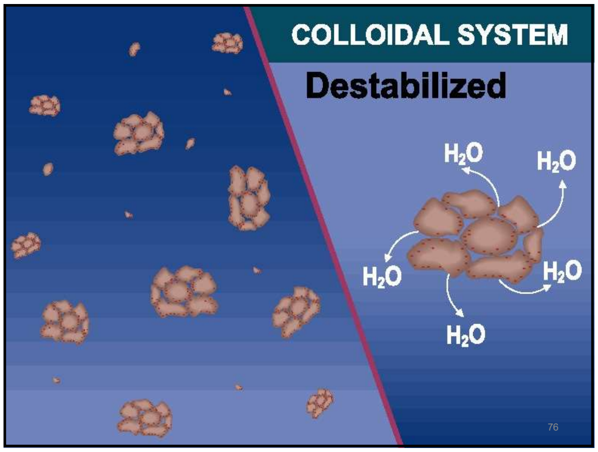
73


COLLOIDAL SYSTEM
Stabilized
74

74


coagulation
Al+++
75

75



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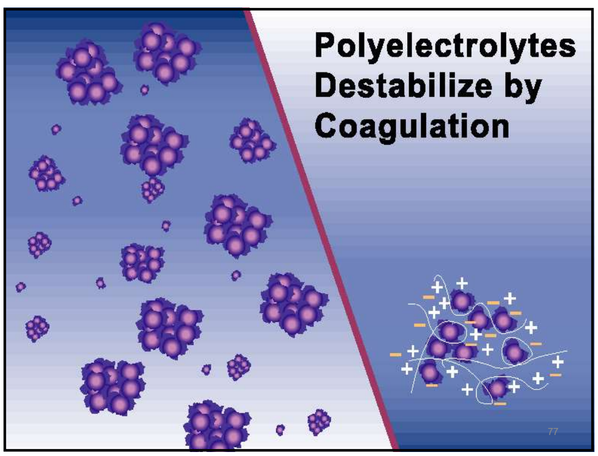

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Chemicals

- COAGULANTS
  - Chemicals used to produce unstable particles and to react with turbidity to form larger particles. One can use more than one coagulant e.g., metal (Al or Fe) salts and high charge density polymers. Both are coagulants or dual coagulants.
- FLOCCULANT AIDS
  - High Molecular Weight Organic Polymers
  - Role is to Bridge Particles Together into Larger Floc Particles; May Also Strengthen Floc
- FILTER AIDS
  - High Molecular Weight Organic Polymers
  - Role is to Bridge Particles to Filter Grains or to Previously Retained Particles within Filter Bed

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Primary Coagulants

TABLE 4-2 Common coagulation chemicals

Common Name	Chemical Formula	Comments
Aluminum sulfate	$Al_2(SO_4)_3 \cdot 14(H_2O)$	Most common coagulant in the United States; often used with cationic polymers
Ferric chloride	$FeCl_3$	May be more effective than alum in some applications
Ferric sulfate	$Fe_2(SO_4)_3$	Often used with lime softening
Ferrous sulfate	$Fe_2(SO_4)_3 \cdot 7H_2O$	Less pH dependent than alum
Aluminum polymers	—	Include polyaluminum chloride and polyaluminum sulfates
Cationic polymers	—	Synthetic polyelectrolytes; large molecules
Sodium aluminate	$Na_2Al_2O_4$	Used with alum to improve coagulation
Sodium silicate	$Na_2O \cdot (SiO_2)_x$	x can range from 0.5 to 4.0; ingredient of activated silica coagulant aids

Source: Adapted from *Water Treatment Plant Design. 1990.*

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Flocculant Aids

Reasons For Using Flocculant Aids…

- to improve coagulation
- to build stronger, more settleable floc
- to overcome the effect of temperature drops which slow coagulation
- to reduce the amount of coagulant needed
- to reduce sludge production

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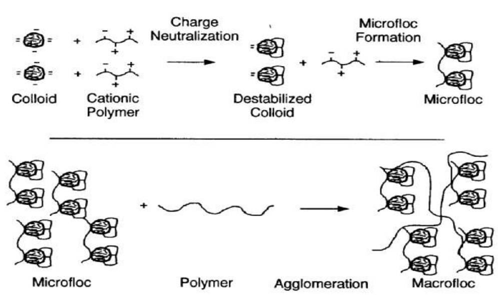
Microfloc and Macrofloc Formation



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Effects of Water Temperature on Coagulation

- Warm Water = Improved Coagulation
- Cold Water = Reduced Coagulation

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Effects of pH & Alkalinity on Coagulation

Aluminum and Ferric based coagulants.....

- react better in waters within a certain pH range and alkalinity range.
  - Alum: 5.5 – 7.5
  - Ferric: 5.0 – 8.5
- require adequate alkalinity for optimum coagulation
  - Alum: 1 mg/L converts 0.5 mg/L of $CaCO_3$
  - Ferric: 1 mg/L converts 0.75 mg/L of $CaCO_3$
- are very acidic and will reduce pH / alkalinity

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Effects of Turbidity on Coagulation

- Low turbidity
  - Sometimes difficult to form a proper floc
  - More coagulant may be needed
  - Coagulant aid / weighting agent may need to be applied
- Fluctuating turbidity
  - coagulant dose must be adjusted

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Low turbidity waters

- May need more alum than high turbidity waters -- not enough particles to collide (chemistry may be right, but physics is wrong)
- Cationic polymers not effective for low turbidity waters in conventional treatment
- Low alum doses and cationic polymers may be effective in direct filtration and for non-conventional clarification including:
  - DAF, sludge blanket, adsorption, ballasted flocculation clarifiers

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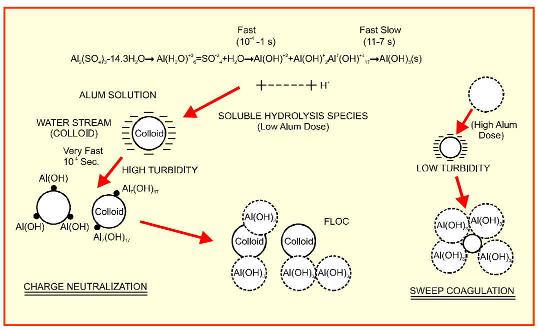
Coagulation Reactions



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Effects of Color on Coagulation

- Color causing organics compounds react with coagulants.
- Pre-treatment with oxidants or adsorbants may be necessary

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Coagulation – Chemical Feed Systems

- Liquid Chemical Feeders
  - diaphragm pumps
  - perastaltic (hose) pumps
- Dry Chemical Feeders
  - volumetric feeders
  - gravimetric feeders

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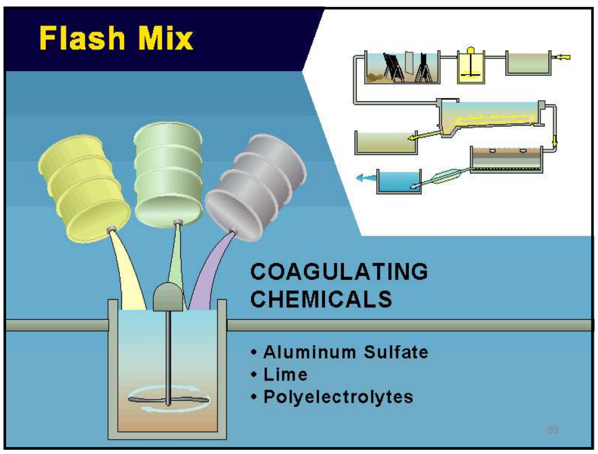

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Coagulation – Rapid Mix

The process of providing rapid agitation to distribute the coagulant and other chemicals evenly throughout the water

Types of Rapid Mix Devices:

- **Mechanical Mixers**
- **Static Mixers**
- **Pumps and Conduits**
- **Baffled Chambers**

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Blending & Motion

Blending Applications in Water and Wastewater Treatment Plants

– Polymer Mixers
– Chemical Batch Mixers
– Rapid Mixers
– Neutralization Mixers

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Factors Affecting Rapid Mix

- Adequate mixing intensity is critical immediately upon addition of coagulant chemical
- Detention time typically 1 – 30 seconds
- Good process control begins with regular monitoring of the raw and settled water quality

Poor mixing intensity

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Operation / Process Control Monitoring

- **Operational control tests and equipment**
  - Jar Tests
  - pH and Alkalinity Tests
  - Turbidity Tests
  - Visual Inspections
  - Filterability Tests
  - Zeta Potential Tests
  - Streaming Current Monitors
  - Particle Counters

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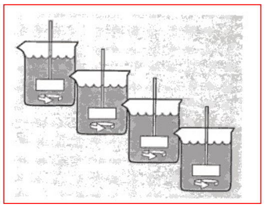
Jar Test



- Simulates C / F / S processes
- Used to evaluate…..
  - coagulant chemicals type, combination, order of application and optimum dose
  - flash mix intensity and detention time
  - flocculator speed and detention time
  - Settling velocity (for sedimentation basin)

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Jar Test

- Should be conducted….
  - using raw water as sample
  - whenever there are changes in raw water quality (turbidity, color, pH, alkalinity, temperature)
  - at least once per day
- Modified version of of jar test should be conducted in-plant to verify results

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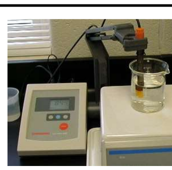
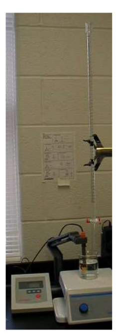
pH and Alkalinity Tests





- Should be conducted on raw water and in conjunction with jar test
- Indicates if pH / alkalinity needs to be adjusted for improved coagulation
- Requires pH meter, burette, and H_2SO_4

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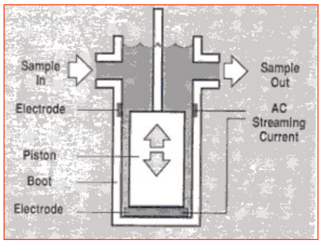
Streaming Current Monitor



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Process Control – Establishing the Coagulant Dose

1. Conduct laboratory jar test
   - Determine optimum dose of coagulant chemical(s)
2. Determine and set chemical feed rate
3. Verify coagulant dose
   - Mini jar test from samples taken at…
     - flocculation basin influent and effluent
   - Turbidity – Settled Water
     - from mini jar test and sedimentation basin effluent
4. Fine tune coagulant dose

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Establishing the Coagulant Dose

- Once you have determined the optimum dose by conducting the jar test……
- Convert dose (mg/L) to a feed rate (lb/day)
  - Formula: lb/day = (Dose mg/L)(Flow MGD)(8.34)
- Verify/fine tune dose

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Safety Factors – Chemical Feed Systems

- Hazard Communication Program & MSDS
- Alum and Ferric based chemicals have a very low pH (acidic)
- Sodium hydroxide has a very high pH (basic)
- Incompatible chemicals if mixed together in concentrated form can generate tremendous heat and cause an explosion.
  - Examples: dry alum and quicklime
- Liquid polymers spilled on floor presents falling hazard
- Proper storage and handling of chemicals is critical

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Safety Factors – Chemical Feed Systems

- Chemical storage areas:
  - Kept dry
  - Well ventilated
  - Heated (where liquid chemicals are stored)
  - Used ***only*** for the storage of chemicals
  - Secondary containment provided
  - "Incompatible chemicals" stored separately
  - No cross-connections

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Common Cross-Connections Owned or Controlled by the Water System

- Chemical Feed Systems:
  - Submerged inlets or water piped directly to chemical feed tanks
  - No anti-siphon valves on chemical feeders
  - Hose bibs with no vacuum breaker
  - Split chemical feeds to raw and finished water

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Operation and Maintenance of Chemical Feed Systems

- Preventive maintenance
- Back-up units
- Condition of housing for equipment
- Chemical storage
- Hazard Communication
- Chemical containment
- Safety
- Calibration of chemical feed systems

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Water Treatment

Flocculation

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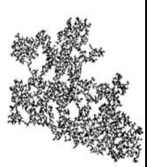
Formation And Settling of Floc Particles

- Flocculation Process is Used in Most Water Treatment Plants
  - Floc formation increases particle size
  - The structure of floc particles includes spaces with water between the original or primary particles causing a decrease in density



- Flocculation Forms Particles
  - With some characteristic diameter (d_f) larger than the primary particles (d_p).
  - With density of floc particles (ρ_f) less than the primary particles (ρ_p)

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Flocculation – Process Description

- Gentle stirring of the water (after coagulation has been accomplished) to bring suspended particles together so that they will form larger, more settleable clumps called floc.
- Detention time typically 10 – 30 minutes
- Flow through velocity typically 0.5 – 1.5 ft/sec

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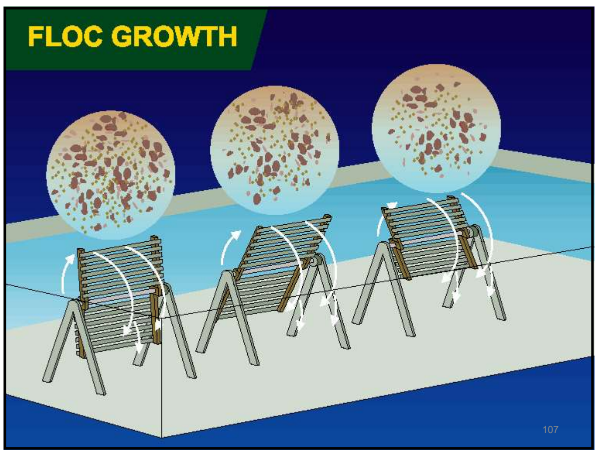

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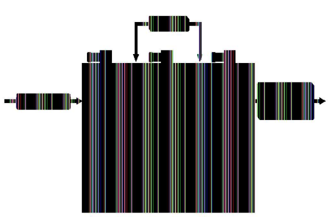
Factors Affecting Flocculation

- Coagulation Efficiency
- Detention Time
- Flocculator Speed



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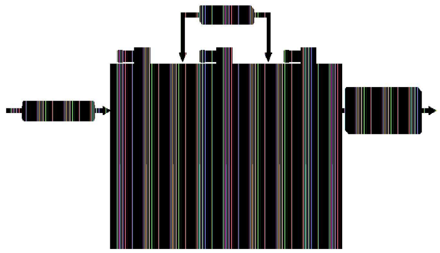
Flocculation Equipment



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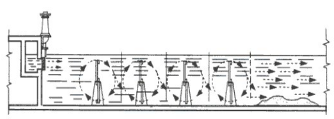
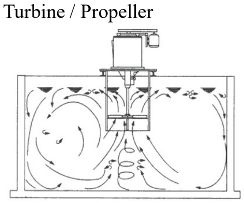
Mechanical Flocculators

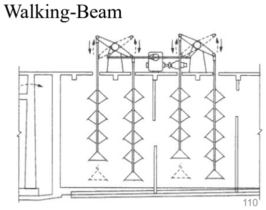
Paddle Wheel



Turbine / Propeller



Walking-Beam



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Flocculation – Operational Considerations

- Floc building in size / density through the process
  - Paddle speed adjusted to prevent shearing or settling of the floc
  - All paddles intact and all flocculators operating
  - Look for indicators of short circuiting
  - Speed adjusted as temperature (water density) changes
  - Adequate number of units in service

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Water Treatment

Sedimentation

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Factors Affecting Settling Rate

- Temperature (4º C)
- TDS
- Particle density
- Flow-thru velocity
- Solids charge
- pH

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Re-Suspending Settled Solids

- Stilling Well too Close to Bottom
- Sludge Blanket too Deep
- High Flow Turbulence
- Side-Wall Short Circuiting

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Travel Time

- Travel Velocity: 1 – 2 Feet per Minute
  - (Grit Drops at 1 fps)
- Assume Drop Velocity of 1 ft / 6 min
- Specific Gravity = $\gamma = \sigma_{liquid} / \sigma_{water} = \sigma/8.34$
- HOW LONG TO REACH BOTTOM OF 10 FT DEEP TANK?

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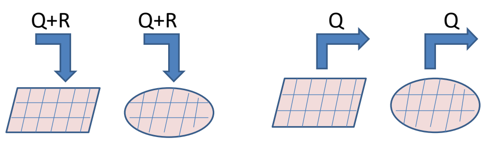
Flow Loadings

Hydraulic Loading Rate (HLR)
- Includes Recirculation

Surface Overflow Rate (SOFR)
- Excludes Recirculation



Square foot Area

- HLR = $\frac{\text{Q+R, gpd}}{\text{Area, sq ft}}$

Square foot Area

- SOFR = $\frac{\text{Q, gpd}}{\text{Area, sq ft}}$

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Detention Time

- DT = Volume / Flow Rate = V /Q
- Volume = πD^2 x Depth
  4
- Flow = Q = gallons per Hour = gph
  - Gpd / 7.48 gal per Ft^3 = Ft^3 / Hr
- DT = Ft^3 / Ft^3 / Hr = Hours
- 2 – 3 Hours Design – Septicity, Denite

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Sedimentation/Clarification Tanks

- Conventional Basins
  - Rectangular Clarifiers
  - Circular Clarifiers
- Dissolved Air Flotation
- Inclined Plate Settlers (Lamella™)
- Floc Blanket - Super Pulsator®
- Solids Recirculation - Accelator®
- Absorption Clarifier - Trident®
- Ballasted Clarifier - Actiflo ™

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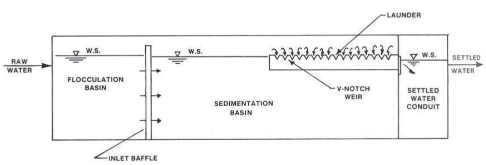
Conventional Basin Designs - Rectangular



- Flow Distribution

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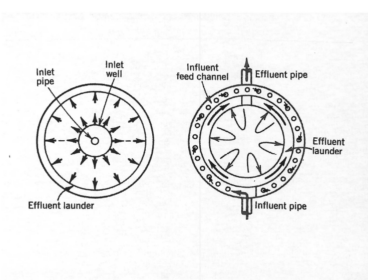
Conventional Basin Designs - Circular



- Inlet Feed
  - Central inlet (radial flow)
  - Multiple peripheral ports (spiral flow)
- Effluent
  - V-Notch Weir

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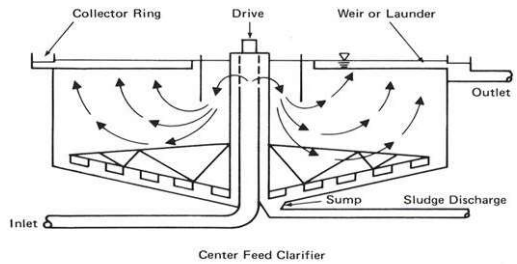
Circular Sedimentation Schematic



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Design Criteria

Surface Loading	0.2 – 0.5 gpm/sf
Water Depth	9 – 15 feet
Detention Time	1.5 – 3 hours
Width:Length	1:5
Weir Loading	< 15 gpm/sf

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Sedimentation / Clarification – Process Description

- Reducing the velocity of water in basins so that suspended material (floc) can settle out by gravity.
  - Detention time typically 1.5 – 3.0 hours
  - Flow through velocity typically 2 – 4 ft/min
  - Surface loading rate 500 – 1,200 GPD/ft^2
- Sludge, the residue of solids and water, accumulates at the bottom of the basin and must then be pumped out of the basin for disposal.

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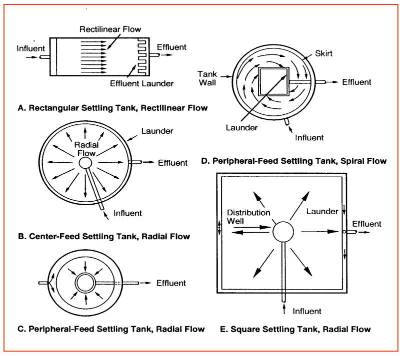
Sedimentation / Clarification – Equipment



Flow Patterns in Sedimentation Basins

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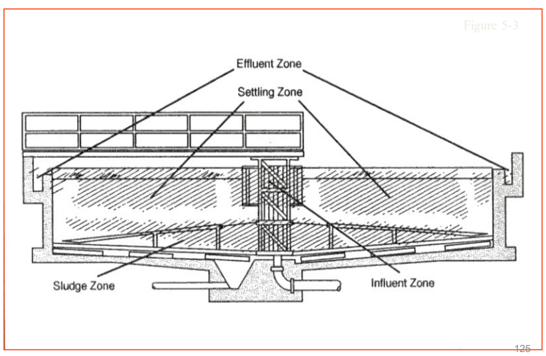
Zones in a Sedimentation Basin



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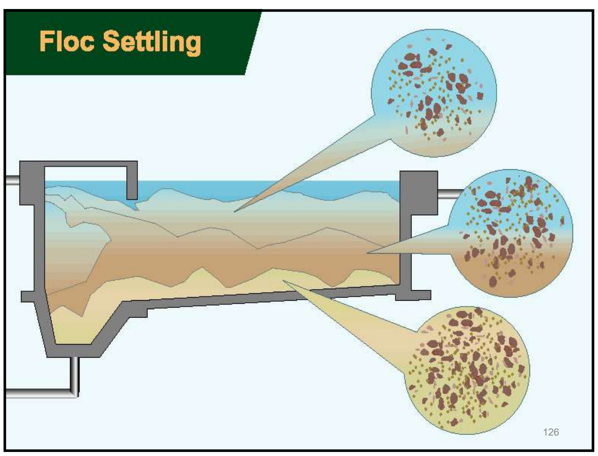
Floc Settling



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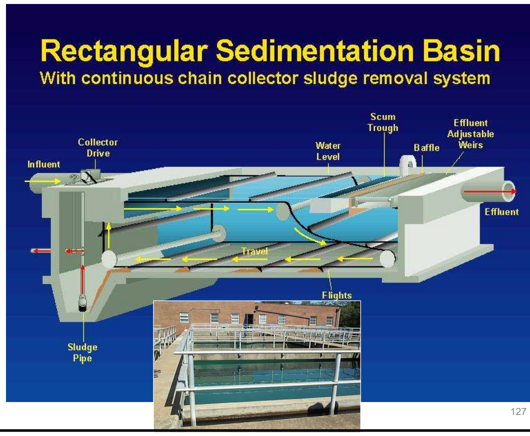

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Solids Collection

- Rectangular Flights
  - Endless chains
  - Travel in Direction of Flow for Grease
  - Travel Against Flow for Settled Solids
- Sludge Hopper > Pump or Gravity
  - Scum Pit > Pump or Ejector

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Circular Sedimentation Basin

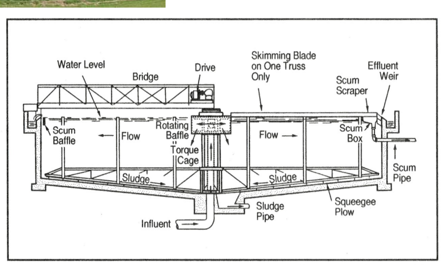

FIGURE 5-5 A typical circular sedimentation basin

Courtesy of FMC Corporation, MHS Division

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Circular Collectors

- Rotate Clockwise
  - Surface Skimmers for Grease
  - Bottom Flights for Settled Solids
- Solids Removal
  - Pump
  - Gravity
  - Draft Tubes

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Pros and Cons – Conventional Sedimentation Basins

Pros

- More tolerance to shock loads ("Bullet – Proof" process)
- Easy to operate and forgiving
- Low head loss and operating costs
- Non-proprietary vendor sourcing

Cons

- Requires large area low loading rate 0.3 gpm/ft^2
- Requires 30 to 40 minutes floc HDT
- Subject to density flow created in the basin.
- Needs to be covered in northern climate (freezing)
- Scrapers can jam and break (need good torque clutches)
- Not so good on algae or light floc
- Expensive to construct

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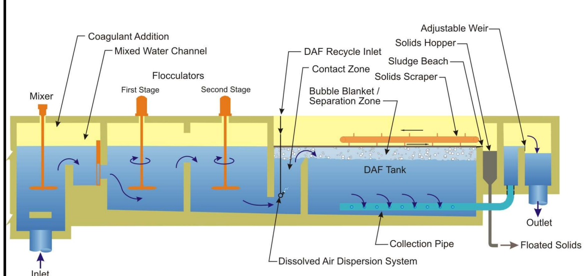
Dissolved Air Flotation Schematic



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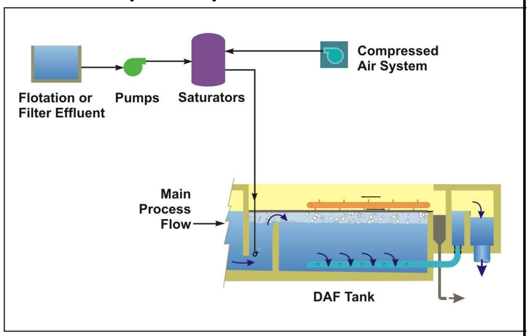
DAF Recycle System Schematic



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Pros and Cons - DAF

Pros

- Compact – high loading rates > 6 gpm/ft^2
- Low flocculation HDT >5 min – compact
- Can be positioned over filter; now extremely compact
- Very suited to reservoir water
- Very good at removing algae
- Fast start up – low HDT
- Not sensitive to water temperature or gradients

Cons

- Needs to be covered in any climate
- Not good with "silty" water
- Energy use from DAF recycle about 5 kW/mgd
- High rate being "over-sold" e.g. 20 gpm/ft^2 – high failure risk

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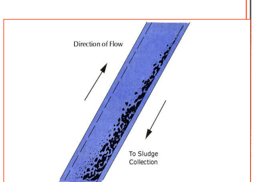
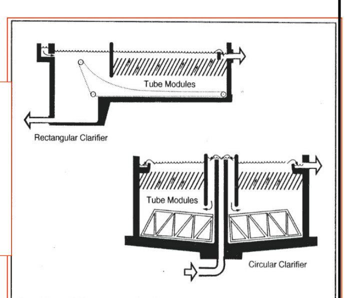
Counter Current Flow Tube Settlers





Courtesy of Wheelabrator Engineered Systems – Microfloc

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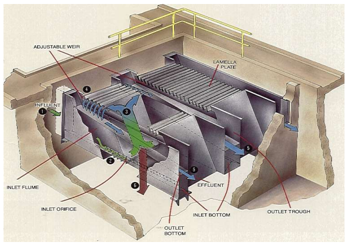
Clarification: Plate Sedimentation



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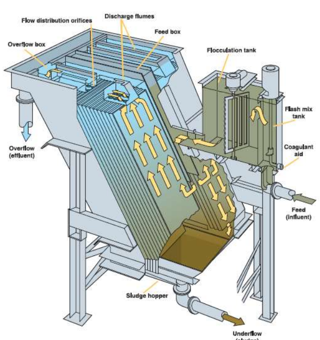
Inclined Plate Settler (IPS)



The most significant aspect of the gravity settler's design is its available settling area

Lamella® Gravity Settler package unit

Lamella® Gravity Settler/Thickener

Parkson Inc.

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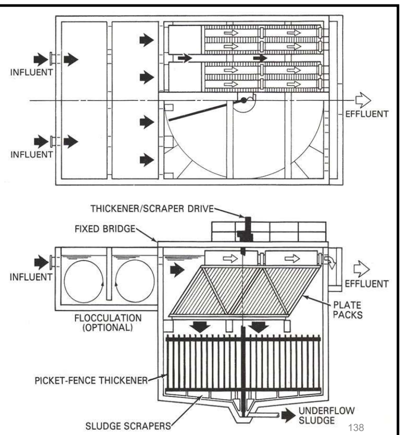
Large-Scale IPS Schematic



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Design Criteria

Surface Loading (based on footprint area)	1.5 – 3 gpm/sf
Water Depth	12 – 15 feet
Detention Time	5 - 20 minutes
Mean Velocity	0.5 ft/min
Weir Loading	5 - 20 gpm/sf

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Pros and Cons- IPS

Pros

- Smaller footprint (higher hydraulic loading based on footprint area)
- Wide application – rivers and reservoir lakes
- Easy to operate and forgiving
- Relatively insensitive to water temperature changes
- Low head loss and operating costs
- IPS Thickener produces 3% solids sludge

Cons

- Requires 30 to 40 minutes floc HDT
- Needs to be covered in northern climate (freezing)
- Scrapers can jam and break (need good torque clutches)
- Not so good on algae or light floc
- IPS produces 0.5% solids sludge

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Performance Goals - Sedimentation

- Turbidity ≤ 2 NTU 95% time when source turbidity > 10 NTU
- Turbidity ≤ 1 NTU 95% time when source turbidity ≤ 10 NTU
- Factors affecting sedimentation
  - Efficiency of C/F Processes
  - Detention Time
  - Surface Loading Rate
  - Weir Overflow
  - Temperature
  - Density Currents
  - Wind
  - Sludge Build-up

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Water Treatment

Filtration

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Filtration

- Process Description
  - Removal of suspended matter by passing the water through a granular porous medium such as sand, anthracite coal, or a membrane.
- Overall Goals:
  - Surface Water Treatment Rule (SWTR)
    - Surface sources must receive filtration and disinfection
    - Finished water turbidity standard of 0.5 NTU
  - Interim Enhanced Surface Water Treatment Rule (IESWTR)
    - Finished water turbidity standard of 0.3 NTU
    - Benchmarking / profiling for Cryptosporidium removal

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TYPES OF FILTRATION

- Granular Media Filtration
  - Most common type
  - Depth Filtration
    - Water moves through the pores between filter grains
    - Particles are smaller than pores and are deposited by colliding with the grain surface and attaching or sticking
    - Filters and Rate: Slow Sand, Rapid Rate, High Rate
- Membrane Filtration
  - Particles larger than pores (removal by sieving)
  - Microfiltration and ultrafiltration
  - Nanofiltration and Reverse Osmosis

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Filtration Process Variables

- Filter media
  - Grain size
  - Shape
  - Density
  - Composition
  - Porosity
- Filtration Rate
- Allowable Head Loss
- Liquid Characteristics (e.g., temperature)

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Filtration Process Variables (cont)

- Influent Characteristics
- Suspended solids concentration
- Particle size
- Particle charge

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Filtration mechanisms

Soil	1-100 μm
Cryptosporidium oocysts	5 μm
Bacteria	0.3 – 3 μm
Viruses	0.005 – 0.1 μm
Floc particles	100 - 2000 μm
Visible particle w/ 20:20 vision	37 μm

Filter media pores range from 50 to 400 μm depending on media size

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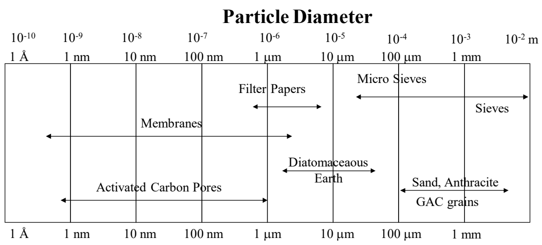
Size Spectrum of Granular Filter Media and Pores



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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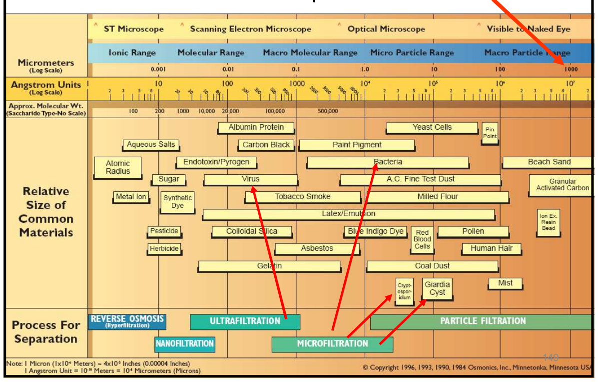
Filtration Spectrum

Log Scale in Microns (1.0 mm)



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Filtration
Particle Removal Mechanisms

- Straining
- Sedimentation
- Compaction (inertial)
- Interception
- Adsorption (chemical)
- Adsorption (physical)
- Adhesion
- Coagulation / flocculation
- Biological growth

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Filter Composition

- Sand & anthracite
- Sand & activated carbon
- Sand & resin
- Resin & anthracite
- Anthracite, sand and garnet
- Activated carbon, anthracite and sand
- Activated carbon, sand and garnet
- Resin beads ($\pm$ charge, neutral)

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Filter Removals

- Bi-Modal distribution of particle sizes
- Sand is more important when floc is weak
- The more layers of different porosity, the longer the run time
- Diatomaceous filter not suitable for activated sludge (erratic operation

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Gravity Filter Components

- Influent Trough (Backwash Return)
- Media
- Underdrain
- Scouring System
- Backwash System (Pumps)
- Effluent Rate-Control Valve

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Gravity Filtration Application

- Removes Residual Bio-Floc: TF & AS
- Removes Residual Chemical/Bio Floc (CNR)
- Removes Residual Coagulation Particles in Phys-Chem Treatment

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Gravity Filters

- Slow Sand: 0.05 gpm/ ft^2
- Rapid Sand: 2 – 6 gpm/ ft^2
- Dual Media: 6 – 20 gpm/ ft^2
- Mixed Media: 6 – 20 gpm/ ft^2
- Continuous Backwash-Traveling Bridge
- Downflow & Upflow

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Water Filtration

Media

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Filter Media

- Broadly speaking, filter media should possess the following qualities:
  - Coarse enough to retain large quantities of floc
  - Sufficiently fine particles to prevent passage of suspended solids
  - Deep enough to allow relatively long filter runs
  - Graded to permit backwash cleaning
  - However, fine sand retains floc and tends to shorten filter runs; the opposite is true for course sand

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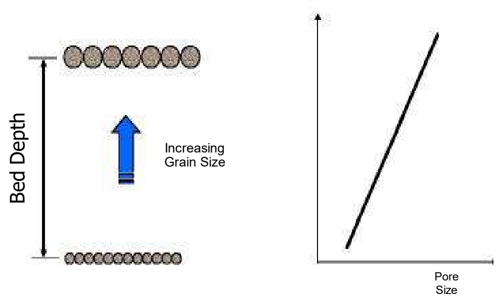
Ideal Filter Media



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Filter Media

- Effective size and uniformity coefficient are defined as follows:
  - Effective size is the 10-percentile diameter; that is 10% by weight of the filter media is less than this diameter (D_{10})
  - Uniformity coefficient is the ratio of the 60-percentile size to the 10-percentile size (D_{60}/D_{10})
  - Conventional sand media has an effective size of 0.45 – 0.55 mm and a uniformity coefficient less than 1.65

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Typical Filter Media Characteristics

Material	Size Range (mm)	Uniformity Coefficient	Specific Gravity	Hardness (MOH scale)
Anthracite Coal	0.8 – 1.2	< 1.85	1.5 – 3.0	3.0
Silica Sand	0.3 – 0.6	< 1.5	> 2.5	7.0
Garnet Sand	0.2 – 0.4	< 1.5	3.8 – 4.3	7.5 – 8.0
Silica Gravel	1.0 - 50	N/A	> 2.5	7.0
GAC	0.8 – 1.2	< 2.0	1.5 – 3.0	N/A

Note: The Mohs scale is an ordinal scale with a relative scale of hardness 1 to 10

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Filter Media

- A sand filter bed with a relatively uniform grain size can provide effective filtration
- Dual media filter beds usually use anthracite and sand
- Multimedia filter beds generally use anthracite, sand, and garnet
- Advantages of dual and multimedia filters are:
  - Higher filtration rates
  - Ability to filter a water with higher turbidity
  - Possibly longer filtration runs

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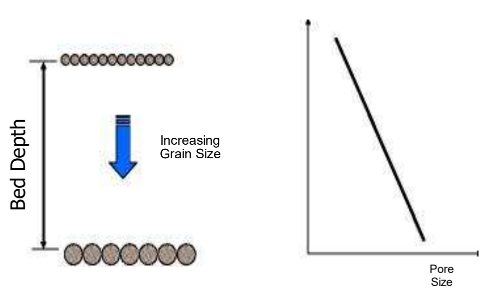
Single Media Filter



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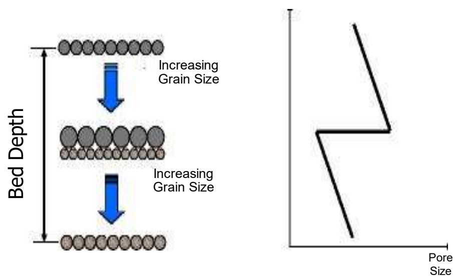
Dual Media Filter



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Filter Media Thickness

- Dual Media
  - Anthracite: 18 inches (8 – 24)
  - Sand 12 inches (10 – 24)
  - Filtration Rate: 6 gpm / ft^2 (2 – 10)
- Multimedia
  - Anthracite: 15 inches (8 – 20)
  - Sand 12 inches (8 – 16)
  - Garnet 3 inches (2 – 4)
  - Filtration Rate: 6 gpm /ft^2 (2 – 12)

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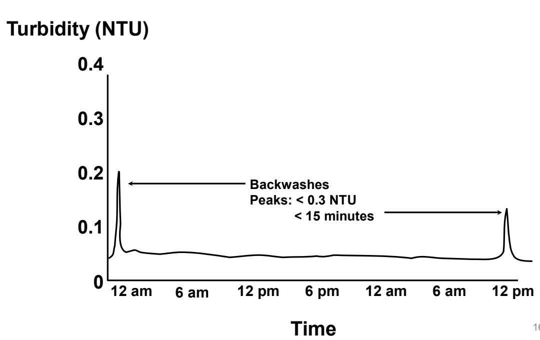
Filter Profile – Good Performance



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Approaches to Filtration

- Filtration by Granular Media
  - Conventional Treatment
  - Direct Filtration
  - Slow Sand Filtration
- Diatomaceous Earth Filtration
- Bag and Cartridge Filtration
- Membrane Filtration
- Reverse Osmosis (RO)

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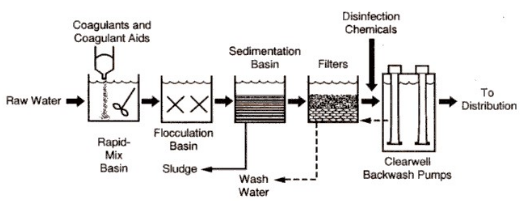
Conventional Treatment



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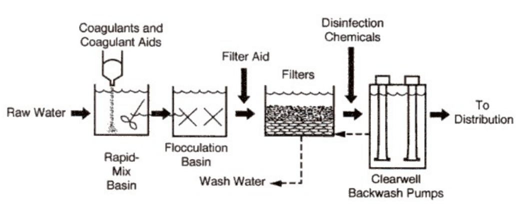
Direct Filtration



Applicable to raw water with turbidity typically below 25 NTU and Color below 25 color units.

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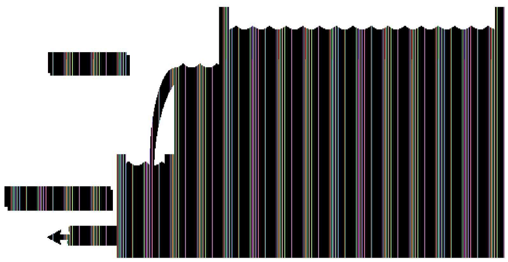
Gravity Filters



Gravity Operated Filter

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Granular Media – Filtration Theory

- Mechanisms of particulate removal
  - Transport mechanisms (major)
    - Sedimentation, impaction, interception, diffusion, and hydrodynamic forces
  - Adsorption (major)
  - Absorption (minor)
  - Straining (minor)

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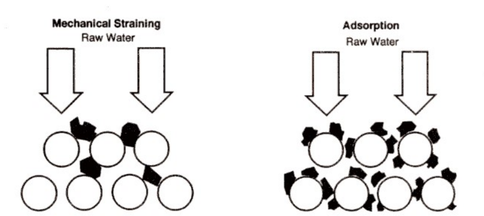
The Filtration Process



Large particles become lodged and cannot continue downward through the media.

Particles stick to the media and cannot continue downward through the media.

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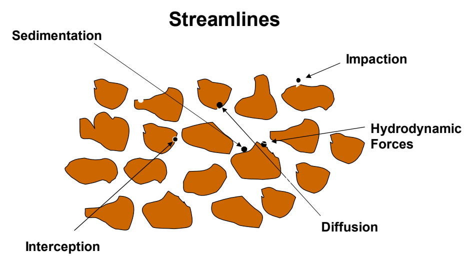
Filtration Attachment Mechanisms



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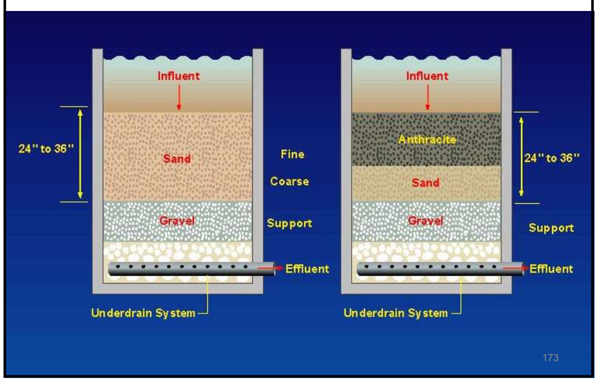
Single and Dual Media Filters



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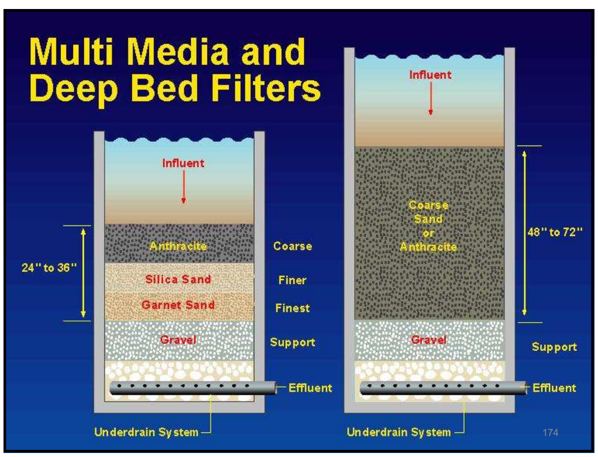

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Comparison of Gravity Filter Characteristics

Characteristic	Slow Sand Filters	Conventional Rapid Sand Filters	High-Rate Filters
Filtration Rate:	0.05 gpm/ft^2	2 gpm/ft^2	3-8 gpm/ft^2
Media:	Sand	Sand	Sand and Coal or Sand, Coal, & Garnet
Media Distribution:	Un-stratified	Stratified	Stratified
Filter Runs:	20-60 days	12-36 hours	12-36 hours
Loss of Head:	0.2 feet initial to 4 feet final	1 foot initial to 8 or 9 feet final	1 foot initial to 8 or 9 feet final
Amount of Backwash Water Used:	No Backwash	2-4% of water filtered	6% of water filtered

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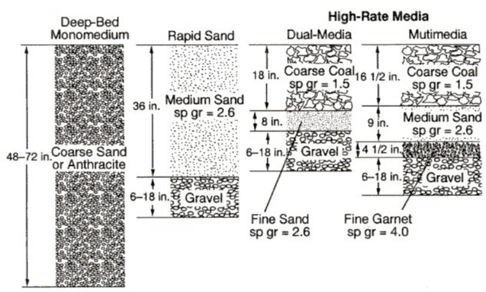
Comparison of Gravity Filter Characteristics



*sp gr = specific gravity

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Filter Efficiency

- Filter media qualities
  - Effective size
  - Uniformity coefficient
  - Specific gravity

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Filter Flow Control Equipment

- Loss-of-Head Indicator
- Rate-of-Flow Controller
- On-line Turbidimeter

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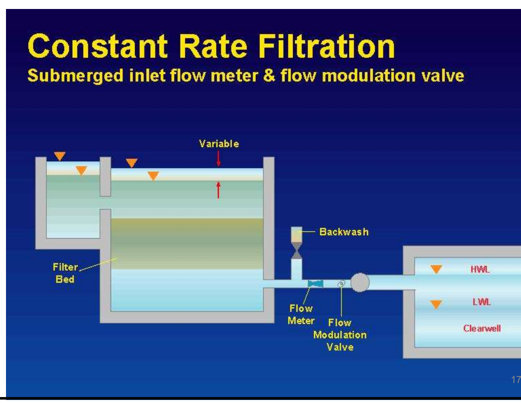
Filter Flow



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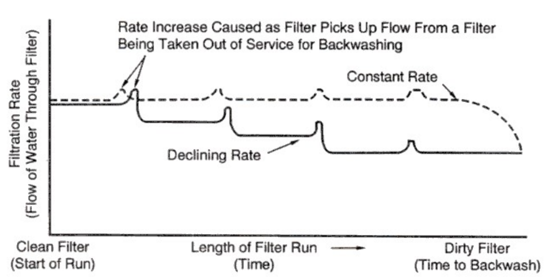
Declining Rate Filtration



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Filter Operation

- Goal is to optimize filtration process
- Operator should routinely evaluate filter performance
  - ➢Filtered water turbidity/turbidity breakthrough
  - ➢Length of filter run/head loss
  - ➢Ratio of the volume of backwash water used to the volume of filtered water

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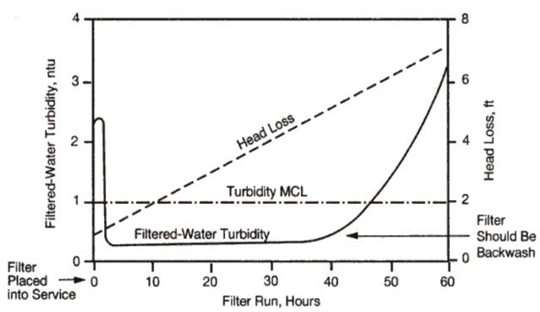
Typical Filter Run



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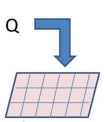
Filtration and Backwash Rates

Filtration Rate (FR) and Unit Filter Run Volume (UFRV)

Q

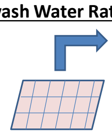


Square foot Filter Area

- FR = $\frac{\text{Q, gpm}}{\text{Area, sq ft}}$
- UFRV = $\frac{\text{Total gallons}}{\text{Area, sq ft}}$

Backwash Water Rate (BWWR)

BWWR



Square foot Filter Area

- BWWR = $\frac{\text{BWWQ, gpm}}{\text{Area, sq ft}}$

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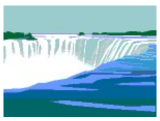
What is Filter Backwash Water?

- Resulting water pushed back through the filter in the cleaning process
- Filter backwashing is an integral part of treatment plant operation



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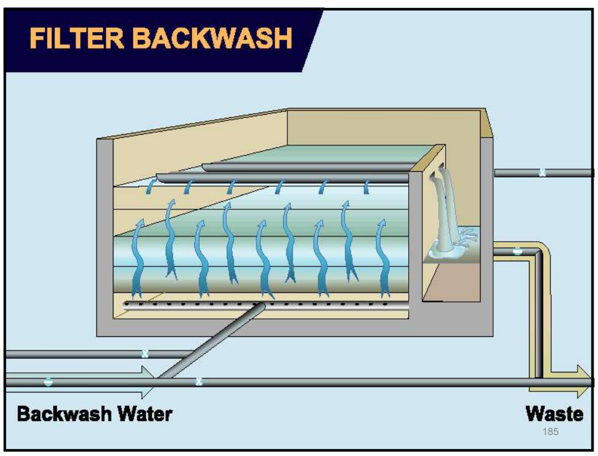

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Filter Backwash Operation

- Backwash
  - ➢Fluidizes (expands) bed by reversing flow
  - ➢Removes entrapped solids
- Backwash rates
  - ➢Range from 10-35 GPM/ft^2 for adequate cleaning
  - ➢Some standards require a minimum of 15 GPM/ft^2 or 50 percent bed expansion

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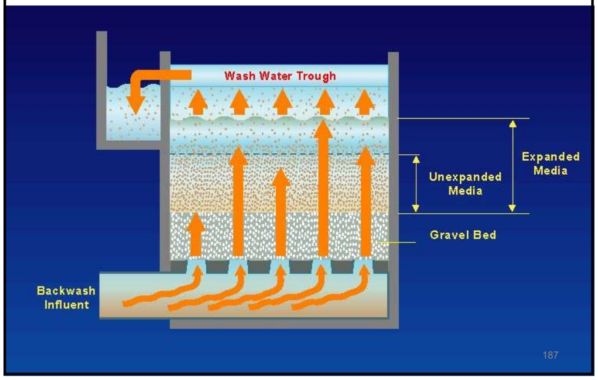
Filter Bed Expansion



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Filter Backwash Evaluation

- Watch the backwash
  - ➢Boils (uneven flow distribution)
  - ➢Media carryover
  - ➢Clarity of wash water (turbidity)
- Observe filter media following backwash
  - ➢Cracks and evenness

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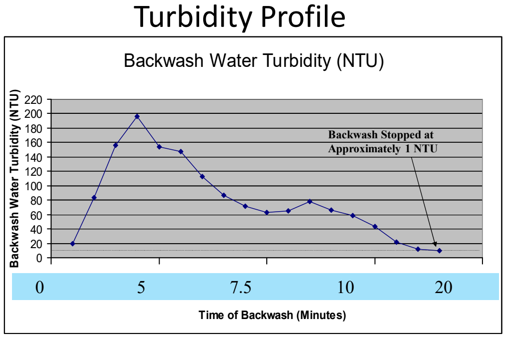
Acceptable Backwash Waste Turbidity Profile



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Water Filtration

Operational Issues

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Visual Inspection of Filter

- Drain filter to examine
- Media surface should be smooth
- **Look for cracks**, **ridges**, **depressions and holes**
- Media in wash water troughs??
- Document everything observed

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Visual Inspection of Filter

Inspecting Media

Freeboard Measurement

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Visual Inspection of Filter

Media in wash water Troughs

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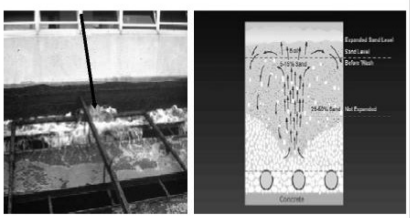
Visual Inspection of Filter

Sand boil in filter bed



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Filter Operating Problems

- Generally, there are three types of filter performance problems:
  1. Poor chemical pretreatment of feed waters to the filter
     - Coagulation
  2. Rapid changes in flow to the filter
     - Flow surges that cause turbidity breakthrough
  3. Ineffective backwashing of filters
     - Mudball formations, filter bed shrinkage, media displacement or loss, and air binding

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Filter Operating Problems

- Poor chemical pretreatment ahead of filter
  - Coagulation/flocculation/sedimentation must be monitored and optimized continuously
  - Adjustments in coagulant added must be made frequently to prevent the filter from becoming clogged with suspended solids or coagulant
  - Turbidity breakthrough in the filter effluent may indicate:
    - More coagulant is needed, or
    - Better coagulant mixing is required

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Filter Operating Problems

- Rapid changes in flow to the filter
  - Effluent turbidity may be affected by surges in flow
  - If flow increases are necessary, increase flow gradually
  - Care must be taken to avoid overloading one filter when backwashing another
  - When starting-up a filter:
    - Backwash before putting them in operation

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Filter Operating Problems

- Ineffective/improper backwashing
  - Mud ball formation
  - Filter media cracking and separation from filter walls (could result from mud ball formations) causing short circuiting of flow through the media
  - Supporting gravel disruption caused by backwash valve opening too quickly or uneven distribution of backwash water due to plugged under drain
    - “Boiling” occurs
    - Media will wash out into under drain

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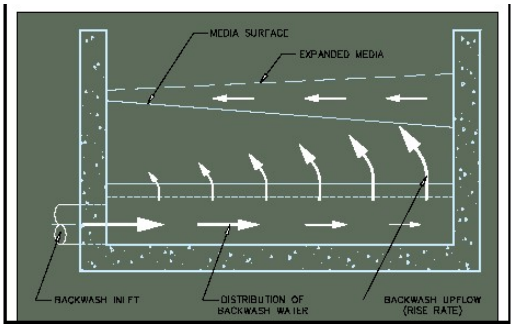
Effect of Backwash Maldistribution on Filter Media Cleaning Backwash Mode



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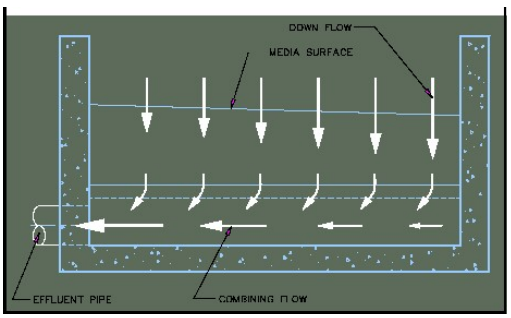
Effect of Backwash Maldistribution on Filter Performance in Filtering Mode (early turbidity breakthrough)



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Using a Filter Box to Inspect Filter Media for Mud balls

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Filter Operating Problems

- Ineffective/improper backwashing
  - Air binding; not common; pressure in the filter becomes negative during operation
    - Air dissolved in the water comes out of solution and becomes trapped in the filter
    - Creates high head conditions and short filter runs
    - Generally occurs when:
      - Water level is less than 5 feet above filter bed
      - Water is cold and super-saturated with air
    - Operate filters greater than 5 feet above filter bed or backwash more frequently

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Filter Operating Problems

- Media loss during backwash
  - Especially when filter surface wash is used
  - Expand filter bed 15 - 30%
    - Bed Expansion, % = Inches of Rise/Total Media Depth
  - Option, turn off surface wash approximately two minutes before the end of the backwash
  - Another option, raise filter troughs to prevent excessive media loss

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Media Appearance after Backwash

- Filter media:
  - Will appear to move laterally during backwash
  - Will show no boils at the surface
  - Will be level and smooth with no cracks or mudballs on surface

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Results of Improper Backwashing

•Turbidity Breakthrough
• Short filter runs
• Air binding
• Mudball formation
• Filter bed shrinkage
• Gravel displacement
• Damage to underdrains
• Media loss

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Gravity Filter Backwashing

- Bed Expansion
- Scouring
- No "Boiling" or "Dead" Zones
- Avoid Air Charging and Water Hammer

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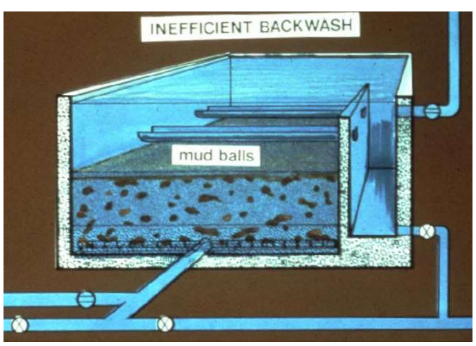
Results of Ineffective Backwashing



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Filter Profiling

- The intent of filter profiling is to allow system operators to **interpret** filter profiles, **investigate** the cause of the elevated turbidity, and take actions to **correct** problems
- If a system does not take **preventative** actions, continued turbidity breakthrough could trigger more problems

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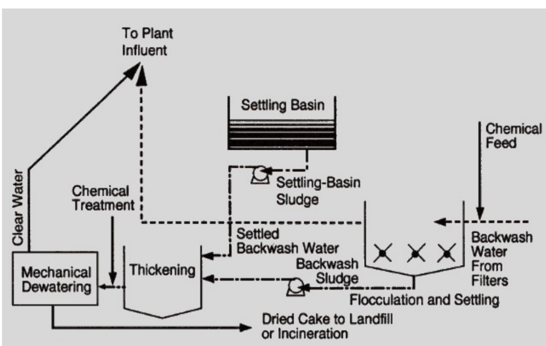
Disposal of Backwash Water



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Backwash Recycle

- The process of circulating spent backwash water to the head of the plant, sometimes with treatment to remove solids
  - ➢ Settling or decanting
    - Basin or lagoon
  - ➢ Flow equalization
    - Holding tank
  - ➢ Is any other waste present in recycle streams?
  - ➢ Recycle (if used) must enter <u>upstream</u> of coagulant chemical feed

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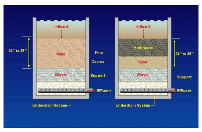
SDWA Individual Rules

- **Filter Backwash Recycling Rule (FBRR)**
  - Reduces risks from recycling contaminants removed during filtration
  - Affects systems that recycle spent filter backwash water, thickener supernatant, or liquids from dewatering



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Background

- Filter backwash recycle reintroduces contaminants back into the treatment process
- 1996 SDWA Amendments require EPA to promulgate a regulation that "governs" recycle of filter backwash water within a treatment plant
- Filter Backwash Rule (2001)

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Purpose of FBRR

- Recycle streams are source of high concentration of microbial pathogens and chemical contaminants
  - Contribute to the contaminant load
  - Coagulant chemistry imbalance
  - Hydraulic surge--overwhelms plant's unit processes
- Waste flows may adversely affect plant performance and, subsequently, pathogen removal

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Purpose of FBRR

- FBRR reduces potential for *Cryptosporidium* oocysts to pass through filters into finished water by ensuring proper management of residual streams
- FBRR also allows States to evaluate recycle practices and identify any potential problems.

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WASTE FILTER BACKWASH WATER OPTIONS

- Waste Filter Backwash Water Options
  - *Discharge to sewer*
    - Sewer availability, discharge constraints
  - *Discharge to receiving water*
    - Treatment & permit probably required
  - *Recycle*
    - Treated or untreated
- Recycle Options
  - *Direct Recycle as Produced*
    - Flow equalization or treatment
    - Problems: High Flow Rate depending on number of filters in the plant
    - States regulate the recycle rate to some percentage of the raw water flow (5 - 10 % is common)

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RECYCLE OPTIONS

- *Flow Equalization*
  - Filter BW Water collected in a tank as produced
  - Water quality is variable if no mixing to homogenize the tank contents. Water quality is site specific: depends on raw water quality, coagulant, and backwashing practice
- *Treatment of Recycle Stream*
  - Most common method is solids removal by sedimentation
    - Batch or semi-continuous (i.e, plate settler)
    - Polymer addition is common for plate settlers
  - Other options for Solids
    - DAF
    - Membranes
  - Other treatment possibility
    - Disinfection

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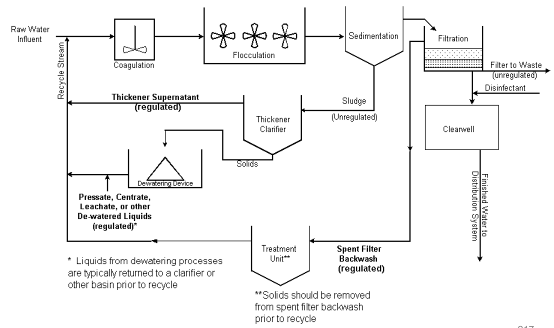
Conventional Treatment Plant



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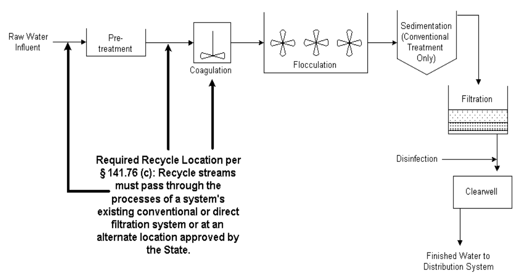
Recycle Return Location



Regulated Recycle Streams: Spent filter backwash water, thickener supernatant and liquids from dewatering processes.

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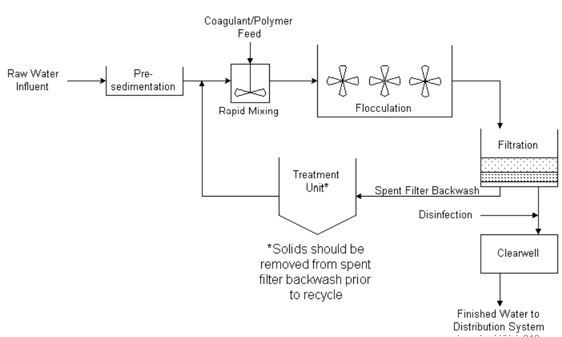
Example 1



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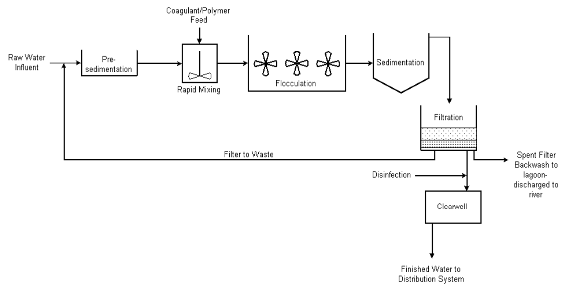
Example 2



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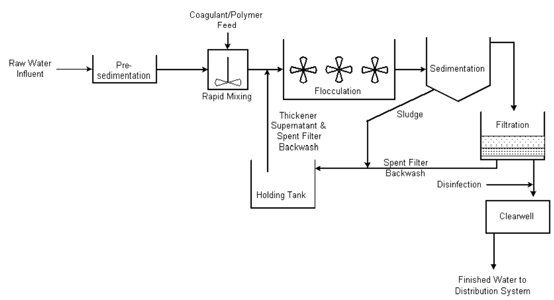
Example 3



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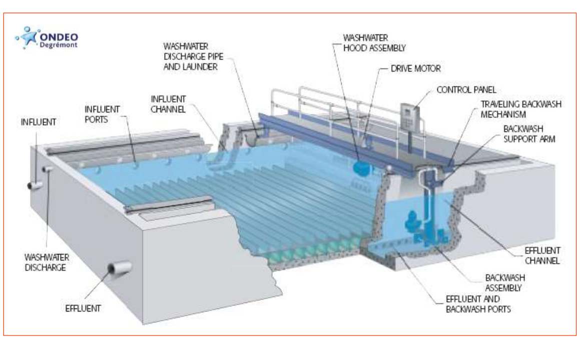
Automatic (Continuous) Backwash Filter



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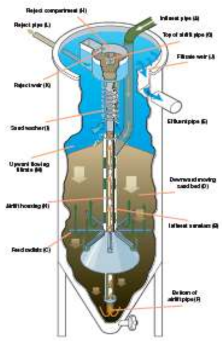
Automatic (Continuous) Backwash Filter



Parkson Dynasand®

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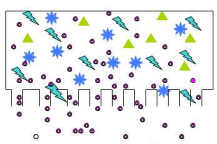
Membrane Filter Technology

- A membrane is a thin material that has pores (holes) of a specific size
- Membranes trap larger particles that won't fit through the pores of the membrane, letting water and other smaller substances through to the other side



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Membrane Filter Technology

- There are four general categories of membrane filtration systems
  - Microfiltration
  - Ultrafiltration
  - Nanofiltration
  - Reverse Osmosis

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Membrane Filter Technology

Filter type	Symbol	Pore Size, µm	Operating Pressure, psi	Types of Materials Removed
Microfilter	**MF**	**1.0-0.01**	**<30**	**Clay, bacteria, large viruses, suspended solids**
Ultrafilter	**UF**	**0.01-0.001**	**20-100**	**Viruses, proteins, starches, colloids, silica, organics, dye, fat**
Nanofilter	**NF**	**0.001-0.0001**	**50-300**	**Sugar, pesticides, herbicides, divalent anions**
Reverse Osmosis	**RO**	**< 0.0001**	**225-1,000**	**Monovalent salts**

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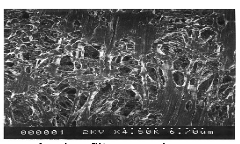
Microfiltration

- Typical pore size: 0.1 microns (10^{-7}m)
- Very low pressure
- Removes bacteria, some large viruses
- Does not filter out:
  - small viruses, protein molecules, sugar, and salts

Microfiltration water plant, Petrolia, PA



A microfilter membrane

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Ultrafiltration

- Typical pore size: 0.01 microns (10^{-8}m)
- Moderately low pressure
- Removes viruses, protein, and other organic molecules
- Does not filter out ionic particles like:
  - lead, iron, chloride ions; nitrates, nitrites; other charged particles

An ultrafiltration plant in Jachenhausen, Germany

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Nanofiltration

- Typical pore size: 0.001 micron (10^{-9}m)
- Moderate pressure
- Removes toxic or unwanted bivalent ions (ions with 2 or more charges), such as
  - Lead
  - Iron
  - Nickel
  - Mercury (II)

Nanofiltration water cleaning serving Mery-sur-Oise, a suburb of Paris, France

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Reverse Osmosis (RO)

- Typical pore size: 0.0001 micron (10^{-10}m)
- Very high pressure
- Only economically feasible large scale method to remove salt from water
  - Salty water cannot support life
  - People can't drink it and plants can't use it to grow

Reverse osmosis (or desalination) water treatment plants, like this one, are often located close to the ocean

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Microfiltration (MF)

MF removes:

- Bacteria, *Giardia*, *Cryptosporidium*
- Turbidity and suspended solids
- Viruses to some degree

MF does not remove:

- Color or organic carbon
- Taste and odor (T&O) compounds
- Dissolved salts

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Why use MF Membranes?

- Removes pathogens; not inactivation
- One step particle removal > 4 log (99.99%)
- Back washable with air/water- keeps flux high
- Membrane integrity test – ensures safe water
- Compact footprint – saves real estate
- Easily expanded – modular concept
- Cost competitive if raw water has low turbidity and TOC/color

MF is not a panacea – extra treatment needed

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MF Hollow Fiber

- Very suited to MF/UF applications
- High solids tolerance
- Back washable
- Easier to chemically clean (PVDF)
  - ▶Oxide (Cl_2) tolerant
  - ▶Acid tolerant
- Flow path
  - ▶Outside to Inside
  - ▶Inside to Outside

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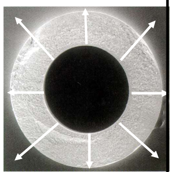
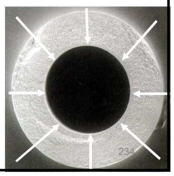
Direction of Permeate flow

- Inside to Outside (e.g. Koch, Norit X Flow)
  - ▶Higher cross flow velocity = good flux
  - ▶Better protection for separation layer
  - ▶Need fine pre-strainers to prevent blockage
- Outside to Inside (e.g. Pall, Memcor, Zenon)
  - ▶High compressive strength
  - ▶Larger surface area to fluid
  - ▶High solids tolerance





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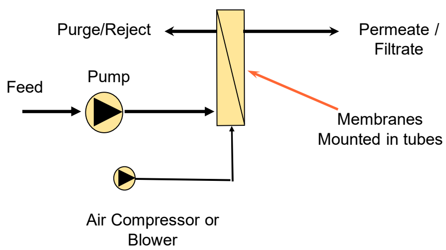
Pressurized MF Schematic



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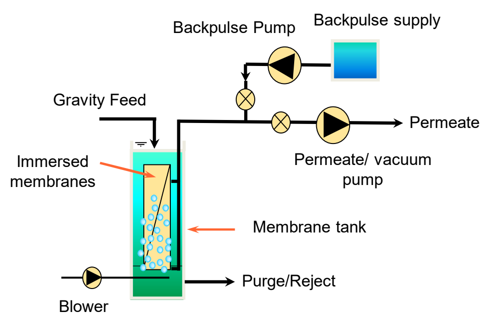
Vacuum MF Schematic



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Vacuum vs. Pressurized

- Vacuum
  - ▶ Uses less energy
  - ▶ Higher solids loading
  - ▶ Uses 5x less valves
  - ▶ Scales up more easily
  - ▶ LCC more competitive
- Pressurized
  - ▶ Operates at higher flux
  - ▶ Less chemical waste
  - ▶ Lower capital cost
  - ▶ Low head room
  - ▶ No crane needed

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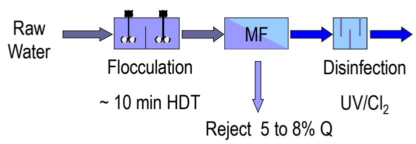
Where does MF fit

Coagulation + Microfiltration for color and TOC Removal



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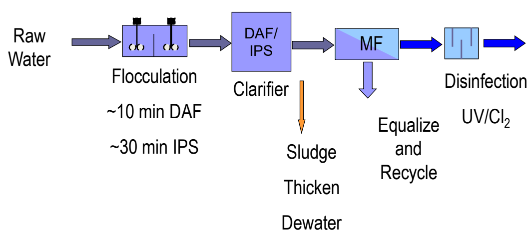
Where does MF fit

Clarification + Microfiltration for color and TOC Removal



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Summary – W & WW Treatment

- SDWA/ESWTRs (Water)
  - Turbidity Removal
  - Pathogen Removal
- CWA - NPDES (Wastewater)
- Coagulation
- Flocculation
- Sedimentation/Clarification
- Filtration

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Conclusions

- **Coagulation** is KEY to proper plant operation regardless of process type
- When filtrate quality is poor, the cause is most probably inadequate pretreatment chemistry, not inadequate flocculator, settler, or filter design
- When head loss development is rapid, the cause is most probably inadequate flocculator, settler or filter design, not inadequate pretreatment chemistry

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Questions?

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Thank You

Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD

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